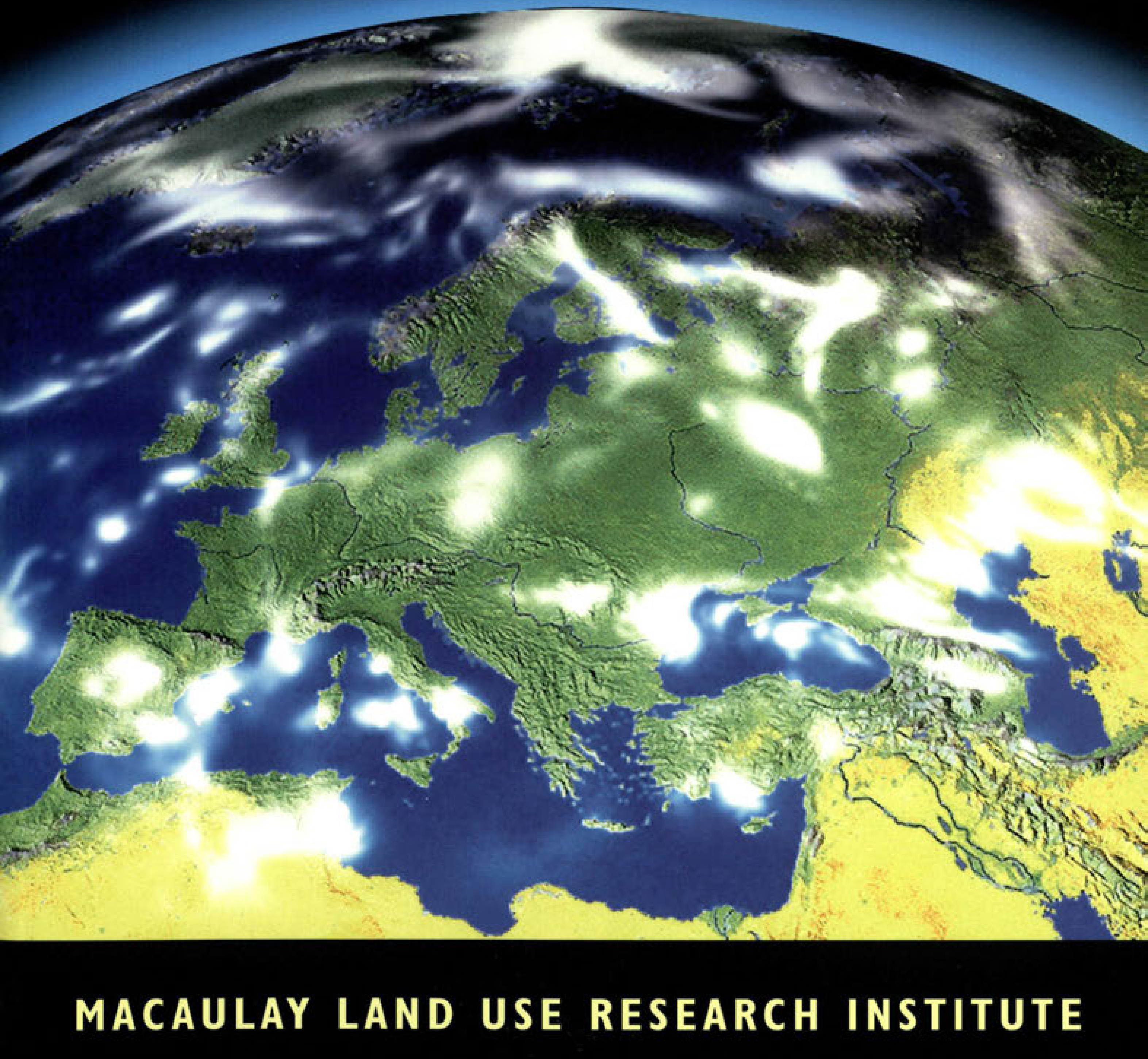

MACAULAY LAND USE RESEARCH INSTITUTE

ANNUAL REPORT 1996

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Craigiebuckler
Aberdeen

ANNUAL REPORT 1996

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DIRECTOR'S INTRODUCTION

In 1987, when the Macaulay Land Use Research Institute came into being, several pundits offered the view that it would take ten years to firmly establish the Institute's identity as a research centre of national and international significance. That we achieved this status somewhat earlier than predicted no doubt influenced the outcome of the recent Prior Options Review, as a result of which the Government concluded that MLURI was needed and should retain its separate existence and remain within the public sector.

Nevertheless, ten years is perhaps a reasonable period over which to review the achievements of the Institute and the contribution it has, and continues to make to land use science. It is also appropriate that we introduce the new themes within which our programmes of research will be promulgated over the next five years.

Ever since the publication "Our Common Future" (WCED 1987) the Institute's programme of research has increasingly focused on issues which have a direct bearing on sustainable land use and sustainable development. Our current research programme themes, of Sustainable Integrated Land Use Options; Integrated Catchment Management; Sustainable Management of Soils; and Sustainable Management of Marginal Lands, identify the specific topics which are addressed within this overall context. The aims of our research are set within our remit and also to meet the challenge of finding successful ways of using land and other natural resources in creating wealth, without compromising environmental quality and the quality of human life, and by increasing the efficiency, and minimising the use of non-renewable resources.

In each of the articles that follow the background to the themes are explained, the issues identified, some of our research highlights over the last ten years presented, and our current and future research initiatives outlined.

During the year the Institute has continued to develop its collaborative links both locally within the Aberdeen Research Consortium, and within CHABOS (Committee of Heads of Agricultural & Biological Organisations in Scotland), and internationally in Europe, south Asia, China, Africa, the USA and Australasia. Its commercial company, Macaulay Research and Consultancy Services, has led to a broadening of the funding base of the Institute as has the success of staff in being awarded research contracts by the European Commission.

The Institute's continued success is the result of the intellectual rigour, creativity, commitment and enthusiasm of its staff. Without their ability to rise above the uncertainty created by, for example Prior Option Reviews and the continuing debate about the role of Institutes with respect to publicly funded research, little would be achieved. It is my privilege to introduce the work of my colleagues and I am proud to do so.

Remit

'To undertake research, in the context of rural land use and resource management, with the objective of assessing the environmental, economic and social impacts of agriculture and related land uses, and the consequences of change resulting from factors and influences such as policy, management, effects of climate, and pollution.'

HISTORICAL BACKGROUND

The Macaulay Land Use Research Institute was founded in 1987 as a result of the Scottish Office decision that, in future, the research supporting their Agriculture and Fisheries Department and the agricultural industry would need to consider interactions with other land users and work within the context of developing UK and EU environmental objectives. The aim was to create a multidisciplinary research institute in which strategic and applied research on land use issues could be undertaken in a holistic manner. The new institute was formed from the amalgamation of the Macaulay Institute for Soil Research (MISR) and Hill Farming Research Organisation (HFRO) and utilised the existing strengths of soil, plant, animal and geographic sciences available within these two organisations.

The MISR was founded in 1930 as a result of a generous bequest from Thomas B Macaulay who bought the Craigiebuckler Estate in Aberdeen and refurbished the mansion house into offices and laboratories. TB Macaulay's grandfather had originated from Lewis and his father had lived there for several years before emigrating to Canada where he rose to become the Managing Director of the Sun Life Assurance Company. TB Macaulay succeeded his father as MD of the company and sponsored several philanthropic projects in Scotland as well as supporting the research activities of various organisations.

From its inception the MISR was financially supported by the Department of Agriculture for Scotland and developed an international reputation for its work on various aspects of soil science including trace element spectrochemical analyses, analyses of soil fertility and the soil survey of Scotland.

The HFRO was founded in 1954 on the recommendation of a committee of enquiry set up by the Secretary of State for Scotland in the early 1940's to look at the problems facing hill farming in Scotland. The HFRO was also financially supported by the Department of Agriculture for Scotland. The research programme adopted an experimental approach to studying animal and pasture production systems and was responsible for the development of the two pasture system for sheep farming, elements of which are now widely used across Scotland. Other notable achievements include the development of pregnancy diagnosis by ultrasound scanning for animals, body condition scoring and red deer farming systems.

T B Macaulay on a visit to MISR in 1938

CONTENTS

SUSTAINABLE INTEGRATED LAND USE OPTIONS

This research theme is set against a background of change in rural economies and rural policy across Europe, particularly the commitment of the UK Government to **sustainable development**. Our challenge is to gain an understanding of how to identify and create sustainable, integrated land use options.

Integrated land use options may be defined as those which attempt to reconcile the often conflicting objectives of:

- producing food, fibre, chemical or energy feedstock
- sustaining the social and environmental functions of the countryside
- maintaining the viability of producers

The issues

Throughout western Europe, rural economies are changing. Although the primary industries of agriculture and forestry are often seen as the 'backbone' of the rural economy, this is less true today than 50 years ago (Birnie *et al.*, 1995). In contemporary rural economies, particularly in areas of high amenity or close to urban centres, a progressive decline in agricultural employment has been masked by a compensatory growth in rural population through so-called 'lifestyle' choices. In these areas, service industries dominate. Only in the more disadvantaged areas of Europe are rural economies still closely coupled to the viability of agriculture and forestry. Therefore, the importance of the traditional primary industries to contemporary rural economies is highly variable in a geographic sense.

The decline in the economic role of primary industries has been accompanied by a growing awareness of their wider importance in delivering other goods and services as the major land users. In the past decade, the new discipline of environmental economics has helped us recognise the fact that agriculture and forestry provide not only marketed goods (e.g. food, fibre), but also a range of other unpriced benefits (e.g. recreation, landscape, local culture) and ecological functions (e.g. production of biodiversity). These are represented in Figure 1. Changes in these extensive land uses has a much greater range of impacts, both on and off-site, than previously acknowledged and they therefore concern a much wider community of interests than farmers or foresters alone.

The significance of these changes has been highlighted by recent land use issues in Scotland. The 1980's could be dubbed a 'decade of land use conflict'. It was a period when the range of individual and community stakeholders in rural land use was thrown into sharp focus by debates such as those over the Flow Country in Caithness, Duich Moss on Islay and Lurchers Gully on Cairngorm. At the heart of these debates, and others like them, lies a fundamental issue concerning 'property rights'. Society has moved from an era where individual landowners were the sole arbitrators of what to do with their land, to a new era which increasingly involves a wider community of interests in the decision-making process. Primary industries now face the challenge of satisfying the legitimate demands of individual producers to make a living, whilst not compromising their role as stewards of the countryside, both now and in the future. This is critical to the ethos of **sustainability**. The question should not be whether the individual or society's 'rights' take priority. Rather, solutions need to be sought through **better alignment of the individual land manager's objectives and those of wider society**. The questions then become: what are desirable and sustainable land use outcomes; how can individual land managers deliver these whilst still achieving economical viability and how far must society intervene in cases of economic or market failure? These questions are central to this research theme.

The theme of **Sustainable, Integrated Land Use**

TOTAL ECONOMIC VALUE

USE VALUES			NON-USE VALUES		
DIRECT USE VALUES		ECOLOGICAL FUNCTION VALUES	OPTION VALUES	EXISTENCE VALUES	BEQUEST VALUES
Marketed Outputs	Unpriced Benefits	Benefits	Benefits	Benefits	Benefits
•crops •meat •timber	•recreation •landscape •local culture	•flood control •carbon storage •waste assimilation	•future drugs •gene pool •recreation options	•satisfaction from knowledge of existence	•passing benefits to future generations

Figure 1 Total Economic Value (after Hodge, 1993)

Options focuses on:

- **Geographical and Resource Analysis** concerned with describing **land resources** and their **potentials**, in terms of both market (e.g. food and fibre) and non-market goods (e.g. biodiversity, landscape), and the development of **decision support systems** for exploring land management options and their associated impacts at both farm and regional scales.
- **Socio-Economics and Policy Analysis** concerned with developing new approaches to **evaluating environmental goods**, new **spatial economic methods** for appraising rural environmental issues and policy, and creating a framework for assessing the **socio-economic sustainability** of rural areas.

Our research aims to fully explore the biophysical and socio-economic dimensions of **sustainable development** and to interpret it in both practical management and policy terms (e.g. through environmental accounting methods).

In this programme of research our scientific objectives are to seek new insights into the concepts of sustainability and scale and the dynamics of change in land use systems. We aim to demonstrate novel applications of spatial analysis, modelling and expert system technologies. Our applied objective is the creation of strategic decision support tools to enable land managers and policy advisors to explore, and to objectively evaluate, alternative land use options. These tools may be used in land use planning and in mediation of land use conflicts.

Research highlights over the last 10 years

Over the past decade the research programme has made contributions to land use science in the areas of **information management, systems modelling** and **environmental and economic assessment**. Some highlights of our work are shown below. These contributions have primarily been used at a strategic level within Scottish Office departments and regional authorities, in connection with developing regional land use strategies (e.g. relating to forestry, sewage sludge disposal, biological conservation), or evaluating the impact of existing land use policies (e.g. Environmentally Sensitive Areas Scheme, Farm Woodland Premium Scheme, Pilot Extensification Scheme, and farmers' attitudes to nature conservation).

Information Management

- Completion of the first ever digital land cover database for Scotland based upon interpretation of 1:25,000 aerial photography (Land Cover of Scotland 1988 [LCS88]) (MLURI, 1993).
- Development of an expert system for the automatic detection of land cover changes from sequences of satellite imagery (SYMOLAC) (Skelsey, in press).
- Development of an integrated and harmonised database which draws together the LCS88 data, the SNH National Countryside Monitoring Scheme (NCMS) data, and the ITE/DOE Countryside Change 1990 data (in collaboration with SNH and ITE) (Brooker, 1995).
- Creation of a new hydrological classification of UK soils (HOST), based on inferred soil physical properties and hydrological characteristics, for hydrological and soils modelling purposes (in collaboration with the Soil Survey and Land Resource Centre and the Institute of Hydrology) (Boorman *et al.*, 1995).
- Application of novel geostatistical techniques to the creation of high resolution climate surfaces for Scotland (Hudson & Wackernagel, 1994).
- Derivation and application of a Bayesian modelling procedure, within a GIS, to predict wildlife distributions from low resolution and incomplete environmental data (Aspinall, 1992; Aspinall & Veitch, 1993).

Systems Modelling

- A founding member of the UK Agroforestry Research Forum, involved in the design and setting up of a national network experiment, and led the agroforestry modelling development on behalf of an EC team. Demonstrated the bio-economic viability of establishing agroforestry in the uplands (Bergez *et al.*, 1996; Sibbald, 1996).
- Developed a process-based upland livestock systems model and a related farm nutrient budget model (Hutchings *et al.*, 1996).
- Created a prototype farm-scale land use allocation decision support system (LADSS) which is an innovative combination of GIS and expert system software environments.

Environmental and Economic Assessment

- Determination of the nitrate N loadings of Scottish rivers based upon satellite image analysis. Calculation of total N-loss and monetary equivalent (@£17M per annum) (Wright, 1994).
- Development of an environmental impact assessment procedure employing landscape visualisation within a GIS framework (Miller & Law, in press).
- Creation of a forestry investment model and the critical appraisal of Indicative Forestry Strategies and second rotation restocking of marginal forestry land in Scotland (Macmillan, 1993).
- Application of Contingent Valuation techniques to the assessment of costs of surface water acidification in Scotland (Macmillan & Ferrier, 1994).
- Contingent Valuation and Value for Money evaluations of recreational and environmental policies (Macmillan *et al.*, 1996).

Current research

An overview of the different components of research under the '**sustainable, integrated land use options**' theme and the complementarity and interrelationships between them is provided in Figure 2. The work is structured within the context of strategic applications of current importance related to land management and planning, and land use policy analysis, and the development of objective methodologies for the analysis, synthesis, appraisal and evaluation of land use options at a range of scales.

Geographical and Resource Analysis

The focus of this research is on the development of strategic land use planning/management decision support tools and the critical methodological approaches that underpin these. A physical and biological perspective provides the framework within which the research is undertaken. The work is concerned with developing tools that support land managers at the farm or management unit level, and land use policy-makers operating at the regional or national levels. A particular strength is our ability to analyse land use issues within a spatial framework, in which we have gained an international reputation for research on the development of new methods for spatial modelling and the application of Geographical Information Systems (GIS).

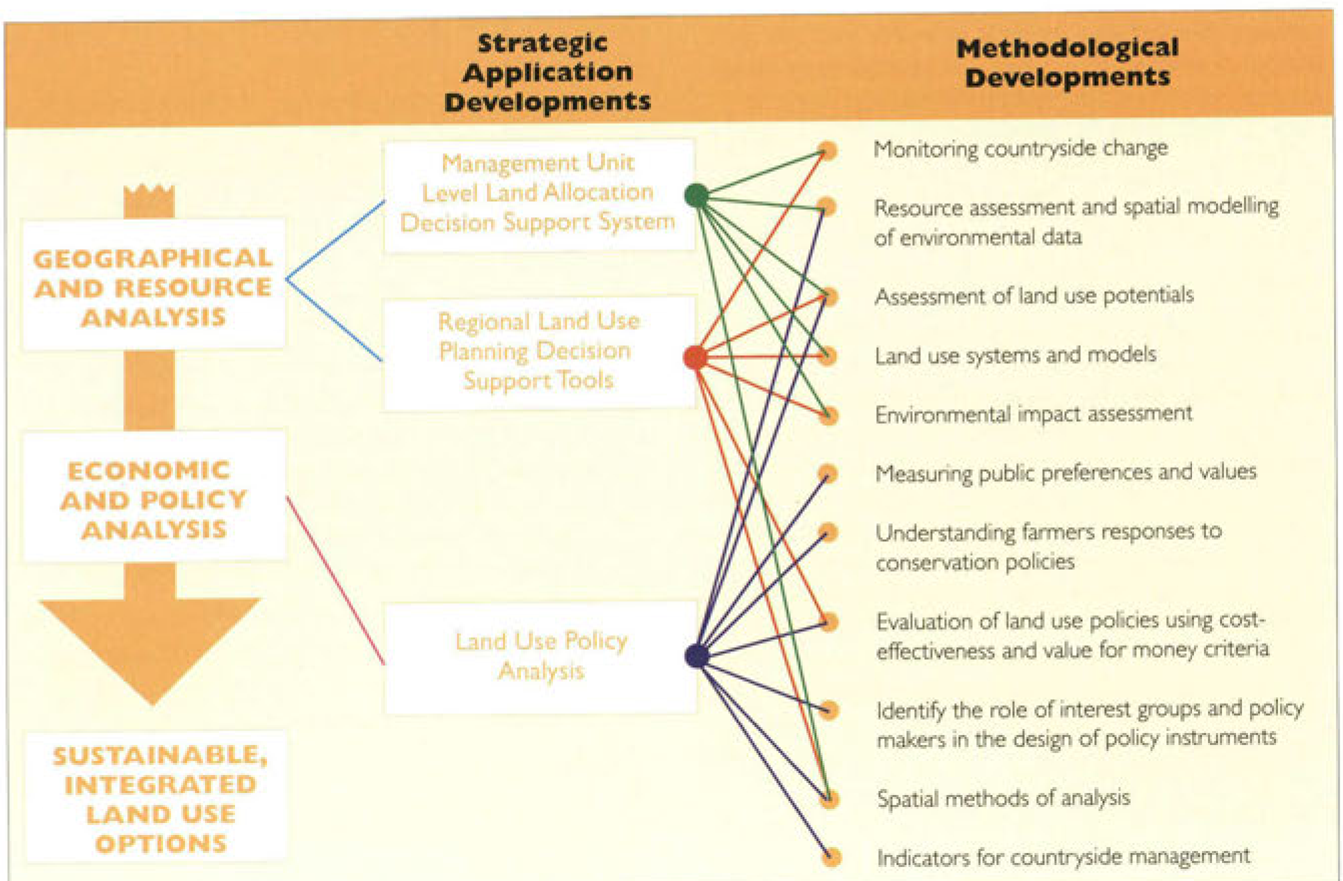


Figure 2 Overview of Research Components

Monitoring countryside change

Information on the condition, trends and rates of change in the countryside is vital to our understanding of the state of our environment. Land cover change is a key indicator of change in natural capital. Developing methods for detecting and measuring land cover change has therefore been a core task of the research team for over a decade. There are a number of remote sensing technologies that may be used. Early work focussed upon satellite-borne sensors such as the LANDSAT multispectral scanner (MSS). However, as our understanding of the relationships between the spatial and spectral resolving power of these platform/instrument combinations improved, it became apparent that a critical part of the science of remote sensing was the matching of the technology to the application. As a consequence of this, the national land cover map of Scotland was based upon conventional aerial photography rather than satellite imagery (MLURI, 1993). This suited the requirement of producing a medium scale map baseline at 1:25,000 with minimum mappable units of between 2-10ha. However, we are aware that having now created this baseline, there are new opportunities to: a) add value to it by integrating it with high resolution satellite imagery (e.g. that derived from LANDSAT Thematic Mapper), and b) use it as the basis of an automated change detection system. Current research focuses upon these two topics (Wright & Morrice, in press; Skelsey, in press).

Resource assessment and modelling environmental data

The MLURI has a long tradition of mapping the natural resources of Scotland (e.g. soils) and producing interpretative maps (e.g. Land Capability for Agriculture). Recent research has been concerned with adding value to this wealth of resource information in three ways:

1 Improving the organisation and accessibility of the data through creation of national databases. This has involved a systematic GIS Planning study (Aspinall, 1994), the identification of so-called 'core datasets', (i.e. ones commonly used across the MLURI's research programme) and the creation of a logical and consistent data model for these.

2 Integrating MLURI databases with those held externally. A particular example of this has been the joint work between MLURI, ITE and SNH on the integration of their respective land cover and ecological databases (Brooker, 1995). Another example has been a joint initiative in developing the European Soils Physical Database (Lilly, in press).

3 Developing new data products. These products can now be developed through the application of GIS functions and novel spatial data modelling techniques (e.g. geostatistics). Particular examples have included: the derivation of new high resolution climate surfaces for Scotland using a combination of trend surface analysis and kriging (Hudson & Wackernagel, 1994; Matthews *et al.*, 1994); creation of a new hydrological classification of UK soil types called the HOST classification (Boorman *et al.*, 1995); development of Bayesian probability, inductive spatial modelling techniques for assessing biodiversity at regional scales (Aspinall, 1995). The current focus of this work is concerned with the creation of the MLURI Corporate Data Centre and extending the access to these databases through improving internal and external access via the World Wide Web. A prototype of such a Web facility has been developed as a key tool in a research programme to create a decision support system (DSS) for alleviating damage to European forests.

Assessment of land use potentials

There is vast experience worldwide on the development and application of methods for evaluating land suitability for agriculture. Foremost amongst these is the FAO framework for land evaluation, published in 1976. The MLURI has established an international reputation for land evaluation. It has published a series of land capability maps and handbooks for both agriculture and forestry in Scotland which are routinely used as source documents in land valuation and sales and in land use planning. However, as the range of potential land uses expands beyond those dominated by agricultural enterprises, to include niche land uses like broadleaved farm woodlands or nature conservation or waste recycling, we realised that there was a need to develop a much wider portfolio of land suitability assessments. These assessments will often be driven by specific user needs and require the development of new land suitability models.

We have a core research effort on land use suitability modelling, which focuses largely on the mathematical and statistical issues associated with data inputs and data analysis. This has highlighted issues of error and uncertainty, and error propagation in land suitability modelling, and techniques are being developed to handle these (Aspinall & Pearson, in press). However, much of the work in this area is application-driven. Prime examples are: a) habitat suitability mapping for a wide range of individual species (Hill *et al.*, in press); b) assessment of land suitability for recycling of organic wastes, particularly sewage sludge (Towers, 1994); c) assessment of land suitability for short rotation coppice. We are developing a generic approach to land resource assessment where suitability models are stored as functions within a GIS framework. The major effort is in pulling together the information to define the suitability criteria. This process does reveal gaps in both data and understanding. This is particularly true in the fields of habitat and biodiversity assessment.

The progress that we have made in formally representing uncertainty in modelling outputs has gained international recognition (Aspinall & Pearson, in press).

Land use systems and models

As the emphasis shifts from single to multiple-objective land use enterprises there is a need to improve our understanding of how such integrated systems can be created and managed. It is possible to model the performance of enterprises individually but it is more difficult to anticipate their interactions when set together in a management system. From a research perspective there are at least two possible approaches to this problem. The first involves setting up of a systems-level field experiment. The second involves the development of more sophisticated systems models where the outcomes are not deterministic; they are instead emergent properties of the interactions between the elements of the system. This is an application of the new theories on the behaviour of complex systems.

We have adopted both a field systems and systems modelling approach to developing our understanding of how integrated upland land use systems might behave. The practical field systems example is provided by our involvement in a national agroforestry network experiment which feeds into the creation of an agroforestry model and also work specifically on upland sheep systems. The latter is concerned with the inputs and multiple outputs of grazing systems. The modelling work centres around the development of a facility for the spatial allocation of land between enterprises *sensu lato* (i.e. includes nature conservation for example) at the management unit level. This latter work aims to develop a Land Allocation Decision Support System (LADSS) and draws heavily upon the land suitability work described above and the environmental impact assessment techniques described below. **The creation of the LADSS is one of the key efforts of the Geographical and Resource Analysis team.**

An agroforestry field system

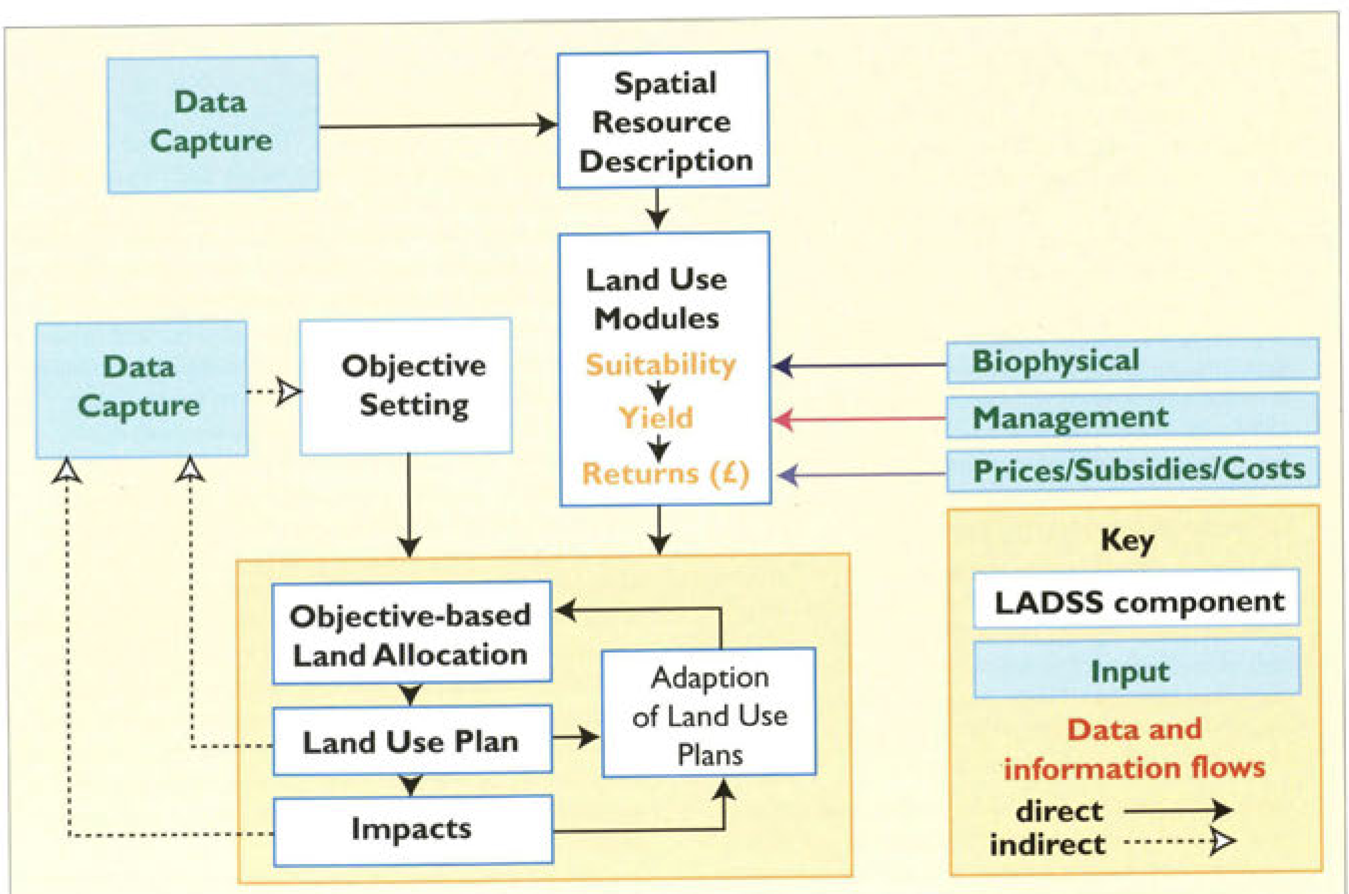


Figure 3 LADSS simplified model structure

Whilst the interactions of biophysical and socioeconomic factors at the level of the individual property are some of the key determinants of land use change we recognise that there are many other processes that influence rural sustainability. These occur at different scales and over different geographical units and are a basic property of open systems. For example, agricultural sustainability is fundamentally exposed to the off-site demands for products (witness the impact of BSE), whilst the breeding success of migratory birds not only depends on the availability of breeding habitat on-site but also on levels of off-site predation in their wintering grounds. These may be in Africa. Any assessment of whether development is sustainable or otherwise must take these inter-connections and scale effects into account. We are incorporating this open-systems thinking into the **development of a facility for land management and planning at regional scales.** We have made particular progress in relation to strategic planning for sewage sludge (Towers, 1994), forestry (Miller *et al.*, 1995) and renewable energy production (Towers *et al.*, 1996).

Environmental impact assessment

It is a requirement of UK planning legislation that every major development proposal (e.g. new oil refinery) is accompanied by an environmental impact assessment (EIA). This has stimulated the development of relevant impact assessment methods. Whilst there is no such general requirement to carry out EIAs in relation to change in agricultural and forestry land uses in the UK, there is a need to have some framework for evaluating their potential effects (e.g. on landscape, biodiversity, water quality, recreational uses etc.) as part of the process of assessing different land use options. Because many of the project-specific EIA methods cannot be used directly, we have been developing new approaches to assessing the wide-area impacts of land use changes. Our work has focussed initially upon the directly measurable biophysical dimensions of change, particularly in terms of landscape impacts (Miller *et al.*, in press) and potential biological conservation impacts (Aspinall, 1995). Our ambition is to draw this work together with social and economic impact assessment methods and to present a more holistic and transparent view of the trade-offs involved in land use decision making.

Economic and Policy Analysis

Land and natural resources are under pressure. Technology and farm business objectives lead to specialisation in the production of food and timber but society also wants to minimise damage to the environment and have sustainable land use. From the work undertaken at MLURI and elsewhere within the biophysical sciences, it is clear that agriculture can make positive contributions to sustainability. It can provide habitat for wildlife, contribute to biodiversity, provide carbon sinks, produce attractive managed landscapes and provide recreational opportunities. The challenge is to use land productively while at the same time maintain diversity of species and habitats, protect valued landscapes and meet increasing demands for leisure and recreation.

While landowners, farmers and forestry interests manage the land, it is government that sets environmental policies and provides the regulation and incentives that affect the way land is used and the extent to which sustainable development can be achieved. The scope of such policies has expanded rapidly in the last decade and our research explores developments in policy formulation and implementation for the agri-environment. Economic analysis contributes by defining principles for good policy design, in evaluating impacts from an economic perspective and in identifying how economic inefficiencies can be overcome. Economic and policy research also contributes a longer term and strategic basis for sustainable development.

Selected topics are amplified below:

Measuring public preferences and values

Since the environment is not marketed and priced alongside other goods and services it is difficult to identify public preferences. But policy makers need to know how to direct public expenditure to priority areas and the public have a role in indicating how they value landscape and environmental change. We have undertaken research on a number of Environmentally Sensitive Areas (ESAs) to identify the willingness to pay of different social groups - residents, visitors and the general public. There are 27 such areas in Britain, where government has offered farmers incentives payments to enhance the countryside in ways that would not be forthcoming under good agricultural practice. Using contingent valuation, we used survey questionnaires in Breadalbane and the Machair (Western Isles) ESAs to present respondents with *policy on* and *policy off* scenarios using visual images to identify impacts on landscape and wildlife habitats.

As may be expected willingness to pay to support these environment-enhancing policies was greatest amongst residents and visitors. When aggregated up to account for the number of people in each group it was the WTP of the general public which dominated the public benefits (Table 1). Compared with the financial

ESA	Residents (£m)	Visitors (£m)	General Public (£m)
Breadalbane	0.19	0.86	44.1
Machair	0.15	0.18	26.8

Table 1 Aggregate willingness-to-pay estimates for ESAs in Scotland (£ per year)

costs of operating the ESAs (about £1m per year) the benefits were substantial and suggest that strong support for agri-environmental policies of this type. Similar results were obtained in relation to environmental policies in the Southern Uplands.

However, such policies face a design problem because public preferences for expenditure on specific elements of the countryside are not well understood. It could thus be that the package of payments to farmers could be adjusted to better reflect public interest. Experiments with contingent choice were undertaken in which the public were offered various combinations of expenditures on attributes included in the policy. For Breadalbane the preference ranking was shown in Table 2, with regeneration of woodlands being most preferred and expenditure on archaeology lowest. In the Machair, archaeology had a higher ranking.

Attribute	Implied Rank
Woodlands	1
Heather moorlands	2
Wetlands/herb-rich grassland	3
Stone dykes	4
Archaeology	5

Table 2 Breadalbane ESA - Ranking of attributes by the public

Understanding farmers responses to conservation policies

Policy delivery suffers from asymmetric information - that is policy makers know very little about how farmers will react to any particular scheme. This can lead to failure of policy due to low uptake and unnecessarily high payments. We have investigated farmers responses using a range of methods. In recent economic work farmers in the Cairngorms were asked their willingness-to-accept (WTA) payments for specific wetland or woodland enhancement. Their responses (Figures 4 and 5) show great variation reflecting variability in farmers attitudes to the environment and in the costs of changing their farming. The spatial location of the woodland proved critical in determining the farmers' WTA.

These WTA curves allow policy simulation and modelling since they reflect how farmers would behave in practice. In this type of situation, a simple payment scheme based on the concept of **compensation does not operate well. It signals the need for more complex approaches, at admittedly greater administrative cost.**

Evaluating land use policies using cost-effectiveness and value for money criteria

The conservation of biodiversity is rapidly becoming an important keystone of sustainable development policy in Europe. Evaluating the benefits in economic terms is extremely difficult and thus poses a problem not just for economists, but also for policy makers anxious to portray expenditure as 'value for money'. Cost-Effectiveness Analysis (CEA) does not rely on monetary valuation of benefits and is the most appropriate method for evaluating biodiversity projects.

CEA seeks to compare the costs of alternative ways of meeting an objective in order to determine the most efficient (least cost) method. The exchequer cost of creating natural woodlands in the United Kingdom under the Woodland Grant Scheme (WGS) was compared with a measure of their effectiveness in restoring a natural woodland ecosystem. An expert group, comprising leading national experts in woodland ecology, was established to derive an ex ante system for measuring conservation effectiveness of new natural woodlands based on a set of weighted criteria under which benefits from individual woodlands were assessed. Using data held within a Geographic Information System, the effectiveness of over 200 new native woodlands was established using this expert system (Figure 6). Grant costs were also estimated and compared with effectiveness of individual woodlands.

Woodlands varied considerably with respect to both cost and effectiveness, with the most cost-effective woodlands established close to existing woodlands using natural regeneration techniques. In order to improve the delivery of biodiversity benefits from the WGS, grant

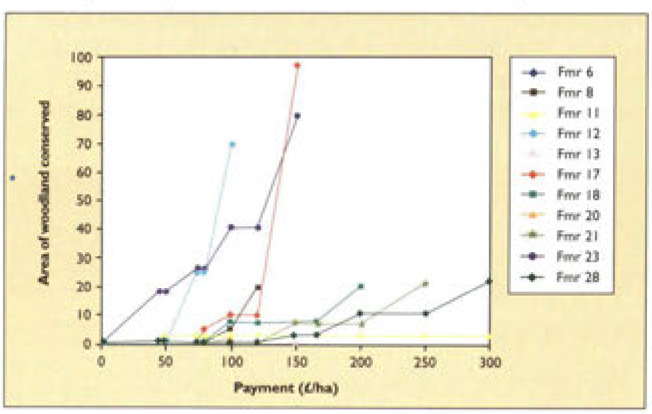


Figure 4 Individual farmers Willingness-to-accept associated with woodland conservation

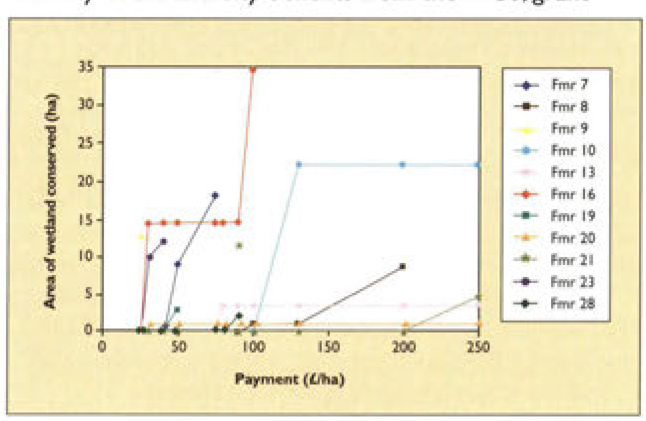
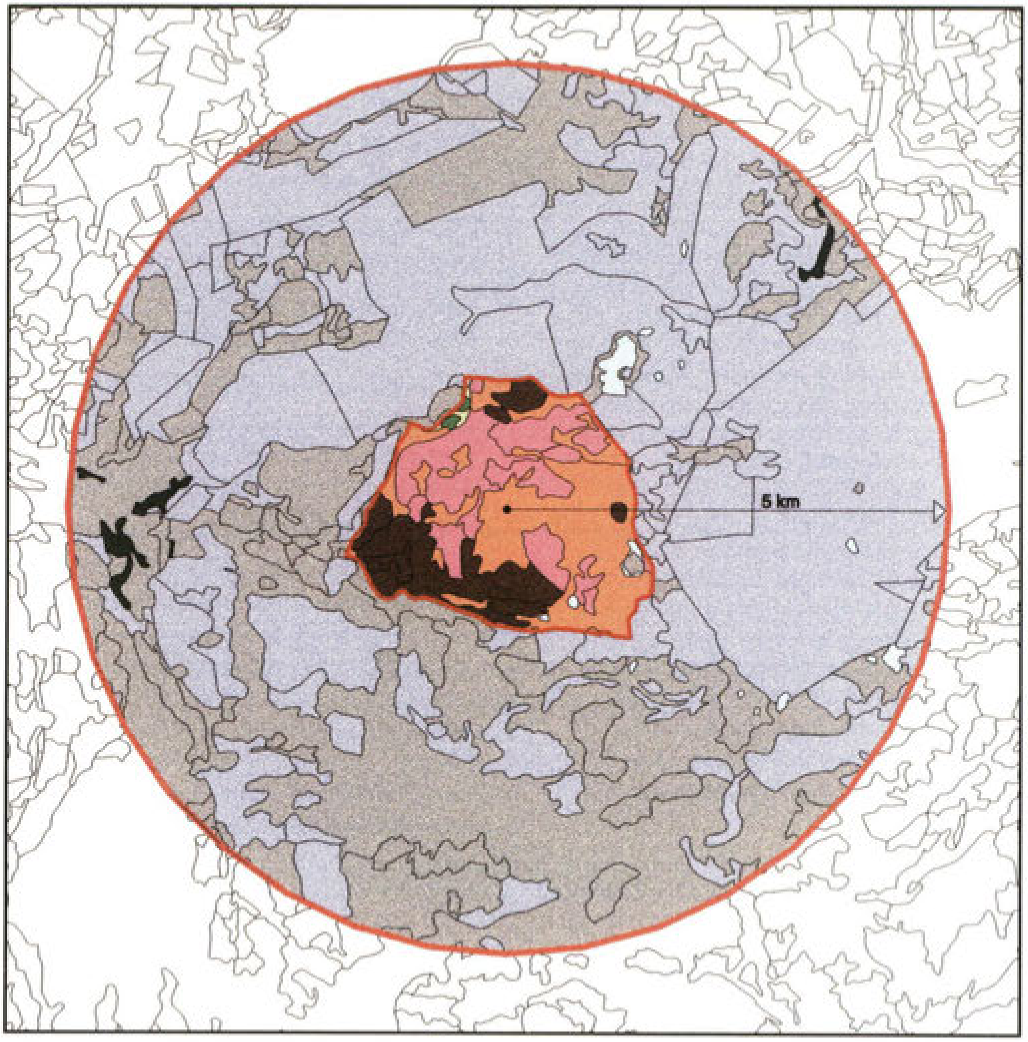


Figure 5 Individual farmers Willingness-to-accept associated with wetland conservation



- New woodland
- Other natural woodland
- Associated habitat
- Other habitat types
- Water

natural regeneration (%)		
precursor vegetation	Blanket bog	41%
	Dry heather moor, no burning	22%
	Dry heather moor, with burning	31%
	Improved pasture	3%
	Smooth Grassland	2%
cultivation		plough
deer control		shooting
woodland area (ha)		705
surrounding woodland in 5km		1
distance to other woodlands in 5km (m)		2532
number of woodlands in 5km		6
associated habitat (%)		24
associated habitat boundary (%)		30

Figure 6 Effectiveness characteristics of a new natural woodland

rates should be increased for larger woodlands and for natural regeneration. Since CEA combines a measure of value for money and incorporates environmental expert judgement concerning conservation benefits it should be attractive to both policy-makers and environmental interest groups for the evaluation of conservation programmes.

Future research

The appearance of rural Scotland today is the product of contemporary socio-economic forces overlaid upon the legacy of past cultural landscapes. Farmers and land managers react in their own ways to social, economic and technological forces and in so doing introduce variety from place to place. Forecasting land use futures cannot therefore be an exact science, but we can gain some insight into the **possible directions of change.**

The major force that shapes the current pattern of rural land use in Scotland is the system of subsidy for agricultural production and woodland planting. The Common Agricultural Policy (CAP) has the predominant effect. Changes in international agreements on trade and prospects of an expanded European Union mean that the system of subsidies under the CAP will become increasingly unsustainable. As a way of stimulating discussion and debate, and assessing whether our research effort will still be relevant under conceivably changed circumstances, we have done an **exercise in 'futuring'** (Birnie *et al.*, 1995).

We have explored the possible effects of three agricultural/rural development scenarios for rural Scotland over the next 10 years. These scenarios are set out in Figure 7a - c and are based upon a common set **assumptions**, as follows:

- technology increases the supply of agricultural products but demands remain stable.
- UK economic policy continues to focus on control of inflation and the budget deficit.
- planning controls remain but there may be a greater emphasis on locally-led planning.
- EU structural funding (e.g. LEADER) increases but continues to be targeted on Objective 1 and 5b areas. This is consistent with the current cohesion policies which are aimed at countering population drift to core areas within Europe.

This futuring exercise highlights the fact that it is likely that socio-economic and policy forces will continue to reinforce the intensification of regional differences in rural Scotland over the next decade. This may most likely be seen in the progressive concentration of intensive agriculture on the better land and the de-intensification of agriculture on the poorer land. All three scenarios agree on this; they only disagree in terms of the rate of

SCENARIO 1 Partially Decoupled CAP

Description

Process of CAP modification occurs on incremental path and the current basis of agricultural support is maintained.

Increasing amounts channelled away from product-related support to agri-environment direct income measures.

Trends

- agricultural land in surplus
- increased set-aside
- transfer of better quality land to non-agricultural uses (farm woodlands, golf courses etc)
- extensification of land uses in marginal areas
- intensification of land uses with comparative production advantages (increased pollution in these areas)
- diversification and off-farm employment reinforced in marginal areas.

Outcomes

Progressive concentration of intensive agriculture on better land, less intensive agriculture on poorer land, and growing regional differences in the intensity of agricultural uses.

Figure 7a Partially Decoupled CAP

SCENARIO 2 Rapid Decoupling of Farm/Agricultural Support (from prices)

Description
Dramatic change from present policies and the rapid transfer to UK agricultural businesses competing in the world market.

Trends
- rapid reduction in producer prices
- decline in land values and rents
- structural changes as financially vulnerable units sold
- land bought by expanding farm businesses and/or 'lifestyle' farmers
- rapid withdrawal from marginal land/intensification on prime land
- more open land market creates opportunities for environmental groups to buy land in attractive areas
- in farmed areas 'conservation dividend' may promote 'cleaner production systems' (world market may demand this)

Outcomes
Pattern of changes in intensification, extensification and land diversion will be highly uneven, reinforcing the differences between preserved and industrial agricultural landscapes.

Figure 7b Rapid Decoupling of Farm/Agricultural Support (from prices)

SCENARIO 3 An Enhanced Rural Development Policy

Description
A shift away from the agricultural fundamentalist view to one where support is given to community-led initiatives in achieving rural development objectives. Assumes that the UK government is prepared to cede power to local communities in parallel with its EU partners.

Trends
- strong local differences depending on community responses
- some prioritise economic development, favouring relaxation of planning controls and diversification of land uses
- some seek to preserve residential amenity and oppose development and land use change
- changes conditioned less by the quality of land, more by community processes, access to resources and opportunities for favourable partnerships
- more fine grained changes than under other scenarios (e.g. community woodlands, rural tourism, alternative energy, lowland crofting etc.)

Outcomes
Greater engagement of the wider rural community in identifying opportunities for future land uses. Outcomes will be highly varied locally, but may not impact significantly on the wider landscape where use is still driven by agricultural priorities.

Figure 7c An Enhanced Rural Development Policy change. We believe that this futuring exercise supports the emphasis that we are placing in our research programme on the spatial context of land use changes and the processes that drive them. The challenge for the future is to ensure that the ethos of sustainable, integrated and multiple-objective land use systems can be applied everywhere.

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INTEGRATED CATCHMENT MANAGEMENT

the sustainable use of catchment resources

The most significant outcome of the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992 was the acceptance of the concept of 'sustainable development' (as outlined in Agenda 21). The basis of this concept was the adoption of a more sustainable approach to the utilisation of the world's resources whether these are renewable or not. Outputs from the Summit are having a direct influence on how we manage our terrestrial and aquatic environments. There is a realisation that water resources must be planned and managed in an integrated and holistic way to prevent shortages of water or pollution of water sources from impending development. The satisfaction of basic human needs and preservation of ecosystems must be the priorities. How is this going to be achieved? Article 21 clearly states that "*by the year 2000 all states should have national action programmes for water management based on catchment basins or sub-basins, and efficient water use programmes*". These should include the integration of water resources with land-use planning and other development activities, and the enhancement of the concept of catchment management. Current and proposed EU policy such as the 'Framework Directive for Water' which is currently in draft, also identifies catchments as a sensible functional unit for integrated management.

Catchments provide the ideal unit for the quantitative assessment of dynamic interactions between the hydrosphere, biosphere and lithosphere. Catchment physiographic characteristics govern soil and plant distributions, the quality and quantity of run-off especially in relation to potential sinks and sources of pollution, and the way in which the land is managed, and ultimately the capacity to sustain employment and social demands. Activities within a catchment which may be in potential conflict with each other (from time to time) include maintaining the quality of surface and groundwater (both chemically and biologically), improving agricultural and forestry productivity, development of tourism and recreation, the conservation of ecosystems and habitats, and meeting the requirements of urban infrastructure and industry.

To achieve sustainable development within a catchment requires that these various activities be managed in a holistic way to minimise conflicts and enhance environmental quality.

The issues

There are many pressures on catchment systems including acidic deposition, and climate change, nutrient enrichment, sedimentation and eutrophication, and the requirements for urban development and industrial water usage.

For example, in Scotland a recent survey of water quality in lochs greater than $1 km^2$ (total of 142 lochs) found that a total of 20% had been significantly altered by human activity (both nutrient enrichment and acidification). In another survey of 91 lochs, 70% had exceeded Scottish Environment Protection Agency's (SEPA) warning threshold for blue green algae on at least one occasion. Urban drainage is responsible for 20% of the downgraded water courses, with sewage effluent from treatment works and sewer overflows accounting for a further 33%.

Waste Water Treatment Plant

In order to implement the minimum standards contained in the EC Urban Waste Water Treatment Directive it is estimated that the new Water Authorities in Scotland will have to invest £1,300 million to upgrade sewage treatment works and sewers by the end of 2005 (SEPA, 1996).

Agriculture accounts for only 5% of the severely polluted (Classes 3&4) length of Scottish rivers but when Class 2 waters are included (i.e. those which have been degraded to some extent) the contribution increases to nearly 30%. There is also clear evidence that the nutrient content of rivers draining arable farming areas has been rising since the 1950's, in many instances directly reflecting the increased usage of artificial fertilisers.

Rivers also provide the major transport mechanism by which pollutants and nutrients are introduced into our coastal environment. Accurate assessment of contaminant loads is an important prerequisite for the development of international legislation aimed at the long term management of marine environments such as the North and Irish Seas.

Current research

The principle aim of the research at the Institute focuses on the interactions of atmospheric deposition, land use and water quality management. Our research determines the hydrological and hydrochemical factors which affect the acidification and eutrophication of water resources, elucidating the spatial and temporal interactions of land use and management within catchment systems, and identifying the downstream consequences and interactions of pollutants. A key element is the integration of this process- based understanding into mathematical models and the development of catchment based decision support systems for resource managers and for the purposes of investigating and evaluating the impact of policy.

Within this overall research strategy, specific efforts have been directed towards investigating the impact of different land uses and management represented within catchment systems. In the uplands' research is primarily focused on the interaction of acidification and commercial afforestation, and the determination of both sulphur and nitrogen critical loads. Central to the calculation of these critical loads is the determination of mineral weathering rates. The Institute is undertaking the evaluation and fundamental analysis of how weathering rates may be determined in relation to setting critical loads. Research also includes the measurement of losses of sediment by erosion and the impact of using sewage sludge and other waste products in forestry. In the intensively used agricultural lowlands, research is directed to determining the potential for nutrient and pollutant loss from agricultural production systems to the aquatic environment: the work is set in the context of environmental and water quality control legislation, such as the EU Nitrates Directive.

This research has led to the formulation of predictive tools for water resource management. For example, the development of a methodology and modelling approach has been used to determine the impact of human activity on the quality of Scottish standing waters, output from which has been used to prioritise specific catchments in which remedial action can be targeted. The development of catchment based models and decision support systems, which balance the requirements of industry and urbanisation with appropriate land management strategies, is seen as a fundamental requirement for the proactive management of catchment resources.

The extrapolation of our understanding of catchment functioning to the larger spatial units of landscape, region, national and continental scales involves collaboration with a number of research groups throughout Europe and North America. It involves the application of mathematical models of catchment behaviour and the collaborative development of appropriate regional and European databases. This work will allow us to address strategic environmental issues involving atmospheric deposition, land use and climate change and is fundamental to the development of future European Environment Policy.

Research highlights over the last ten years

- Elucidation of the mechanisms of soil and water acidification and the role of upland afforestation (Miller *et al.*, 1988; Mason, 1990).
- Determination of the critical loads of acidity of soils and waters in Scotland. Identification of areas in the country that are currently 'exceeded', and susceptible to further damage (Langan and Wilson, 1994).
- Identification of the role of Sitka spruce in enhancing the deposition of acidifying compounds from the atmosphere, in comparison with other conifers (Miller *et al.*, 1991).
- Development of mathematical models to determine the impact of atmospheric deposition and land use on soil and water quality (Wright *et al.*, 1994; Ferrier *et al.*, 1995).
- Development of a soil moisture probe for measuring soil moisture profiles in remote locations, which has been patented by MLURI, and is now in commercial production (Gaskin & Miller, 1996).
- The frequency of damaging acid episodes in streams and rivers can be reduced by applying limestone at 10 tons per hectare to sources areas approximating to 15% of the catchment (Miller *et al.*, 1995).
- Consideration of the patterns of nutrient cycling in plantations has explained much of the anomalies in reported fertiliser responses, and has improved management practice (Miller & Miller, 1987).
- Scottish rivers have shown increased nitrate concentrations over the last 30 years which reflect the general intensification of agriculture over the same time period, the trend for phosphorus is more complicated and is less related to land use (MacDonald *et al.*, 1995).
- A bioeconomic assessment of the impact of sulphur emissions on a regional fisheries resource. Agreed emissions reduction would result in a £1.4M increase in the value of the fisheries in SW Scotland (Macmillan and Ferrier, 1994).

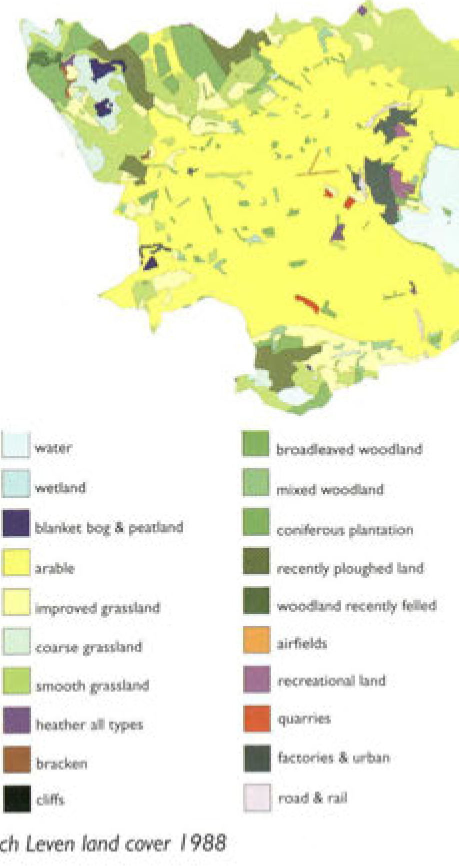
Selected current case studies

Enrichment of nutrients in the loch waters of Scotland

In 1995 SEPA undertook an assessment of the Standing Waters of Scotland and produced a classification scheme which highlighted the extent to which human activity has downgraded water quality and aquatic ecology.

MLURI was commissioned by the Scotland and Northern Ireland Forum For Environmental Research (SNIFFER) to develop a methodology by which to determine the change in nutrient status of 170 lochs and to classify these into one of four sensitivity bandings. This was assessed using the change in total phosphorus loading (TP) to the individual lochs from 1850 to the present day.

Loch Leven

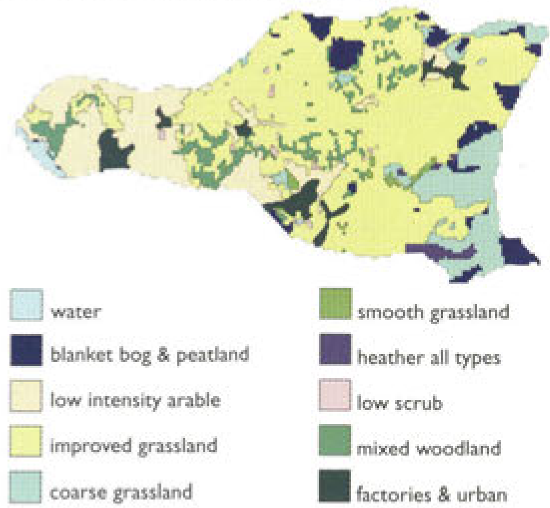


Loch Leven land cover 1988

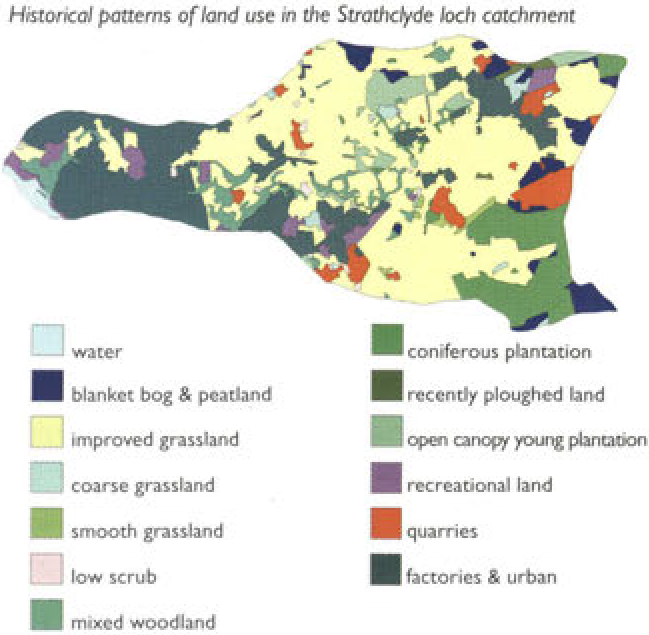
Current phosphorus loading to any loch system can be divided into two sources, namely

- POINT sources (e.g. sewage treatment works, septic tanks, industrial discharges etc.)
- DIFFUSE sources (i.e. P loss that is attributable to land use and management)

Historically (1850), point sources can be considered as negligible, and the dominant source of phosphorus was that associated with the management of the land. Therefore, in order to determine the extent of nutrient enrichment that has been caused by man's activity, it is necessary to determine the historical land cover of Scotland (a process known as '*hindcasting*').



Historical patterns of land use in the Strathclyde loch catchment



Present day land cover in the Strathclyde loch catchment

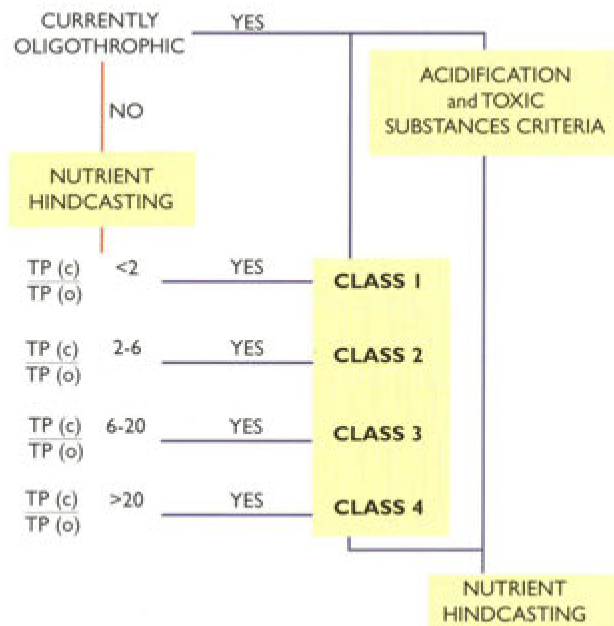
Once the historical land use patterns within each catchment have been calculated, a mathematical model called PLUS (Phosphorus Land Use and Slope) was used to calculate the actual loss of phosphorus from the land area to the loch. This was also done for present day.

The classification scheme then determines the overall banding of the water bodies into one of the four categories using the ratio of TP (current) / TP (hindcasted). Class I waters are in good condition, while those in Class 4 are severely damaged systems.

The Scottish Standing Waters Classification Scheme involves the determination of three factors;

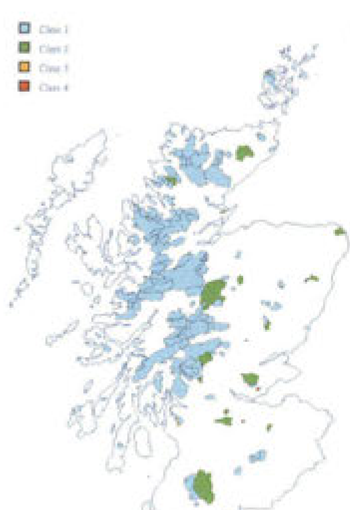
- changes in nutrient status (highlighted below)
- acidification classification
- toxic substances.

NUTRIENT HINDCASTING OF SCOTTISH STANDING WATERS



Schematic of classification procedure

The final output from the nutrients classification and the complete standing waters classification is shown below.



Impact of land management: The Ythan catchment (Grampian region)

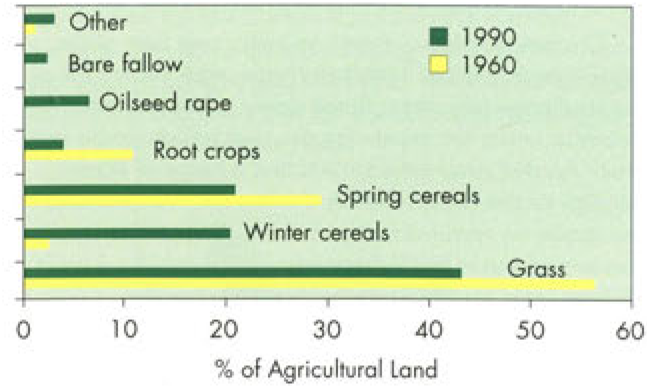
The EC Nitrate Directive (91/676/EEC) requires Member States to identify waters which are polluted by nitrates arising from agricultural sources. Thereafter they are required to designate the areas contributing to the polluted waters as Nitrate Vulnerable Zones and implement measures to reduce the pollution in those areas. Pollution is indicated not only by the exceedence of a specified concentration limit but also by the manifestation of nitrogen-driven eutrophication.

SEPA has reported that the Ythan estuary is eutrophic in terms of the criteria set out in the Directive's implementation guidelines, by virtue of its elevated nitrate concentration. It is assumed that the elevated nitrate concentration has increased substantially the presence of mats of the benthic algae *Enteromorpha* spp. In turn, this has induced changes in the numbers of mud-dwelling mollusc *Corophium volutata* which, being a food source, has affected the number of wading birds on the estuary.

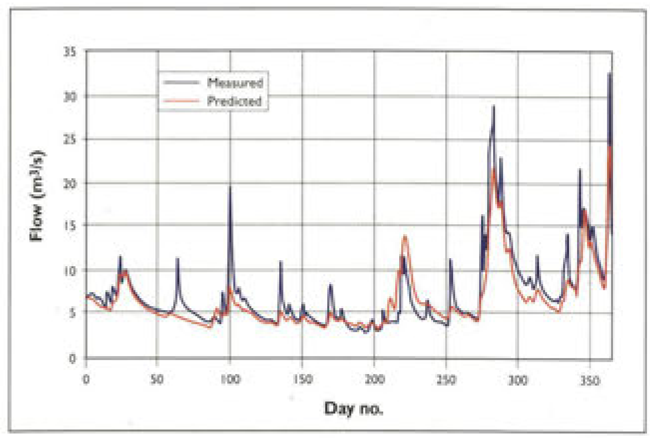
Overall only 2% of the 5,000 kg of nitrogen, compared with 48% of the 50 kg phosphorus, which enters the estuary daily, derives from sewage discharge. It is, therefore, concluded that the elevated nitrogen status of the catchment derives from soil processes associated with land use practices, which, for this catchment, implicates agriculture and its use of fertilisers and livestock slurries. The original North East River Purification Board Report recommended that further scientific studies focusing on the "cause and effect" of pollution in the Ythan catchment and estuary would be appropriate. In response SOAEFD have initiated a research programme to identify processes leading to eutrophication and evaluation of possible measures to alleviate the problem. This collaborative project, involving MLURI, Scottish Agricultural College and the Institute of Hydrology, has different research themes (Figures opposite). Firstly, a nitrogen balance for the whole catchment area is being undertaken using agricultural census data. Secondly, an assessment is currently underway of the amounts of nitrogen which are applied to different crops as manures and slurries, in addition to inorganic fertiliser practices.

A hydrological model has been developed to predict the spatial and temporal inputs to the stream network. Predictions of daily flow have been validated against measured flow for the period 1992-1994.

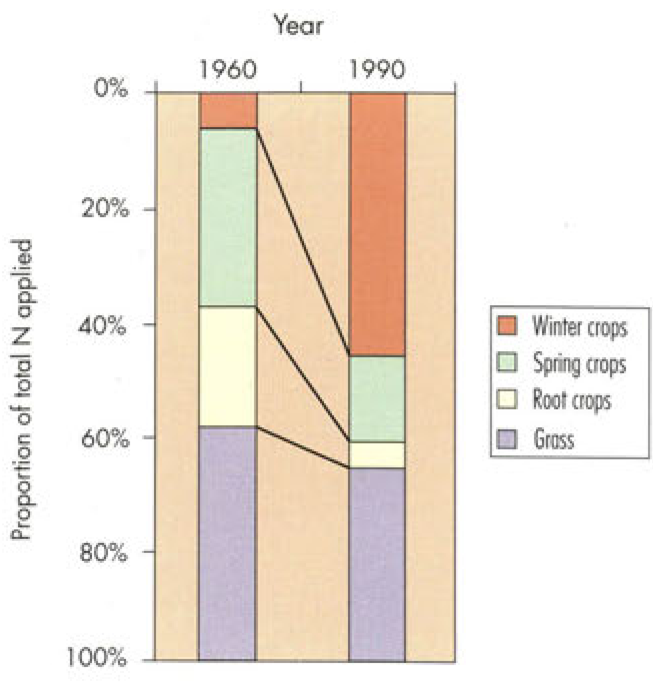
A key feature of this collaborative project is the development of an economic assessment of specific land use practices within the mosaic of different farm types located in the catchment. Collaboration between these different disciplinary studies is targeted towards the development of an integrated catchment management plan, which will reduce the levels of nitrate in the river and into the estuary, whilst minimising the effect on farming practices and income. The official designation of the Ythan catchment as a nitrate vulnerable zone in the meantime remains under review.



Changes in cropping areas 1960-1990



Measured and predicted streamflow at Ellon for 1993



Proportion of annual N inputs to main crops and grass: 1960-1990

Upland afforestation practices: The Halladale catchment (Highland region)

The forest industry forms an important part of the rural economy in the Highland region, with some 12% of the land presently under forest cover. Considerable potential exists for expanding this area which would bring much needed rural employment and a range of other benefits to the region (HRC's IFS Report 1994). A major constraint on forest development, however, is the concern of water and fishery interests about the impact of large scale conifer forestry on the freshwater environment.

Salmon Fisherman

The Highland region has an extensive, high quality freshwater system which supports important commercial and recreational fisheries, as well as containing key sites of conservation interest. This resource is thought to be at risk from the soil disturbance and hydrological changes accompanying ploughing, drainage, road building and harvesting operations, the nutrient losses following fertiliser applications, and the scavenging of acidic pollutants by the growing tree crop.

Although the Forestry Commission introduced a set of Forest and Water Guidelines in 1988 in order to address these potential problems by promoting good management practice, doubts remain in some quarters about their effectiveness in practice. Consequently the sustainability of forestry within sensitive water catchments is in question.

In 1991, a large scale proposal to afforest approximately 1000 hectares of the headwater catchment of the Upper Halladale River raised serious concerns about the threat to the local salmon fishery. The Halladale River forms a small, but productive fishery, which makes a significant contribution to the local economy. The upper section of the river above Forsinard comprising one of the main spawning and nursery areas, was thought to be at particular risk from the planting scheme. An extended period of consultation failed to address all of the concerns, with the emphasis being placed on the acidification issue. In an attempt to resolve this situation, a research study was undertaken in the upper catchment in 1993/94 by a consortium of organisations. This concluded that the proposed afforestation posed little threat of surface water acidification and as a result approval was finally given in January 1995 for the scheme to proceed.

The planned afforestation of the upper catchment scheduled between January and April 1996 presented an ideal opportunity to study the impacts of ploughing, drainage and fertilisation operations on a very sensitive freshwater system. This would help to assess the efficacy of the Forest and Water Guidelines in protecting the freshwater environment and so determine appropriate levels of sustainable forest development. A positive result would demonstrate the compatibility of both land uses in highland catchments and provide a sound basis for planning woodland and forest operations sensitively in other parts of the region.

Panorama of Halladale catchment

The key forestry measures adopted were

- avoid ploughing all riparian and wetland areas and keep clear of natural drainage lines.
- use shallow ploughing which minimises the exposure of underlying mineral subsoil, with short furrow runs separated by narrow buffer strips.
- mound, rather than plough, the steeper slopes.
- hand application of initial phosphate fertiliser.

Results to date show that, in the short-term, the impact on stream water quality has been minimal with

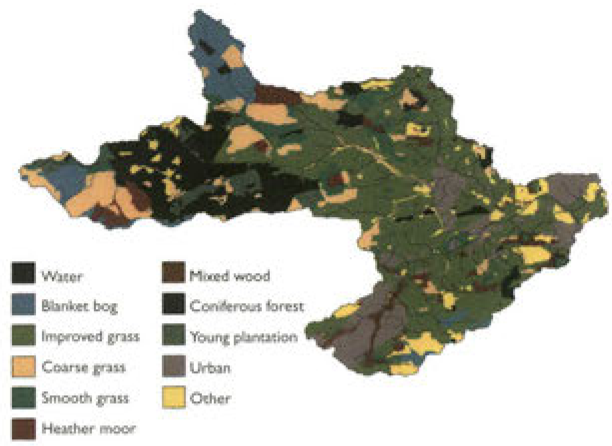
- colour and turbidity data suggesting that the cultivation has led to no significant losses of soil material into the river system.
- stream pHs, along with calcium, magnesium and aluminium, have remained essentially unchanged confirming that there has been minimal disruption of the underlying ironpan and indurated horizons.
- the main nutrient response has been increases in phosphate concentrations during a wet period in late 1996. Whether significant fertiliser losses will continue remains to be seen.
- there has been no apparent impact upon either the invertebrate or fish populations.
- there was no significant differences in the survival of fish fry in control or experimental sites during fish egg implantation experiments.

However, in view of the relatively short time interval that has elapsed since the completion of these forestry operations, it is important that the research studies continue in order to confirm these findings in the medium term.

Integrated catchment management modelling: The Carron catchment (Central region)

Catchment water quality is an integrated response to the many activities and management practices that occur within the area of land drained by a river. Despite this, there has been a tendency in the past to tackle water quality problems through a single issue approach. For example by focusing on only one problem, such as acidification, and identifying management practices that may be adopted to target that particular problem. This may do little to improve the overall water quality of the catchment and in some instances may actually counteract a general improvement. The alternative approach is to develop tools that may be used to analyse the integrated effects of all activities in a catchment. In this way a system of proactive catchment management may be developed to tackle multi-issue water quality problems.

The potential for implementing this type of system is being investigated through the development of a case study model for the Carron Catchment in Central Scotland. The River Carron, draining around 200km^2 of land, rises in the Campsie Fells at an elevation of around 500m a.o.d. and flows east for 25km before reaching its tidal limit with the River Forth.



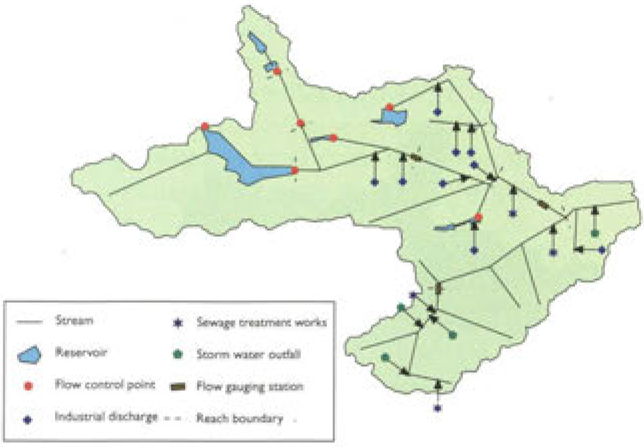
Land cover - Carron catchment

In the upland region of the catchment there are commercial forestry plantations and the water resource is extensively managed for public water supply. The Carron Valley Reservoir covers an area of over 4km^2 and has the capacity to store up to 21.4 Mm^3 of water. The Carron flows through agricultural land in its central stretches before reaching the urban and industrial areas of Bonnybridge and Falkirk. Thus, a wide range of activities and land uses contribute to the overall water quality of the Carron, and the catchment provides an appropriate test-case for the development of an integrated modelling approach.

A catchment water quality model must be capable of combining two distinct sets of processes. Firstly, there are the diffuse inputs to the system, generated by runoff of water and pollutants from the land surface into the streams. Secondly, there are the point source inputs to the streams and the in-stream transport of pollutants. These two sets of processes can be combined by linking a distributed stream delivery model with an in-stream model.

The distributed model calculates the temporal inputs from the land to different reaches of the stream network, taking into account physical and topographic influences as well as the land use. This will include factors such as the local rainfall, the slope of the land and the length of the flow path and the export of pollutants.

In collaboration with the Institute of Hydrology, in-stream modelling is being linked to the delivery model framework. The stream network is divided into a set of reaches with the relevant influences for each reach defined as inputs to the model. The inputs include factors such as water abstractions, effluent releases from sewage treatment works, industrial discharges and the diffuse runoff from the distributed model.



Model structure developed for Carron.

Output from the model, such as nutrient and oxygen concentrations, will assist in identifying catchment water quality problems, both temporally and spatially. The model may then be used in a predictive capacity to investigate how different scenarios of management might influence the overall catchment water quality status. In the case of the Carron, the model will demonstrate how factors such as the management of the upland water resource affects the water quality of the lowland area, and how to optimise all uses of the water resource within the catchment to maintain sustainable development without compromising environmental quality.

Future research

Research will continue to focus on the determination of the hydrological and hydrochemical factors which are responsible for the movement of pollutants and nutrients into the freshwater and estuarine environment. This will require further understanding of both solution and particulate transport mechanisms within the catchment system, and in particular the focus will be on representation of these processes in a spatial framework (such as the field - farm - catchment continuum). The development of sustainable land management strategies requires the definition of functional units, and this is especially so for economic assessment. A key future challenge is to link the spatial representation of catchment process to those of socio-economics so that 'cost - benefit' assessment of sustainability can be determined.

In order to manage catchment resources it is important that consideration is given to pressures on the whole catchment system rather than just a specific area. For example, in certain areas upland headwater streams are subject to acidification pressures and lowland areas are similarly under pressure from aspects of nutrient enrichment. However, for the management of a large river basin it is important to understand the nature of the time and space boundaries of these impacts, and how they interface with the other pressures on water resources. Indeed, future management options must be considered in a proactive rather than a reactive way and focus on the continuity of the catchment system and the effect of downstream impacts.

Future EC policy is likely to further influence water quality management through the establishment of the Framework Directive for Water which is currently in

Beautiful loch - peace and harmony on the waterfront draft. Subsumed within this will be the "Ecological Directive", which highlights the importance of protecting the ecological status of river systems and so focuses attention on extremes of water quality rather than average or mean conditions. This will have implications for the way we currently approach optimising issues for water resources within catchments, and indeed such integrated management can only be achieved through the employment of catchment based dynamic models.

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SUSTAINABLE MANAGEMENT OF SOILS

Concepts of sustainable development have achieved considerable prominence during the 1990s (UK Strategy for Sustainable Development, HMSO, 1994) and, currently in the UK, attention is being focused on the development of indicators of sustainability (Indicators for Sustainable Development, DOE, 1996) within the Pressure-State-Response model proposed by the Organisation for Economic Co-operation and Development (OECD). In order to implement this framework fully, there is a requirement to define concepts of soil quality, whereby the multifunctional role of soil in the environment may be formally recognised, and to develop indicators by which quality or 'fitness-for-purpose' may be measured. However, it is important to recognise that soil scientists have, for many years, been concerned with the development of specific indicators of soil quality. For example, in the early years of the Macaulay Institute for Soil Research much of the scientific impetus of the Institute was strongly driven by the desire to manipulate the chemical quality of soil for the growth of crops through the addition of fertilisers. On the other hand, in the Hill Farming Research Organisation attention was paid to the management of nutrient cycling in 'poorer' soil environments that supported a range of semi-natural vegetation. The formation of the Macaulay Land Use Research Institute in 1987 provided an opportunity to place much of this previous research within a new integrated context that is now contributing to the development of land use science. Sustainable management of soil is an integral part of this strategy. It includes research on the definition and measurement of soil quality using current indicators and the development of new indicators based on key soil processes and on specific aspects of land use and management.

The issues

The protection of soil has been identified as 'crucial for future sustainability' (UK Strategy for Sustainable Development, HMSO, 1994) and 'the chosen indicators relevant to this objective are soil quality' (Indicators for Sustainable Development, DOE, 1996).

Current soil quality indicators are relatively crude and are largely based on measurement of particular aspects of soil composition (Figure 1). However, in order to address pressures and responses, implicit in the full implementation of the OECD model used by Government, a 'second generation' of indicators will be required. These require to be aimed at **key processes** in relation to sustaining specific functions of soil rather than the definition of specific aspects of composition. In this context the MLURI programme will be aimed particularly at those processes relating to soil-biosphere and soil-hydrosphere interactions. Thus, the aims of our research are to;

- analyse the agro-environmental functions of soil,
- identify key soil processes in the definition of soil quality and
- develop a series of process-based indicators.

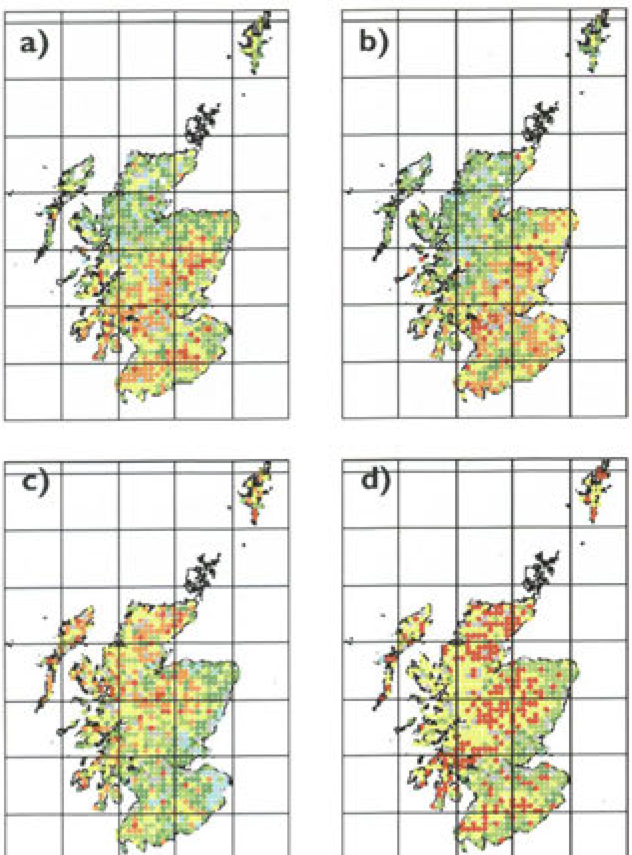

Figure 1 Key indicators for Scotland including a) Pb, b) Zn, c) organic carbon, d) pH.

Only in this way can the complexity of soil response to environmental change be represented and the manipulation of processes, which forms the basis of sustainable management and good stewardship, be placed on a sound scientific footing.

The 19th Report of the Royal Commission on Environmental Pollution on the Sustainable Use of Soil (HMSO, 1996) has identified soil contamination and the utilisation of wastes on land as critical issues facing the UK in the future and our programme seeks to address these within a Scottish context. The safe re-use of contaminated land is important from two perspectives - firstly, to avoid 'leakage' of pollutants to other environmental media, e.g. water, and secondly, to relieve development pressures on green-field sites which result in irreversible loss of agricultural land. In the case of waste utilisation there are many pressures to change current practices. These include UK North Sea treaty obligations, European Union directives such as the Urban Waste Water Directive, fiscal measures such as the landfill tax, as well as the desire to recycle valuable nutrients contained within many organic wastes (Figure 2). For all of these reasons, waste recycling to land used for agriculture and forestry, as well as its use in reclamation projects, is an attractive option, provided that sufficient knowledge exists on which to make an informed judgement of the long-term impact. A major aim of our programme is to provide such guidance from studies of the basic processes involved in soil responses to the addition of a range of wastes. This encompasses both nutrient cycling and the impact and fate of pollutants that may enter the soil environment.

The programme has been constructed in discussion with potential end-users and recognises that technology transfer does not occur by default, and that, as well as strategic studies of fundamental processes, efforts must be directed at the management unit scale to refine recommended protocols and Codes of Practice, and at regional or national scale to investigate the impact of policy options.

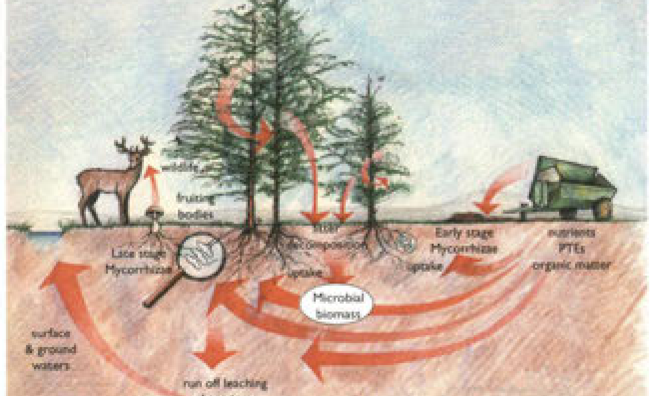

Figure 2 Potential effects of sewage sludge on forest ecosystem processes

Research highlights over the last 10 years

Much of the work in this area over the past ten years has been concerned with developing our understanding of soil interactions with pollutants thus establishing a conceptual framework by which we may address one of the science and technology priority areas identified by the Agriculture, Natural Resources and Environment Technology Transfer report, namely environmental research programmes encompassing modelling, monitoring and forecasting. In more recent years we have been able to build on this basic understanding to provide tools by which the impact of policies may be evaluated and have contributed through collaborative work to the development of improved Codes of Practice in, for example, the utilisation of wastes.

- Development and application of a rule-based framework by which the suitability and availability of land for sludge disposal may be assessed (Towers, 1994).
- Assessment of the sensitivity of Scottish soils to heavy metal inputs through linkage of process based understanding to MLURI spatial datasets (Paterson *et al*, 1996b; Towers and Paterson, in press).
- Identification of specific interactions between soil organic matter and copper contaminants by electron spin resonance spectroscopy (Cheshire *et al.*, 1994).
- Increased understanding of the mobility of radiocesium in organic upland soils (Shand *et al.*, 1994).
- Development and application of single species microbial assays to assess the toxicity of soil solutions from contaminated soils (Paton *et al.*, 1995a; Paton *et al.*, 1995b).
- Participation in a national network of sites to assess the impact of sewage sludge on long-term stability of soils.
- Identification and quantification of anthropogenic inputs of lead using thermal ionisation mass spectrometry (Bacon *et al.*, 1995).
- Assessment and investigation of pollution in urban soils in both Scotland and the Czech Republic (Sanka *et al.*, 1995; Paterson *et al.*, 1996a).
- Use of chemical complexation models to describe the interactions between metals and soils (Lumsdon *et al.*, 1995; Lumsdon, 1996).
- Description of transport processes of pollutants in soils using a novel computer model linking chemical and physical processes (Meeussen *et al.*, 1996).
- Application of mineralogical techniques to identify inter-element associations of pollutants in contaminated soils (Rybicka *et al.*, 1994; Adamo *et al.*, 1996; Chlopecka *et al.*, 1996).

A number of these projects have been developed and are continuing within our current programme with science-centred groupings complementing the increased emphasis on issue and application-driven research within the programme itself.

Current research

Mineral weathering and dissolution in the soil environment

Mineral weathering is a key process in soils and determines not only the response of soils to acidification, as discussed elsewhere in this report, but can also play a more fundamental role in determining the 'inherent fertility' of soils. This control is largely felt through the supply of major cations by weathering although, in some cases, parent material can have a marked influence on the amount and availability of trace metals, such as nickel and zinc (Figure 3).

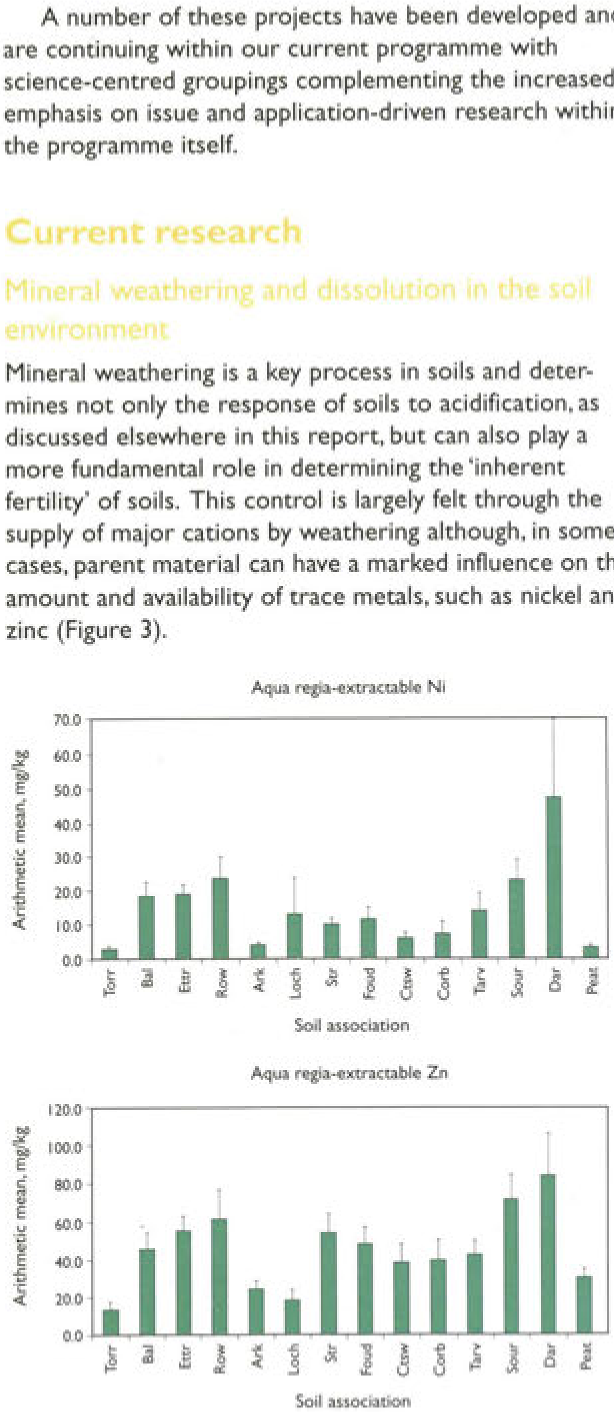

Figure 3 Bar graphs of Ni and Zn contents of Scottish topsoils as a function of soil association.

The use of the soil association concept in the mapping of Scottish soils allows the ready translation of geochemical and mineralogical understanding for wide-area environmental modelling and extensive use of these relationships have been used in the critical loads programme (see Integrated Catchment Management). However, to

- apply these concepts at a range of spatial scales and
- replace expert judgement with mechanistic understanding

a range of process-based models are currently being critically evaluated. One of these, PROFILE, is the subject of continuing collaboration with a group in Sweden. Thus far, our work has shown that there are a number of difficulties with the manner in which specific surface area is represented within the model and this has led to a fundamental re-evaluation of the role of interfacial area in the dissolution and weathering of primary minerals.

Pollutant distribution and transport in the soil environment

The distribution and mobility of pollutants in the soil environment is dependent on their partition between the solid and liquid phases in soil. Thus, surface reactions, such as adsorption and exchange, may be considered as key processes which determine the behaviour and fate of pollutants. The soil components active in these processes are likely to be suitable indicators of soil quality. Surface reactions in the highly competitive environment in soils can be complex. Our approach to gaining an understanding of this complexity is two-fold.

First, we continue to develop sophisticated experimental approaches to characterise the sources of metal pollutants by evaluating their stable isotope signature. This approach has been applied successfully to a range of environments, from the Scottish uplands (Bacon *et al.*, 1995) to more highly contaminated systems in Poland (Chlopecka *et al.*, 1996). However, it is the combination of this method with selective chemical dissolution that is now providing an unique insight into the redistribution of metals within various 'pools' represented in soils. For example, in a site with low levels of atmospheric deposition lead in the three mobilizable fractions of the surface soil had identical isotopic compositions indicating that redistribution can readily occur within the soil environment. The use of stable isotopes also provides an opportunity to study these processes of redistribution using 'spikes' added to soils, without any of the difficulties and hazards associated with radionuclides. Again, a very rapid redistribution of added metals occurred between the various operationally defined fractions obtained by selective dissolution (Bacon and Steegstra, 1994).

Secondly, from studies of purified soil materials and well defined synthetic model compounds, we have used a series of chemical models which have been developed to incorporate the various mechanisms involved. Some commonly used models for mineral surfaces include the constant capacitance model (CCM), the generalised two-layer model (GTLM) and the triple-layer model (TLM) whereas for organic surfaces we are collaborating with colleagues in Europe (University of Wageningen, The Netherlands) to develop new models.

The application of surface complexation models to describe adsorption reactions in an heterogeneous medium such as soil raises a number of problems, such as how to

- represent the active surfaces responsible for adsorption and
- take account of the presence of competing solution species.

In the case of the oxyanion, molybdate (MoO_4^{2-}), the active surfaces were taken to be the hydrous oxides of Fe and Al and the clay mineral, kaolinite. The amount of each of these species was estimated by selective chemical extraction and by infra-red spectroscopy of the clay fractions. When the experimental data are compared to the data obtained by applying the GTLM model, it can be seen that a significant overestimate of the adsorption occurs but when the presence of the phosphate as a competitive anion is included much better agreement is obtained (Figure 4). Similar approaches have been deployed in order to account for the adsorption behaviour of metals, such as cadmium.

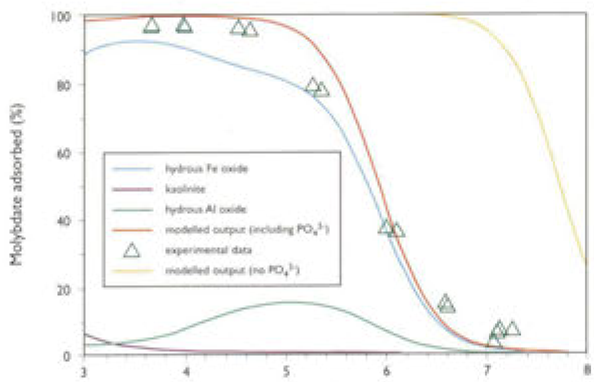

Figure 4 Experimental and modelled uptake of molybdate by soil

In order to predict the movement of contaminants which interact strongly with soil components via the mechanisms outlined above, both chemical and physical models must be coupled within a single framework. This has now been achieved using an entirely new approach based on an object-oriented computing framework (Meeussen *et al.*, 1996). Within this model the chemical reactions involved for any particular case are represented as 'objects' whilst the central computing core carries out the necessary calculations to solve the mass- and charge-balance equations involved for each equilibrium. A new algorithm has been developed for calculating these equilibria at each stage in the transport process in order to increase the overall speed of the model such that predictions may be made over time periods that are considerably longer than any that might be achieved in laboratory systems.

The application of a simplified version of our chemical modelling knowledge base to the range of soils represented within Scotland has been carried out by identifying key components and representing their behaviour within a spatially based framework such as the weighted parametric approach used by Towers and Paterson (in press).

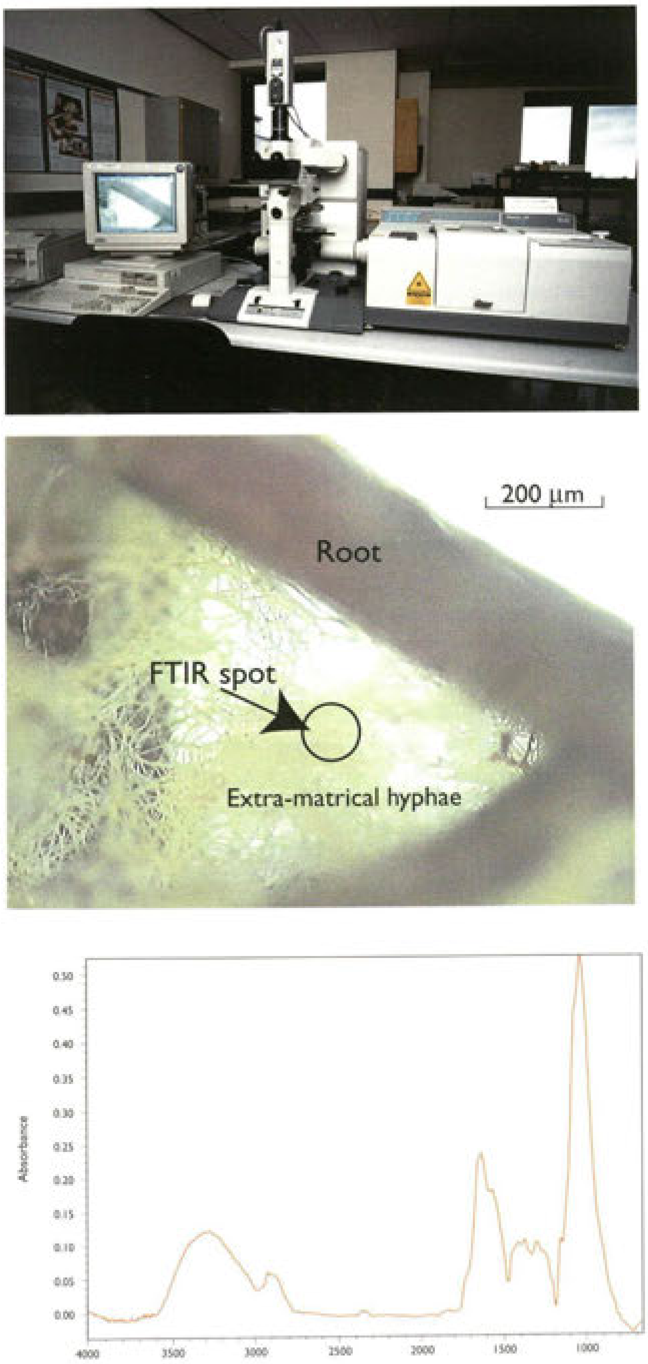

Figure 5 (Top to Bottom) photograph of FTIR instrument, image and spectrum of mycorrhizal fungi

Microbial ecology and diversity

In order to detect changes in soil quality early enough to implement management to protect soils, more sensitive techniques aimed at key soil processes are required. Micro-organisms play a key role in the function of soil. Many microbially-based indicators of soil quality have been proposed e.g. measures of microbial biomass, activity and diversity, including the presence and activity of root dwelling symbionts. The underlying rationale for these selections is that micro-organisms may be the most sensitive part of the soil ecosystem. Recent work has concentrated heavily on microbial diversity which may be of particular importance in assessing the resilience of soils to stress, such as that imposed by the presence of pollutants.

There are three principal methods by which the diversity of micro-organisms may be defined - genetic, taxonomic and functional. Genetic diversity may be studied using molecular biology techniques, although the relationship between genetic diversity and soil function is not straightforward. Work being carried out in the SOAEFD-funded Micronet programme is pioneering the study of the relationship between rhizodeposition of carbon and microbial diversity using a range of techniques including molecular approaches. Taxonomic diversity is amenable to study by more conventional techniques such as identification of the presence of specific organisms or by quantification of biomarkers, such as phospho-lipid fatty acids (PLFA). This avoids problems of culturing some organisms but interpretation in terms of key soil processes may only be possible for highly specific organisms such as *Rhizobium*. Recent work has shown how sophisticated instrumental techniques, such as microscopic Fourier-Transform Infra-Red Spectroscopy (FTIR), may be used to obtain a spectroscopic fingerprint that can be used to identify mycorrhizal fungi growing on root tips (Figure 5).

For processes such as C and N mineralisation, which are carried out by a wide range of organisms, the linkage between function and diversity is difficult to establish and an approach based on community level physiological profiles (CLPP) may be more appropriate. This addresses the functional attributes of the microbial community in terms of its ability to degrade sole carbon sources which can then be related to the quality and quantity of carbon flow in the soil. These techniques can be used to detect population shifts in response to pollution stress and as such they are sensitive, functionally significant and cover a wide range of organisms.

Finally, it is important that biological changes are related to physical and chemical changes in the soil environment. Methods are being developed using techniques, such as FTIR, which characterise the nature of the soil resource and its relationship to microbial diversity as measured by PLFA and CLPP techniques. For polluted soils where soil micro-organisms may be sensitive indicators, work is taking place which attempts to link microbial bioassays to chemical speciation modelling. It has been shown that the toxicity of Zn and Cd could not be completely ameliorated in the presence of fulvic acid even though model predictions had estimated complete complexation of free ions. This suggests that organisms compete with the fulvic acid for metal binding and therefore the availability of the metal is higher than predicted based on the complexing ability of the solution alone.

Future research

The UK has made a significant start towards identifying and defining a broad family of indicators and thresholds which can be used as a means of managing systems more sustainably. There is now a need to consider these indicators and others within a framework that will be more readily related to

- the full range of soil functions within the diversity of land use in the UK,
- the requirements of a wide range of end-users, from policy makers to farmers and foresters,
- the risks and benefits that arise from utilisation of wastes on land,
- the impacts of contaminated land on other environmental media.

These will form the key objectives of our programme and we shall seek to identify and quantify key processes in the definition of soil quality so that we can objectively assess the impact of contamination on soil quality, ensure that the application of wastes enhances soil quality and thus maintain the long-term functionality of soils.

In order to ensure that our work can serve the interests and needs of as wide a range of end-users as possible the work will take place at a series of spatial scales. Process-based experimental approaches and modelling techniques will be closely integrated. Modelling will be extensively used for technology transfer over various spatial scales. The ultimate aim is to develop decision support tools which integrate knowledge and guide end-users in determining systems of sustainable soil and land management.

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Spatial scale	Objective	End-user
National/regional	provide a framework for the assessment of policy options	Government and regulatory agencies
Field/site scale	contribute to development of sound management protocols	Farmers, foresters, heritage managers and advisory groups
Laboratory/microcosm studies	enhanced understanding of basic processess	scientists and technology transfer specialists

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SUSTAINABLE MANAGEMENT OF MARGINAL LANDS

The aims of sustainable management of marginal lands encompass a need to provide scope for economic development, stable employment and the protection and enhancement of the natural heritage.

Marginal lands are characterised by having soils of low nutrient status and pH, seasonal extremes of climate, a wide diversity of flora and fauna, and by being used mainly as grazing resources for large domestic herbivores and the production of trees. Agriculture, forestry and recreational sport are the traditional activities associated with these areas and more recently, reflecting the high natural heritage and landscape value of some of these areas, a greater emphasis is being placed on their conservation and environmental enhancement. Furthermore, the tourism and recreational industries continue to develop in these areas as a consequence of people with substantial amounts of leisure time and discretionary income creating a demand for access and the recreational use of these lands. While providing alternative employment opportunities in these rural areas, this also brings additional pressure to bear on resource use and leads to greater emphasis being given to landscape and wildlife management.

The research issues which emerge from this analysis and which are relevant for sustainable development are several fold. To remain economically viable both agriculture and forestry have a need to adopt new technologies and develop new products. This has led to the study of diversification options and new systems, some of which involve more extensive management and operate with less labour as a means of spreading fixed costs across an increasing range and level of outputs. Many of these marginal land ecosystems will nevertheless continue to be maintained by grazing animals but at varying levels of intensity of use. There is therefore a need to investigate the effect of changes in animal numbers and the species utilising these resources with respect to their social and foraging behaviour and their impact on vegetation cover, plant competition and vegetation change. Similarly, changes in silvicultural practice and tree harvesting technologies need to be evaluated with respect to their impact on tree productivity and soil fertility, erosion and resilience.

Though the research we do is undertaken primarily within the UK and Europe, it has strong resonances with the marginal lands of Africa, parts of Asia, Australasia and the Americas. It is increasingly set, therefore, within a wider international context since these lands are under many of the same pressures and require the application of similar principles for their sustainable management. Our research therefore focuses on developing principles which can be applied to the specific issues which are important to land use in the less favoured areas of the UK but which also have relevance throughout the rangelands and other marginal lands of the world.

The issues

Large herbivores are the major determinants of the dynamics of ecosystems in marginal lands. Through grazing, trampling and excretal return they affect nutrient flows, vegetation community dynamics and the responses of the associated fauna. Consequently a knowledge of the behaviour of herbivores is required in order to determine their impact on the natural heritage, including plant communities, at a range of geographical scales and to determine the relationship between land resources and herbivore population performance.

The aim of our research on herbivore foraging is to quantify the relationships between the habitat and the foraging behaviour of domestic and wild herbivores in these heterogeneous ecosystems. These ecosystems include the semi-natural vegetation and permanent pastures of upland UK and other terrestrial grassland and shrub biomes. The approach being taken to increase our understanding is through the development and testing of herbivore foraging theory. The effects of the distribution of vegetation, its physical and chemical composition, the distribution of microclimate variation and the social environment on foraging behaviour are being studied through a combination of broad-scale data collation and analysis, experimentation and mathematical and simulation modelling.

Our research emphasises the role that the spatial heterogeneity of grazing and soils play in determining vegetation dynamics, and the interactions between animal foraging and vegetation distribution within heath, extensively managed grassland and semi-natural woodland communities in the UK. The approach is to undertake research at several geographical scales in order to;

- understand the mechanisms which ultimately influence plant competition and hence vegetation dynamics,
- describe and understand the outcome of different grazing pressures on the spatial and temporal changes within and between plant communities
- develop computer-based models to predict the impacts of large herbivores on vegetation change.

In these ecosystems described above, and in most tree-based systems, such as plantation forestry, farm woodlands, coppice systems for biofuel and agroforestry systems, most of the nutrients used for plant growth come from the decomposition of soil organic matter and leaf litter by soil microbes and the cycling of nutrients within the plant rather than from the use of artificial fertilisers. In both grassland and tree-based systems, understanding carbon/nitrogen interactions at an ecophysiological level is central in determining the impact of management factors on soil-plant and plant-animal interactions. Such an understanding will enable the consequences of different management strategies for so-called low input systems to be assessed in the context of sustainable land use. Our research aims to understand the main ecophysiological processes regulating nutrient supply to, and use by, plants for growth in extensive systems on marginal lands.

In many marginal lands there is concern about the sustainability of agricultural animal production systems

Figure 1 Countries in which the n-alkane technique to measure intake and diet composition is being used and the species being studied

with respect to their economic viability, impact on the environment and on animal welfare. For example, within the European Community there are surpluses of many of the traditional livestock products which form the basis of agricultural output for many of its marginal upland areas. In terms of natural heritage objectives there are many areas which suffer from overgrazing or undergrazing. There are systems which may compromise the welfare of animals. Our research aims to identify new options for land use by large herbivores and to investigate the biological properties of these systems. The research concentrates on the development of systems of animal fibre production from cashmere goats and fine wool sheep, and on understanding the biology of growth and shedding of fibres. The principles are also explored which underlie the design of grazing systems for the sustainable utilisation of semi-natural vegetation and permanent pasture resources by large herbivores and which do not compromise the welfare of animals.

Technology transfer of the results of the programmes of research described above is achieved increasingly through the development of a range of models. These are incorporated, for example, into computer-based decision support tools which predict the impact of grazing by species, such as sheep, cattle and red deer, on vegetation dynamics, animal productivity and animal population dynamics. These tools are developed through close involvement with user groups.

Research highlights over the last 10 years

Herbivore Foraging

- Developed new methods, based on the n-alkane content of plants, for the measurement of herbage intake and diet composition in free-ranging herbivores which are accurate and easy to make. The methodology is now used throughout the world (see Figure 1) (Mayes *et al.*, 1986; Dove and Mayes, 1991; Mayes *et al.*, 1995).
- Advanced the theory underlying foraging behaviour of large herbivores of different body size (Illius and Gordon, 1987; Illius and Gordon, 1993).
- Developed a mechanistic model of ingestion and digestion by large mammalian herbivores which allowed interpretation of the evolution of foraging strategies and animal community structure (Illius and Gordon, 1991 and 1992; Gordon and Illius, 1994 and 1996).
- Increased understanding of seasonal cycles of intake and digestion of ruminants in temperate environments (Iason *et al.*, 1994; Milne *et al.*, 1990; Sibbald and Milne, 1993; Sibbald, 1994).
- Generalised optimal foraging theory to predict foraging behaviour of grazing animals (Farnsworth and Illius, 1996).
- Increased understanding of influence of digestion and metabolism of glucosinolates on intake of forage brassicas by sheep (Duncan and Milne, 1992 and 1993).

Vegetation Dynamics

- Developed model to predict the impact of sheep grazing on the utilisation of the major UK upland vegetation types (Armstrong *et al.*, in press a and b).
- Described impact of defoliation on the regrowth of *Molinia* and *Nardus* species (Grant *et al.*, 1996; Grant *et al.*, 1996).
- Quantified the importance of remobilisation in supplying N for leaf regrowth following defoliation in a range of perennial grass species (Thornton *et al.*, 1993).
- Demonstrated that the size and distribution of patches of grass in grass/heather mosaics influenced the foraging behaviour of sheep and red deer differentially and hence leads to differences in the spatial distribution of vegetation (Clark *et al.*, 1995a and b).
- Increased understanding of how to maintain white clover content in grass/clover swards (Marriott *et al.*, 1987; Barthram and Grant, 1995).

Land Use Options for Plants

- Demonstrated that N mobilisation from storage for spring growth in both deciduous and evergreen trees occurs before root uptake and is dependent on the size of the store and unaffected by current N supply (Millard and Proe, 1992 and 1994).
- Showed that in trees there was a differential partitioning of both N and P when taken up by roots or remobilised from storage (Proe and Millard, 1994 and 1995).
- Demonstrated that whole tree harvesting can reduce the growth of Sitka spruce in the next rotation and that this can be caused by short-term changes in microclimate and long-term impacts on tree nutrition (Proe and Dutch, 1994; Proe *et al.*, 1994).
- Developed a non-destructive boroscope method to study root length density and turnover in situ (Buckland *et al.*, 1993).

- Determined that soil microbial diversity under trees differs between species in relation to the loss of carbon from their roots (Grayston and Campbell, 1996).
- Differentiated microbial communities from different grassland systems based on their metabolic profiles (Campbell *et al.*, in press).
- Developed a site/yield model for Sitka spruce and used it to predict the impact of climate change on tree growth (Allison *et al.*, 1994; Proe *et al.*, 1996).
- Demonstrated that pasture production in silvopastoral systems can be predicted from easily measured attributes of trees (Sibbald *et al.*, 1991; Sibbald *et al.*, 1994).
- Demonstrated that soil compaction associated with grazing around trees can reduce survival and growth of trees (Wairiu *et al.*, 1993; Sibbald, 1996).
- Developed a biophysical model of silvopastoral systems (Bergez and Msika, 1996).

Land Use Options for Animals

- Established heritability of fibre traits of cashmere goats (Bishop and Russel, 1996).
- Developed new breed of fibre-producing sheep, the Bowmont, suited to UK upland conditions.
- Discovered IGF-1 receptors on hair follicles of goats (Dicks *et al.*, 1996).
- Quantified use of sward height as predictor of intake and performance of suckler cows (Wright and Whyte, 1989).
- Demonstrated value of sequential grazing of grass/clover pastures in mixed grazing systems in maximising animal performance (del Pozo *et al.*, 1996).
- Developed understanding of mechanisms by which body condition at calving controls the length of the post-partum anoestrous period in beef cows (Wright *et al.*, 1992; Pinto Andrade *et al.*, 1995).
- Showed that nutrition in early life influenced the lifetime reproductive performance of the Scottish Blackface sheep (Gunn *et al.*, 1995).
- Quantified the behavioural and physiological responses of farmed red deer to capture, transport and management procedures (Goddard *et al.*, 1996; Grigor *et al.*, in press).
- Showed that the immune response to psychological stress in farmed red deer was predicted better by lymphocyte than antibody responses (Hanlon *et al.*, 1994 and 1995).

Farmed Red Deer Stag

Current research

The focus of the current research programme is on developing principles of how marginal lands can be used and applying these principles to the specific issues which are important in the context of rural land use in the less favoured areas of the UK. Since grazed vegetation and trees are a feature of most marginal lands, greatest emphasis is placed on their study.

The grazed vegetation that is considered is that associated with conventional pastoral agriculture in the UK, i.e. permanent pasture, and that of temperate rangelands, typified by the semi-natural heaths and grasslands of the hills of the UK. The research issues for each of these resources differ not only because of the different geographical scales involved but also because of a different balance of objectives that require to be achieved.

Permanent Pasture

In relation to the grazing of permanent pastures by sheep and cattle, the implications of government policy on the extensification of these pastures are that the research should enable vegetation change and its benefits in terms of biodiversity to be predicted. At the same time animal production needs to be maximised within the context of these objectives. This requires an understanding of:

- plant competition as it influences vegetation change,
- the interaction of defoliation with soil nutrient status at the plant scale and at the larger feeding patch scale,
- the choices that ruminants make about what they graze within a feeding patch and which feeding patch they graze,
- how different ruminant species behave and
- how this information can be synthesised into the development of grazing systems

Plant Competition

To understand how grazing influences plant competition, research is being conducted on how defoliation of individual plants of different grass species influences the partitioning of nutrients, and nitrogen in particular, within the grazed plant after grazing. Differences between plant species in their responses to defoliation in laboratory experiments have been demonstrated which appear to reflect their competitive ability in grasslands (Thornton *et al.*, 1994). A mathematical model has also demonstrated the importance of nitrogen storage in the plant as a means of responding to defoliation (Birch and Thornton, in press). Techniques are currently being developed which will allow measurements of nitrogen partitioning to be made in the field and a mathematical model is being constructed to incorporate nutrient uptake from roots in the current model. This latter aspect is being explored in relation to how defoliated grass species respond to a heterogeneous nutrient supply from the soil. In collaboration with the Scottish Crop Research Institute, the Scottish Agricultural College and Biomathematics and Statistics Scotland, an integrated programme of research (see Figure 2) is being conducted, using molecular techniques, to explore how genetic differences within *Agrostis*, *Festuca* and *Rumex* species relate to differences in nitrogen partitioning. Seasonal differences in the genotype and phenotype responses between species in growth are also being studied using stable isotope natural abundance discrimination techniques.

While the long-term objective of the research is to attempt to relate the processes at the plant level to that at the feeding patch level much can be achieved by understanding plant competition at the feeding patch level and at the field scale. For example, the extensification of sheep grazing on permanent grassland has been studied in a long-term experiment where all fertiliser application has been removed and a number of grazing treatments, simulating reduced stocking densities, have been applied at a field scale. This study, linked to a similar experiment at the Institute of Grassland and Environmental Research, has been undertaken for 6 years and is planned to continue for another four years. The results (Marriott *et al.*, in press) show that, although rapid changes in species composition of the sward occur in the ungrazed sward, the changes in species composition across the grazed treatments are small. The lack of application of nitrogen fertiliser increases dramatically the white clover content and hence helps to maintain the animal productivity per unit area. The patchiness of species composition at the field patch level, particularly on the less heavily grazed areas, was high. This is partly due to variation in the physical and chemical nature of the soil found on the site (Cook *et al.*, 1996) and to the grazing behaviour of the sheep. The nature of the heterogeneity is currently being described and experiments conducted to examine the importance of the above factors in influencing this heterogeneity. A spatially-based mathematical model is also being developed, which describes the competitive interactions within and between feeding stations in relation to the relative growth rates of species, and this will be tested against the experimental results.

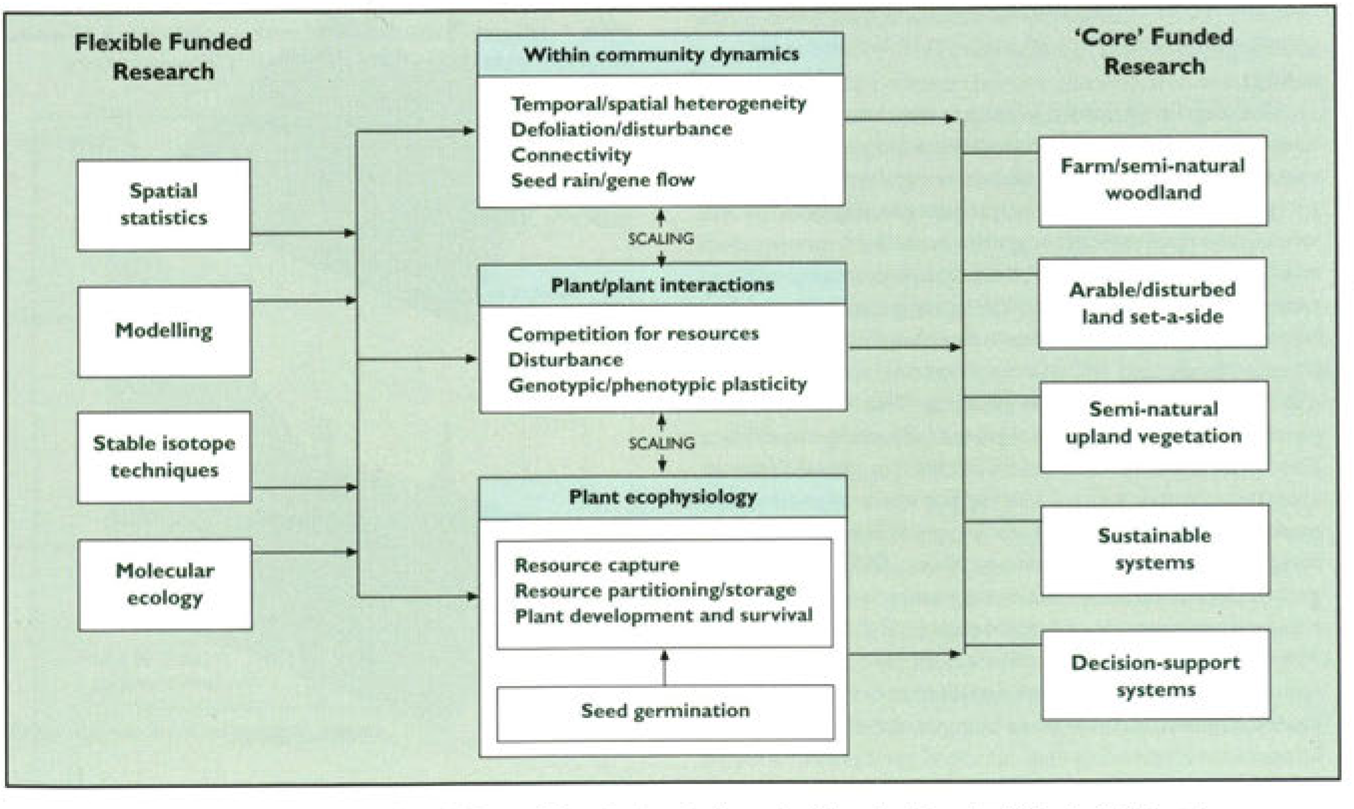

Figure 2 Co-ordinated Programme between Scottish Research Organisations for the study of Vegetation Dynamics in Species-Rich Vegetation

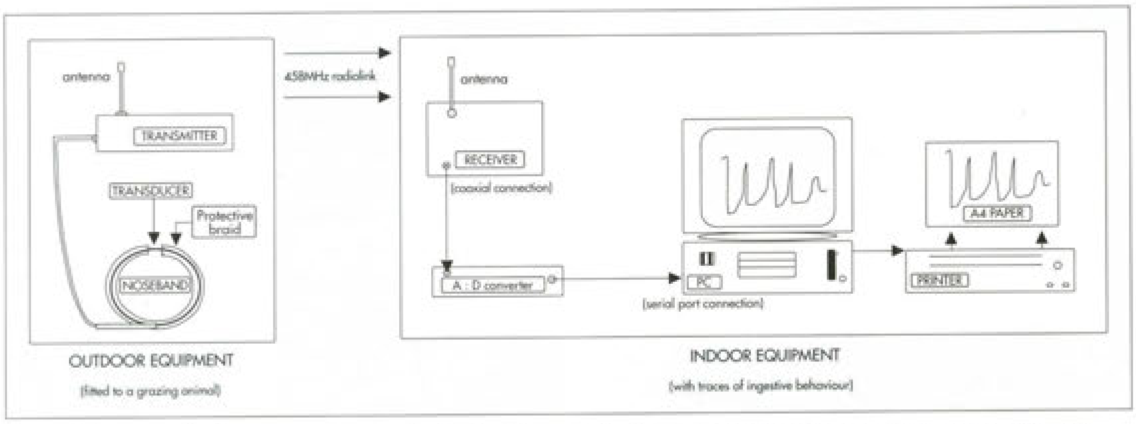

Figure 3 Diagram showing measurement and collection of ingestive behaviour data using automated telemetric techniques

Vegetation heterogeneity

Biodiversity is not only increased through increasing the plant species found in pastures but also by increasing the structural heterogeneity of pasture which increases invertebrate diversity (Dennis *et al.*, in press). The foraging behaviour of sheep and cattle, which influences structural heterogeneity, is being studied experimentally. This research is based on describing their foraging and ingestive behaviour and through the application of recent advances in foraging theory made at MLURI (Farnsworth and Illius, 1996). The Institute has developed an international reputation in the measurement of intake and diet selection (see Figure 1) in such pastures (see Dove and Mayes, 1996), and, by the measurement of biting rate, grazing time and other components of grazing behaviour through recently developed automated telemetric techniques (see Figure 3), it will be possible to describe foraging behaviour and hence test hypotheses about how grazing allows structural heterogeneity of pastures to develop and change.

The degree of heterogeneity in the pasture can also have important implications for the productivity of domestic animal systems. With pastures of low heterogeneity, it has been shown that sequential grazing systems, i.e. where one species follows another, can be more productive (see Figure 4) whilst, if the pasture is structurally heterogeneous, complementary grazing can be more effective (Figure 5). This depends upon the social interactions between and within animal species as well as the distribution of patches of vegetation. This is being explored experimentally, and theoretically, using bio-diffusion theory (Farnsworth and Beecham, in press). Size of animal and other factors, such as previous experience and genotype differences, can have an important effect on foraging behaviour (Gordon and Illius, 1994). This, together with differences between genotypes in other attributes, for example milk yield potential (Wright *et al.*, 1994), can determine the efficiency of pastoral land use, and the significance of these attributes to the efficiency of pastoral land use is currently being researched. This is of importance in deciding the choice of genotypes for a grazing system and which attributes to improve through genetic selection.

	Previous Species	
	Sheep	Goats
Proportion clover in swards	0.20	0.39
Weaned lambs		
Proportion clover in diet	0.14	0.29
Herbage intake (kg/day)	1.05	1.33
Live-weight gain (g/day)	153	207

Figure 4 Effect of previous species of grazer on performance of weaned lambs on a grass/clover sward - an example of sequential grazing benefits

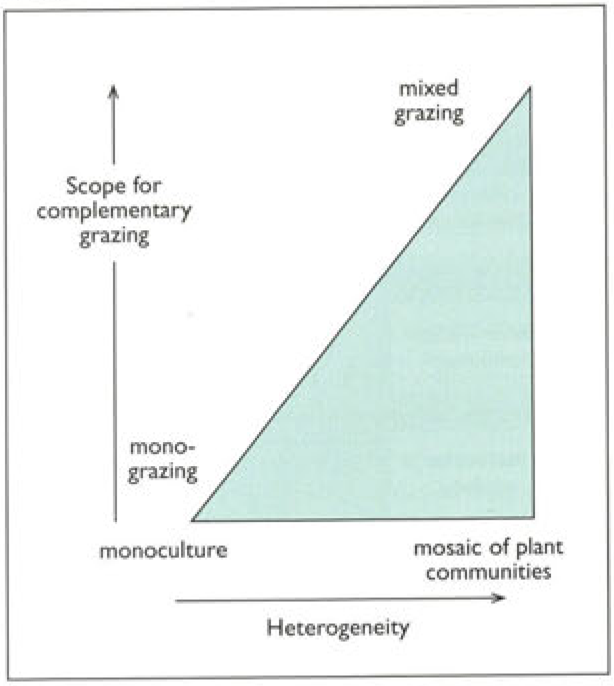

Figure 5 Relationship between vegetation heterogeneity and type of grazing system

Temperate Rangelands

Herbivore Foraging

The main emphasis of the research has been to improve our ability to predict where large herbivores will graze across the range of vegetation communities which make up the open landscapes of many temperate rangelands. Within the context of the UK, this has meant developing appropriate theoretical approaches based on variants of optimal foraging theory and ideal free distribution theory, and testing and developing them spatially. For example, the foraging behaviour of red deer on the Island of Rum, Scotland has been modelled using ideal free distribution theory and shelter-seeking behaviour (see Figure 6) and shown to fit observed data fairly well. The foraging behaviour of sheep in a hill area of Scotland has also been predicted reasonably well using a modification of ideal free distribution theory (Armstrong *et al.*, in press a and b). Current research on sheep and red deer is examining experimentally the trade-offs between shelter-seeking and feeding behaviour, and between the motivations associated with social needs and feeding. The use of Global Positioning Satellite systems now enables the measurement of the position and ingestive behaviour of large herbivores to be studied more easily and MLURI has initiated a programme of research to develop a suitable methodology for use with wild red deer. This will allow the testing of theory and answering questions of practical significance to deer managers.

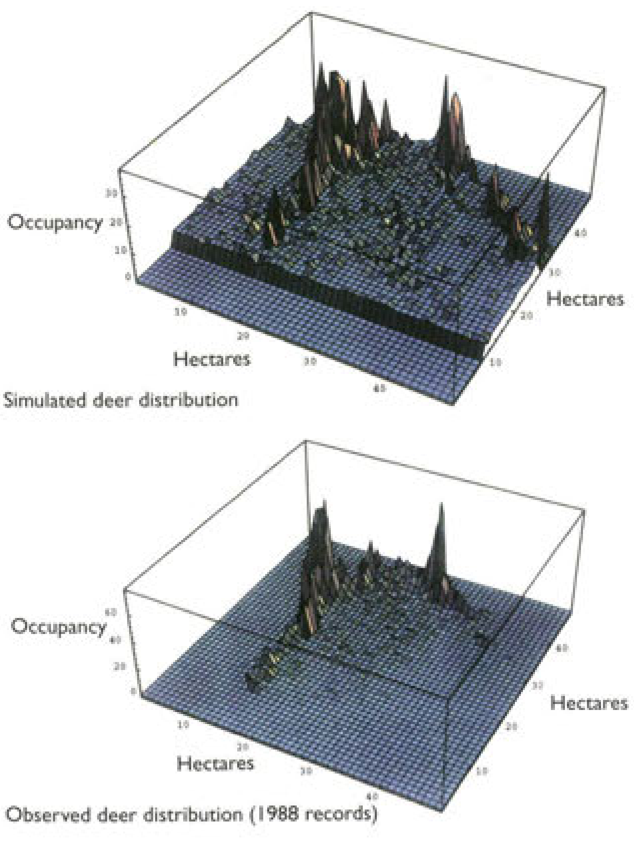

Figure 6 Diagrams showing good relationship between simulated and deer distributions observed by F Guiness, University of Cambridge on the North Block of the Island of Rum, Scotland

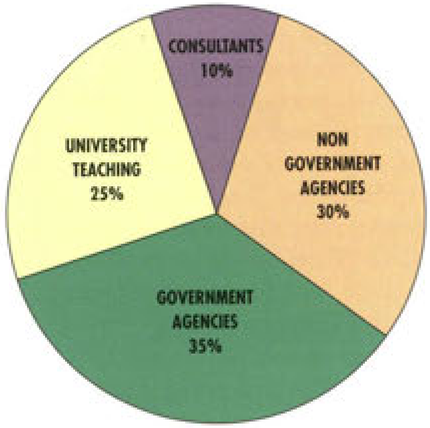

Figure 7 Clients for Hill Grazing Management Model

Vegetation Dynamics

Information on which plant communities are grazed throughout the year is being collected to allow the long-term impacts of grazing on different plant species to be predicted. Experimental evidence is being obtained on the effect of sheep grazing density and seasonal use of wet heather moorland and *Festuca/Agrostis* acid grassland on its plant species composition and productivity, and on the effect of sheep, cattle and goat grazing on the vegetation dynamics and productivity of *Nardus* grassland and cattle grazing on *Molinia* grassland (Grant *et al.*, 1996; Grant *et al.*, 1996). Furthermore the effect of cattle grazing and mixed grazing by sheep and cattle on *Nardus* grassland on achieving plant communities which are more diverse from a plant and invertebrate perspective (Dennis *et al.*, in press) is being studied and their implications for cattle and sheep productivity quantified.

The results of the research described above, together with results from research from elsewhere in the UK, has been synthesised into three decision support tools which have been designed to aid policy makers and implementers, and land managers, in considering land use issues in the hill and upland areas of the UK. The Hill Grazing Management Model was designed primarily for natural heritage organisations, such as Scottish Natural Heritage and English Nature, to predict the impact of sheep grazing on the utilisation rate of a number of vegetation types (Armstrong *et al.*, in press a and b). It has proved valuable in this context and has been widely used for consultancy and teaching as well (see Figure 7). The next generation of decision support tools is now coming on stream. These have been developed in C++, an object-oriented language, which allows greater developmental flexibility to facilitate the incorporation of new plant growth, herbivore foraging and animal production sub-models in the future. HILLDEER, a second decision support tool, was developed for the Deer Commission for Scotland and the Association of Deer Management Groups for Scotland in conjunction with Biomathematics and Statistics in Scotland and the University of St Andrews. It answers questions about the sustainability of red deer populations depending upon the culling rate adopted, the vegetation present and the objectives of the management. It also takes into account the presence of other large herbivores and disturbance from man (see Figure 8). HILLPLAN, a further decision support tool, predicts the impact of sheep and cattle numbers on the vegetation dynamics and animal productivity of sheep and cattle systems for the hill areas of Scotland It has been designed for the Scottish Office in order that they can monitor the effectiveness of some of the Agri-Environmental Scheme options. It has the flexibility to be extended to meet the objectives of a wide range of clients.

Diversification of animal production systems

Alternative products to sheep meat and beef from permanent pasture and permanent rangelands are venison, cashmere fibre and fine wool. Previous research has shown that pastorally-based systems of farming red deer can be developed (Milne and Reid, 1989) and recently completed research has described the limited extent to which the welfare of red deer is likely to be compromised within such systems (Grigor *et al.*, in press). Research on cashmere production is focused on the environmental and nutritional factors influencing the moulting of the cashmere fibres from goats since this determines the yield of fibre and the ease of harvesting. The timing of the moult is primarily under the control of photoperiod but level of nutrition has also been shown to be important (see Figure 9). Current research is examining these nutritional and environmental factors further and examining the hormone control of growth at the individual follicle level in influencing cashmere fibre yield (Dicks *et al.*, 1996). By reducing the fibre diameter of wool (i.e. increasing wool quality), it is possible to increase financial returns (see Figure 10). A new breed of sheep, the Bowmont, has been produced at MLURI which produces 2.5 to 3.5 kg of extra-fine wool and current research is examining the appropriateness of the breed to be managed extensively in upland areas of the UK in relation to hardiness and the maintenance of fibre quality.

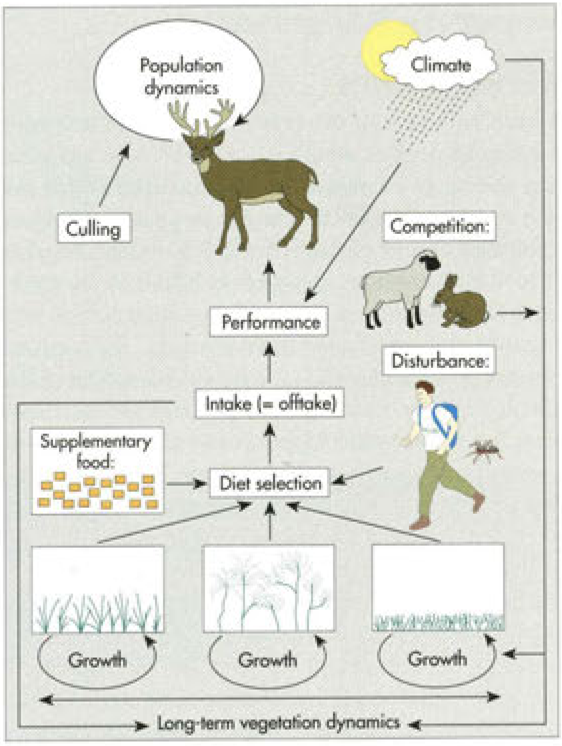

Figure 8 Modelling the impact of Red Deer on Scottish vegetation communities

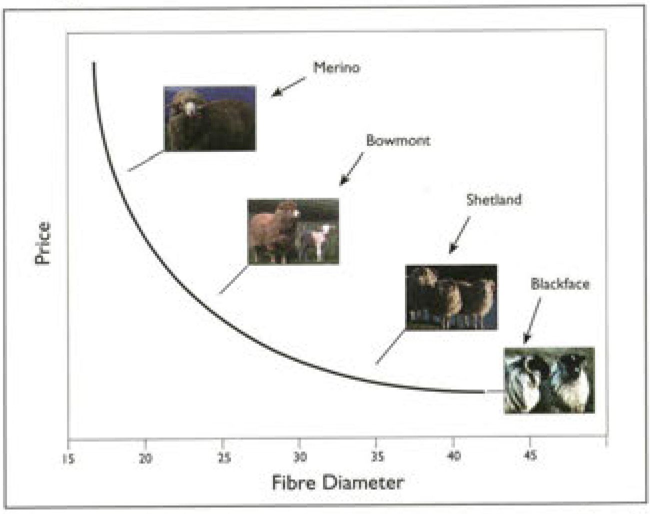

Figure 10 Relationship between fibre diameter and price per kg of wool

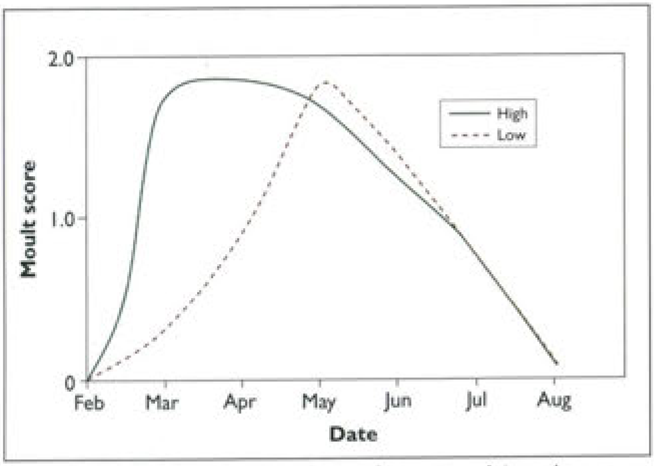

Figure 9 High levels of nutrition advance the coat moult in cashmere goats

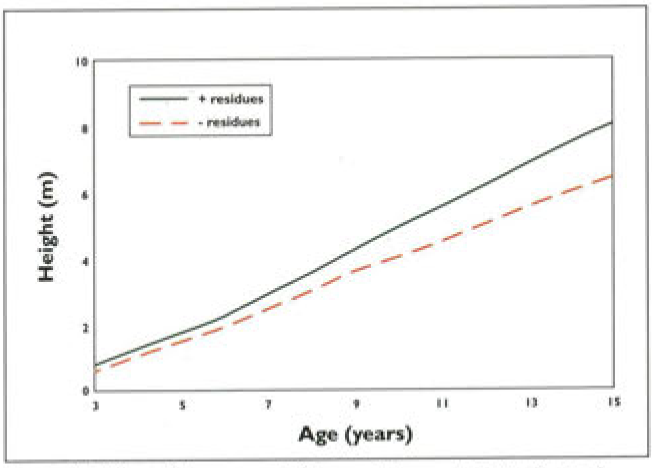

Figure 11 Effect of the removal of tree residues on height of second rotation Sitka Spruce in Kielder Forest

Trees

The research on tree systems mainly focuses on tree nutrition, and more specifically carbon/nitrogen interactions, as this is central to determining the impact of management of soil-plant and plant-animal interactions. Such an understanding of ecophysiology will enable the consequences of different management strategies for low input systems to be assessed in the context of sustainable land use (Proe *et al.*, in press). These strategies can influence the efficiency with which second rotation plantations develop in the UK, how pruning and fertiliser application should occur in forestry systems, how trees can be used as a source of biofuel, how agroforestry systems can be designed and how native tree regeneration in open hill areas can take place.

The importance of nitrogen storage in the autumn for remobilisation the following spring, thereby allowing growth before uptake by the roots, has been demonstrated experimentally (Millard, 1996). The next challenge is to develop techniques for measuring the nitrogen storage capacity of larger trees, growing in field experiments. This is necessary so that the impact of management strategies, such as fertiliser applications, can be assessed in relation to the sustainability of the system. Nitrogen translocation patterns in the spring are being quantified by analysis of the amino acid composition of xylem saps and are providing species-specific markers for nitrogen remobilisation. Such an approach is being applied to a study of the fertilisation of peach and apple orchards (in collaboration with the University of Bologna and Agriculture and Agri-Food Canada). A study of assimilate partitioning in relation to the pruning of Radiata pine (in collaboration with Lincoln University, New Zealand) has also been initiated, in order to understand the mechanisms whereby pruning influences tree nutrition.

One possible diversification option for marginal areas is the production of biomass as a source of biofuel. Under conventional harvesting only the stems are removed. With whole tree harvesting, in addition to reducing labour costs, the residues can be harvested as well and used as a source of bioenergy. In conjunction with the Forestry Commission we have shown that whole tree harvesting can have detrimental effects on the development of second rotation Sitka Spruce plantations (see Figure 11) by short-term microclimatic effects and longer-term nutritional effects (Proe and Dutch, 1994; Proe *et al.*, 1994). This has considerable importance to the UK forestry industry and research is being extended to cover a wider range of soil types and management protocols. The information from the research will be incorporated into a computer simulation model of tree growth, in collaboration with the University of British Columbia, to provide guidance to forest managers on the sustainable removal of biomass.

Short rotation forestry through coppicing every 3 to 5 years or single stem production every 10 to 15 years offers another diversification option for biofuel production. On a site in Scotland, using alder, poplar and willow, we have shown that different management systems affect biomass yield through changes in canopy structure, light interception and allocation of biomass within the trees. Yields from coppice or single stem production were similar and spacing had the greatest impact on biomass allocation (see Figure 12). Willow had advantages over poplar. This work has been extended to describe the suitability of land in Scotland for short rotation willow production (see Figure 13) and will be further extended to consider the optimum siting of biomass production for economic benefit and the implications for landscape and environmental impact.

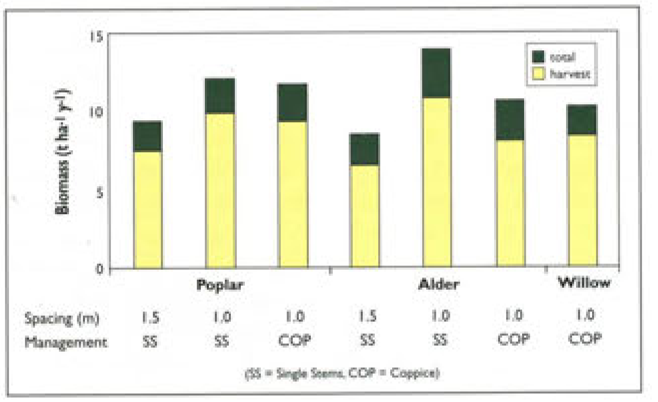

Figure 12 Effects of management on biomass production in contrasting short-rotation forest systems in Central Scotland

Silvopastoral systems, involving the growing of trees in swards grazed by sheep in the UK, have the potential to reduce the imports of high-quality timber and at the same time allow upland farmers to have continued income from sheep production for a period of at least 20 years. Research with other research organisations in the UK (UK Agroforestry Network) has concentrated upon the tree establishment phase when there is competition between grass and trees for nutrients below ground, for

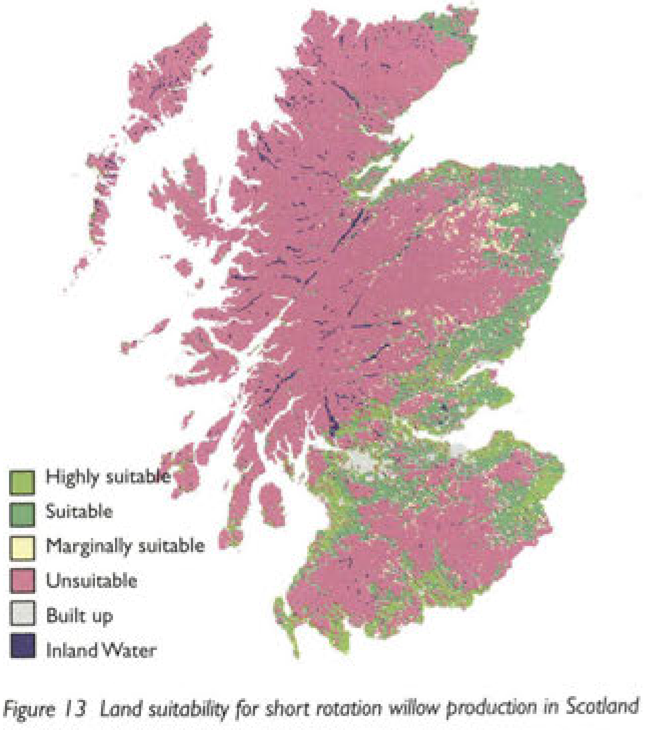

Figure 13 Land suitability for short rotation willow production in Scotland

light interception above ground and interaction with the animal species (see Figure 14). Results to date have shown that trees planted at 400 per hectare can grow for 9 years and up to 5 metres in height without affecting agricultural output (Sibbald, 1996). It has also been shown that grazing sheep utilise the trees for shelter (Sibbald *et al.*, 1996) resulting in increased soil compaction around trees, especially around trees planted at the lower density of 100 per hectare (Wairiu et *al.*, 1993), and reduced survival and growth of trees at this lower density (Sibbald, 1996). In mature silvopastoral systems it has been shown that the seasonal pattern of pasture production is altered with more growth in spring and autumn than in an area without the sheltering benefits of trees (Sibbald *et al.*, 1991). In collaboration with INRA, France and other UK institutes and universities, a model has been developed which will allow researchers and those involved in assessing policy options throughout Europe to consider a range of scenarios in relation to tree species and density, fertiliser application and animal management system (Figure 15). Currently, research is being extended to investigate the ecological impacts of silvopastoral systems on plant species composition, ground insects and visiting birds.

Natural regeneration of pine and birch in the hill areas of Scotland depends upon the suitability of the soil, the availability of a source of seed in the soil, the extent to which the seedlings and saplings of trees are browsed and the extent to which these seedlings and saplings can tolerate browsing. These latter two issues are the ones where there is most uncertainty. Whilst recent research has shown the importance of size of tree in initiating browsing activity and the presence of secondary plant compounds in determining the extent of damage (Iason *et al.*, 1995), the role of nitrogen storage and the presence of surrounding vegetation in influencing browsing damage and in competing with trees for nutrients, when the tree is recovering from browsing, are unknown and are the subjects of current research.

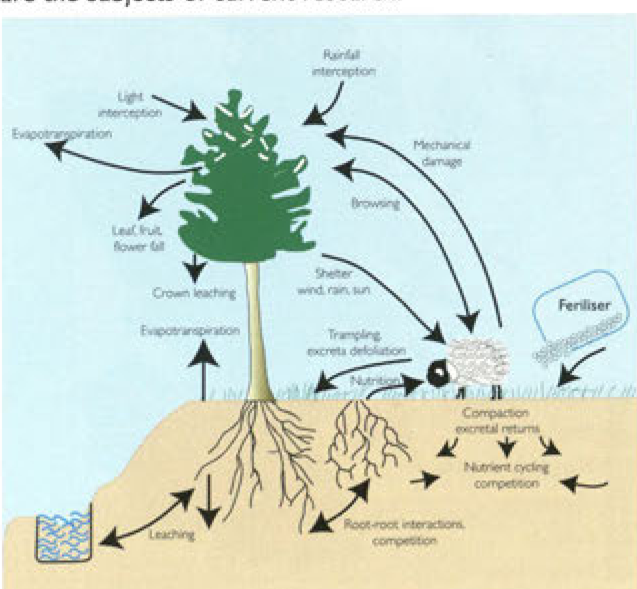

Figure 14 Below- and above-ground interactions in silvopastoral systems

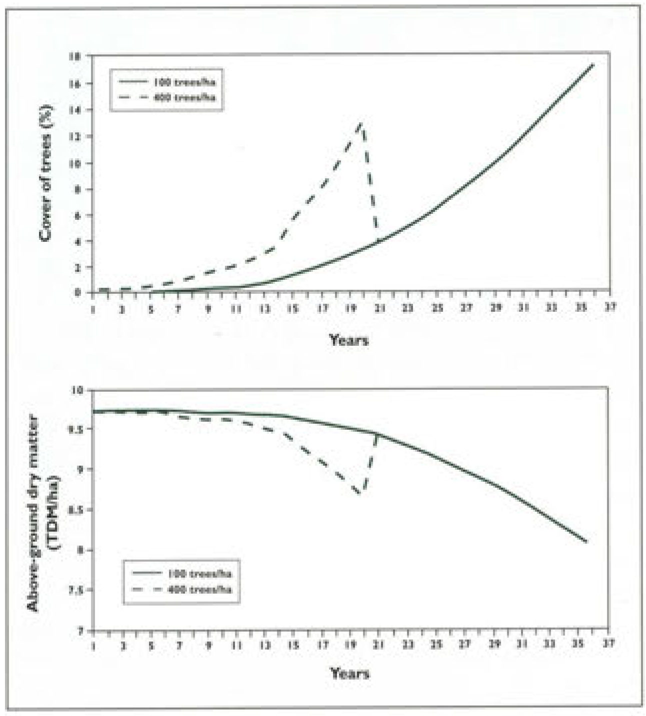

Figure 15 Model prediction of tree canopy cover and pasture yield for two agroforestry management scenarios

Future research

Soil-Plant-Animal interactions

The amounts of available nitrogen and phosphorus are low in most marginal soils. In consequence, understanding the processes regulating the availability of nutrients at the rhizosphere is the key to understanding the cycling of these nutrients in these ecosystems. It is of particular relevance in those ecosystems which involve large herbivores and where excretal returns are potentially important components of nutrient cycling. The processes at the rhizosphere are complex, involving the effects of resource partitioning in plants influencing rhizosphere carbon flow, which in turn have an impact on soil microbial activity and nutrient dynamics. The development of molecular techniques to characterise the microbial population and the use of stable isotope techniques to characterise nutrient flows offer considerable potential to understand the key processes in such systems which have important significance in terms of understanding the concepts of biodiversity and sustainability and in predicting the possible outcomes of global warming. Some of this research is already underway as part of a coordinated UK research programme, entitled MICRONET. It is planned to make significant advances in developing a conceptual model of nitrogen dynamics in peat soils with collaborators in Europe. The model will deal with both dissolved and suspended colloidal fractions of nitrogen, in the measurement of carbon substrate utilisation preferences of rhizosphere bacteria in comparison with exudate profiles from plant roots, and in understanding the role that microbial detritus play in the transport of organic phosphorus in the rhizosphere.

Plant-animal interactions

The future research challenge lies in understanding the spatial nature of the behaviour of plants and herbivores in relation to vegetation dynamics and foraging behaviour. At the permanent pasture level this will involve extending current research so that the spatial description of plant species and structure in a grazed pasture can be predicted more precisely from an understanding of the spatial heterogeneity of the soil and of foraging behaviour. It is planned to do this partly in collaboration with INRA, France, as a component of a Twinning Agreement. For temperate rangelands research will concentrate on understanding foraging at the landscape level, and its implications for biodiversity, with a greater emphasis on measuring the relationship between resource availability and population size of animal species. This will be undertaken with particular reference to the red deer. Other aspects of grazing behaviour that will be researched are the motivation to feed in relation to motivations to perform other types of behaviour and the role of learning in influencing foraging behaviour.

Animal production systems and rural sustainability

Ruminant production in marginal areas is likely to be seen more and more in the context of multiple objectives and rural sustainability. Diversification of ruminant production to produce new or more value-added products has the potential to be relevant in both these contexts. From a European perspective the production of cashmere from goats and fine wool from sheep, as non-food fibre products, is likely to continue to be attractive. Research will be undertaken in this area with the emphasis on understanding the mechanisms controlling the shedding of the cashmere fibre and using new genetic selection methods to delay the date of shedding, following on from the success in increasing fibre quantity by over 30% without reducing quality significantly through genetic selection.

The emphasis of future research on ruminant production systems will be on developing systems which meet objectives relating to environmental sustainability as well as designing systems in terms of economic sustainability. In designing such latter systems labour use efficiency will become a priority and the research will be undertaken to resolve the potential conflicts that will arise between meeting environmental and economic sustainability objectives.

Technology transfer

Computer-based decision support tools are likely to become increasingly important in technology transfer, utilising the information arising from our research and transferring knowledge in the management of marginal lands. This is because they can help the user manipulate potentially complex ideas and let them have access to large data sets of information. Decision support tools will be developed to allow land managers to manage biodiversity in upland landscapes, to predict the regeneration potential for native trees for upland Scotland and ultimately to predict the consequences of herbivore grazing pressure spatially. It is also planned to develop a decision support tool to allow forestry managers to predict harvesting impacts on the productivity of second rotation Sitka Spruce plantations.

Many of these tools will be used in land use planning. In such circumstances other components of the planning cycle will also be required such as resource descriptions and monitoring of changes in resources. For example in the development of deer management plans there is a need to provide an assessment of the current state of the habitat and how it will change over time. The development of an appropriate and cost-effective method for the assessment of these large-scale habitats will be achieved as part of a package of outputs from research to aid the managers of marginal lands in the future.

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MILLENNIAL MUSINGS ON THE NATURAL HERITAGE OF SCOTLAND

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What I want to do today is to present a series of Millennial Musings about a vision for the Natural Heritage of Scotland; it is not a scientific discourse, of which I am incapable, nor is it a scientific blueprint of which I suspect no one is capable. It is thinking aloud, rather than speaking with tongues.

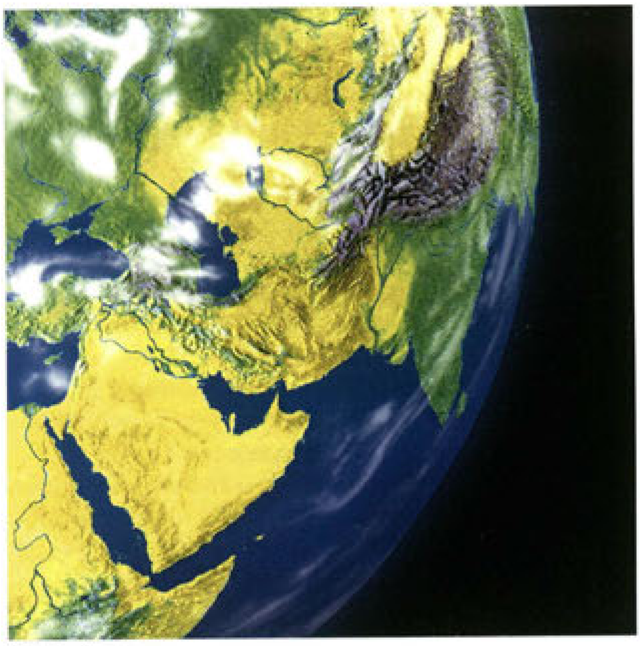
It will not, I am sure, have escaped your attention that it's Millennium Time. A fraught century is ending, and the air is loud with wailing and the gnashing of teeth and fraught prophecies of Armageddon and worse. It's not just the end of the millennium, it's the end of history, the end of nature, the end of the world itself.

It's a familiar phenomenon, this pattern of *fin de siécle* anxiety and gloomy anticipation. About 500 years ago, in 1498, it inspired Albrecht Durer's celebrated *Four Horsemen of the Apocalypse*. A thousand years ago, between 995 and 1000 AD, Scandinavia was converted to Christianity - just in case the millennium really did mean something. In 1001, however, when the threat seemed to be over, all Scandinavia (except Iceland) relapsed into comfortable paganism.

Any historian could multiply these examples of end-of-century angst and despair as society compulsively counts down the years to the century's end as if it were the end of the line. People feel distraught and diminished; traditional patterns are breaking down. We believe that events and inventions are spinning out of control, and that meanwhile the world (like us) is ageing, civilisation is going to pot, moral standards are declining. And oh yes, the climate's going to hell and back again, species are vanishing or becoming threatened at ever-increasing rates. Old Nature herself is losing her vitality.

But every coin has its obverse. The obverse of millennial angst is millennial optimism. We may worry about the gloomy inheritance we are bequeathing to our posterity, a legacy of irremediable blight and insufficient bounty and inevitable disappointment; but we can also nurture hopes of resurgent life, of a new Golden Age growing from the rubble of the 20th century.

In this scenario the millennium speaks of radiance rather than ruefulness. More and more we can see ourselves in the largest contexts, as a species which is part of a world web, a whole populated globe. Our new-found ability to scan Planet Earth from orbit amplifies our environmental sight and insight. The *fin de siécle* is not necessarily a *cul-de-sac*; it can be a highway to a new future. We can harness the familiar tensions of the calendar ends of centuries to will the necessary changes, and will the means as well. The future beckons - let's go for it!



Satellite image

The real point, of course, is how?

I was listening recently to Professor John Holmberg, assistant professor of Physical Theory at the Chalmers University of Technology in Sweden, propounding a rather intriguing thesis - an earnestly Nordic version of 'Back to the Future', but in reverse, as it were. The knack, in his view, is not to try to **forecast** the future based on extrapolations from the present state and current trends, but to **back-cast** it by describing the vision for the future within a framework of guiding principles, and then to develop, retrospectively, a programme for change which is compatible with that vision. Although this approach, and the principles adopted, are specifically aimed by Professor Holmberg at mega corporate businesses like Electrolux, it struck me as being an equally valid approach for the natural heritage.

In this scenario we borrow the jargon of corporate business and say to ourselves, 'The earth will go bankrupt if we fail to cope with the increasing demands of society in an environmentally sustainable way'. But how? The secret is to turn Time on its head and not simply try to forecast the future based on extrapolations from the present state and current trends, but to **back-cast from the future**, by describing our vision for the area of the environment with which we in SNH are most concerned and for which we have most responsibility - the Natural Heritage of Scotland - and then by tailoring, retrospectively, the strategies for change which are compatible with that vision.

Now, in order to back-cast a vision for the natural heritage, we have to address four aspects:

1. What do we have now, and how did we get here?
2. What is our vision? Where do we want to go?
3. How do we get there?
4. How can we afford it?

1. What do we have now, and how did we get here?

Let us consider what we have got, and how we got it. This is where science and technology have been and continue to be of crucial importance.

The one, the only, constant in the history of heritage is **change**. 'All is flux, nothing stays still; nothing endures but change', as Heraclitus wrote in his treatise On Nature around 500 BC: 'You can never step into the same river twice'. I think of the history of heritage in images and metaphors. I think of it as an eternal reciprocating engine of huge processes since time began: the movement of continents across the surface of the planet like croutons floating in a bowl of thick soup, endless volcanic eruptions, the birth of mountains and the creation of new landscapes, devastating ice ages punctuated by warmer periods of melting and erosion.

It's still happening, of course. We have seen it very vividly in Iceland recently, when the volcano Loki (named after the Norse god of mischief) erupted under the glacier Vatnajökull and sent a furious glacier burst crashing destructively over the southlands. And modern science now tells us how abrupt these changes can be. The cores from the Greenland Ice Cap show regular rhythms of climatic cooling and warming - but sometimes the change has been extremely abrupt, with switches of 10 degrees Celsius in air temperature being recorded over only two decades. The switch can also be uncertain - the 'flickering switch' phenomenon when the ice disappeared from Scotland, and then a cold snap brought an extension of the ice-cap in the West Highlands and glaciers back into the Cairngorms and Eastern Grampians - the so-called Loch Lomond Re-advance.

So the first lesson from the past is that change is ever present, but that it is neither constant nor predictable. Hence, in seeking to achieve our vision we must be flexible and not overly prescriptive: a vision not a blueprint.

The history of human impact on the environment has been documented, exhaustively at times, and is rehearsed at every environmental conference and seminar. But here, too, science in the largest meaning of the word has applied its own sober and rational corrections. For instance, Rick Batterbee and his colleagues at University College, London, have translated their work on acidification in freshwater lochs in Scotland into absorbing historical fact. Starting in Galloway, but now covering the whole of Scotland, they have been studying diatoms, the fossil forms of a fundamental building block of the freshwater system. What their work shows is that in the 10,000 years since the end of the last Ice Age there was no significant change at all in the level of acidification - and then, suddenly, around the middle of last century, coinciding with the development of the Industrial Age, the level started to rise. It was only a small rise at first, but the rate has been accelerating very seriously in the 20th century and despite our attempts to control aerial (and terrestrial) pollution, it is still going on. This is a prime example of science demonstrating with incontrovertible accuracy an impact on the environment which is entirely due to the scientific and technological inventiveness of the human mind.

The Industrial Age, and the voracious appetites it unleashed, has also been blamed for the disappearance of the so-called Great Wood of Caledon which once covered so much of Scotland. But the study of fossilised pollen has radically altered our picture of the prehistoric environment. Palynologists like Graeme Whittington of St Andrews University have shown that the woodland maximum in Scotland occurred no less than 5,000 years ago, and that there has been decline ever since. This decline seems to have been mainly due to climatic change - more rainfall, lower temperatures - which assisted peat formation and hindered successful pinewood seed deposition.

What part did people play in this decline? Pollen studies show clearly that from the Neolithic period onwards, grass and cereals enter into pollen profiles which had hitherto been dominated virtually entirely by woodland. It could even be that Mesolithic people cleared parts of the woods in order to attract large grazing animals like aurochs to come and feed in the clearings, but that is a bit speculative. What is not speculative is that Neolithic and Bronze Age Man had a very considerable impact.

When we reach the Iron Age, c. 500 BC, what Richard Tipping calls 'the biggest land-change in Scottish history' took place in the Lowlands - bigger than the Improvement era of the 18th century or the afforestation of areas like Galloway earlier this century. The result of this agricultural revolution in 500 BC was that when the Romans arrived 2000 years ago they found the Lowlands substantially cleared of woodland in many places, and very heavily populated. If you have ever wondered why the Romans built the Antonine Wall of turf, it was because there were hardly any trees left!

So the second lesson from scientific appraisal of the past is that many of the changes to our landscape, vegetation cover and ecosystems occurred many millennia ago. The climate now differs considerably from that of 3,000 years ago in terms of temperature and precipitation, and soil conditions have changed significantly, and there is a greater degree of acidification. Hence, attempts to recreate the past in any strict sense are at best foolhardy.

When we come to the picture of the present, I am going to highlight just three of the many available documents about the way we are now and how we have got here, because they were all initiated or done in collaboration with MLURI.

Last year, SNH published *The Natural Heritage of Scotland - an Overview*. It collated the latest information on Scotland's flora and fauna, its geology and geomorphology, its soils, its land cover and landscapes, its natural beauty and its amenity. The *Land Cover of Scotland* census, undertaken by MLURI in 1988 and published in 1993, provides a baseline against which past and future change can be monitored as well as giving us for the first time authoritative information on the land cover of Scotland. And the *National Countryside Monitoring Scheme*, published by SNH in 1994 in collaboration with MLURI, presents a comprehensive study of land cover change in Scotland from the 1940s to the 1970s - and next year we shall complete the picture of change for the rest of the post-war period.

The NCMS is only a sample survey, but it has given us a picture of gross changes in the post-war period. The most striking changes which took place during this period were that coniferous afforestation expanded by more than fourfold (although that trend is now slowing), while semi-natural habitats associated with open moorland, such as mire and heather, were reduced by a fifth. Long established or semi-natural woodland was reduced by nearly a half through clearance or under-planting with conifers. Among the linear features, running canalised water and unsurfaced track expanded, while lines of trees and hedges contracted. These are the statistical facts, the 'chiels which winna ding', as Burns called them.

Overall, the vegetation of Scotland and its associated habitats and wildlife has been transformed from one of predominantly woodland cover to grass and heathland. Most of our large mammals have disappeared - brown bear, elk, beaver, wolf, wild cattle, wild horses, wild boar. The bleak grandeur of so many of our landscapes hides a perilous biological impoverishment; hillsides once clothed in native forest are now over-grazed and scoured by erosion; straths and valleys once verdant are now bitten to the quick by Man's beasts - not only sheep but also the rabbits he introduced in Norman times and the red deer he has allowed to multiply far beyond the capacity of the natural habitat to carry them sustainably.

In the Highlands, what Sir John Lister-Kaye has dubbed the 'Balmorality Epoch' gave us a system of sporting estates which now, coupled with the effects of sheep subsidies, has bequeathed a process which has all but exhausted the land and brought natural productivity to an all-time low.

The marine ecosystem has been dislocated by industrial fishing on a scale far beyond the regenerative capacity of the sea. Modern transport systems continue the fragmentation and loss of habitat and landscape character. Many species continue to decline in numbers and range. The cumulative impacts of acid rain and other pollutants persist and continue to develop. So some current trends will obviously have to be reversed in order to bring any vision within future environmental, social and economic parameters.

Wolves

Beaver

2. What is our vision? Where do we want to go?

When most people think of a vision for the natural heritage of Scotland, they think in terms of restoring lost or damaged ecosystems: the mythical Great Wood of Caledon, and so on. I can quite understand that, but my own starting point is rather different. It is concerned with the values of society towards its environment: what set of values would we wish Scottish society to have towards its environment?

I hope it goes without saying that these values should be based on the concept of sustainability. I hope it also goes without saying that sustainability espouses economic development, as long as it does not endanger the natural systems which support life on earth: the atmosphere, the waters, the soils and living creatures. As John Gummer put it in his inimitable way, 'We must not cheat our children'.

Sustainability has many definitions and approaches. I give you the five guiding principles developed by SNH in our publication *Sustainable Development and the Natural Heritage*, the five principles which must inform all our thinking about sustainability: **Wise Use** of renewable and non-renewable resources; care for the **Carrying Capacity** of the ecosystem for regeneration; the maintenance and enhancement of **Environmental Quality**; judicious application of the **Precautionary Principle**; and the fair **Sharing of Benefits** through equitable distribution of benefits and losses alike.

If these principles, and more particularly the philosophy and common sense underlying them, are accepted by society (by which I mean individuals, families, institutions, government and business), then whatever precise vision we paint, and however it is modified by our successors, we shall be in a position to achieve a balance between Man and his environment in which the environment comes first and as a consequence Man benefits.

Putting the principles of sustainability into practice are vital as a first step. No vision can possibly be fulfilled without them.

Increasing the biological productivity of the land and sea is fundamental to it all. Science and technology have proved in practice that we can increase food production by the use of agro-chemicals and other technological innovations; but the net productivity of the land and the water has actually declined as a result of our practices. Putting back to compensate what we have taken out, especially in organic matter, is crucial.

The continued reform of the reformed CAP and other land-use regimes is clearly vital, too. Happily, agricultural policy is drawing back from the spiral of ever-increasing intensification of production, because this whole issue of the intensity of agriculture, whether it be livestock or arable, is critical. It has a number of manifestations. One is the perennial issue of **over-grazing**: we know which animals cause it, but we have not been able to sort out properly which is the more significant: red deer? sheep? rabbits, for heaven's sake? We know the answer in certain parts of the country, yet in other parts it is a mixture. We are already doing a lot of work on modelling, jointly with SAC and MLURI, to demonstrate the effect on the vegetation of numbers of deer or sheep or combinations of these; and we are testing various ways of calibrating the model at the SAC farm at Kirkton near Drymen. This has given us a model in a simple piece of software which explains the problems of overgrazing and what to do about it. Allied to that there is the manual which is currently being field tested by SNH, on how to recognise the impact of grazing pressure on vegetation. So if we want a certain kind and density of vegetation cover we can estimate with reasonable accuracy how many animals a hill can take.

But it's not just pastoral land which has to be involved. Arable land, too. We are also engaged in a major project involving the role of new technology in promoting sustainable agricultural development. It is called TIBRE - Targeted Inputs for a Better Rural Environment - and is designed to investigate how new technology (chemical, biological, Information Technology and engineering) can best be introduced into existing intensive agricultural systems to improve cropping.

Underlying all this, of course - quite literally - is the soil. Ever since I heard our Chief Scientist, Professor Michael B Usher, addressing the SNH conference on Soils, Sustainability and the Natural Heritage two years ago, I have been acutely aware that whenever I tread on a square foot of land I am pressing down on several hundreds of species of life. I don't know precisely what they are all doing down there, but I do know that it is this teeming life which gives soil its significance: busily engaged in decomposing dead organic matter and recycling nutrients on which plant productivity, and ultimately all animal life (including our own), depend. Any and all of our land-uses (and even small changes in a particular form of land-use) can have large effects on these soil biota. Any invasive species, whether or not introduced by Man, and any genetically modified organisms, can affect the soil ecosystem. The number of times a farmer drives a tractor over a field in order to treat the crops will affect the degree of compaction the natural structure of the soil will suffer and therefore affect its productivity; so if technology can give the farmer more precise information of where to drive the tractor, and how often, it will be an obvious boon. The soil ecosystem might be out of sight, but it must never be out of mind. It is a central pillar to the study and practice of sustainability - and soil sustainability cannot be separated from the sustainability of terrestrial ecosystems in general.

I would like to think that this demonstrates that SNH is not against modern developments. We don't want to turn the clock back - we want to turn the clock forward, but also to ensure that we don't merely advance it to some millennial Doomsday for mankind.

Revision of the Common Agricultural Policy is also gradually allowing for more regard to be paid to wildlife

Leaping salmon

and scenery. The single-purpose monoculture forestry which was the result of forestry policy for much of this century is giving way to a new multi-purpose ideal and to special programmes to create and enhance native woodlands or to improve landscape and community amenity. Programmes to halt direct industrial pollution and to reverse its effects on rivers and lochs are having some success with the return, for instance, of salmon to the Clyde. There is growing recognition of the desirability of managing heather moorlands better and of reducing the overall numbers of red deer. Several other species are expanding their ranges after years of decline, including the pine marten and the peregrine.

Related to this is the need to replace some of the diversity of landscape which has been lost. Aggressive monocultures have resulted in a 'sameness' of landscape in parts of Scotland and a loss of naturalness; replacing trees and hedgerows in the landscape has aesthetic and wildlife benefits and benefits to farmers. Increasing species variety in our planting schemes in forests, woodlands, flood-plains and moorlands is the way forward. The machair with its floral variety, the heather moorland with its faunal richness, the native woodlands of ash and oak and pine - these should all be a much greater part of our land-cover in the future.

We can now envisage the virtual reality of the future through computer modelling, using the Land Cover Survey of 1988. I know that MLURI has developed simple techniques to help us to create different land covers and therefore different landscapes. Extending our tree cover must be a major element of our vision: extending out from core areas and linking them through corridors, developing such corridors along river valleys and in gullies.

And should we not let nature take its course more often than we do at present? The engineering of rivers creates at least as many problems as it solves, and at a high financial cost, as we know only too well from the Tay floods of recent years. Flood-plains are the natural regulators, so let's reinstate them. Canalising rivers and building high banks merely create problems downstream: let's systematically consider how many of these engineering structures can be removed to the benefit of the aquatic environment and the communities living on the river banks. And what about the coastline? Should we not be letting nature takes its course on the coast? Does the fact that the coast is eroding away in some places and building out in others constitute something which we should try to stop? Are one or two threatened greens on a golf course to be considered so sacrosanct that we have to destroy the natural processes in Montrose Bay or St Andrews Bay to safeguard them? All too often, Man's engineering solutions in one place just transfer the problem elsewhere.

Do not misunderstand me: I am not advocating that we should never intervene in anything. Indeed, if we are to achieve greater diversity of wildlife and landscape we must intervene; but we must judge when it is sensible and cost-effective to intervene, and when it is more sensible to let Nature take its course.

One way we should intervene, it seems to me, is to remove evidence of past damage to our landscape. Scars of the past can be healed through remodelling or planting forests and woodlands. Tracks and paths can be removed where they are creating physical damage and are visually intrusive. Others should be in the appropriate state of repair to withstand increasing human use. And that brings me to the last point I want to make in this phase of my musings: making sure that the natural heritage is equitably shared by all.

We want to achieve workable mechanisms for responsible public access to Scotland's countryside, to coasts and inland waters, to moor and high tops, to forest and farmland. We are engaged on this through the Access Forum which we set up. Our vision is that people should know where they can go without damaging or disturbing legitimate economic activity or privacy, and that those who own and manage land should facilitate this approach in an equally responsible manner. That's what the Concordat on Access to the Open Hill was all about. In this respect, too, SNH's Paths for All initiative and its aim of the equitable Sharing of Benefits will help to disperse visitor pressure as well as giving people a chance to know and love their country better. It truly is a project for the millennium and beyond.

3. How do we get there?

There are as many answers to this question as there are pundits: nationalise the land, or at least give it over to public or environmental body ownership; abandon sporting estate management; institute a much more regulatory regime of land use; abolish all compensatory support; lay down mandatory codes of good environmental stewardship; repopulate the glens (because man, not wildlife, is the real endangered species); bring back cattle and outlaw sheep; introduce National Parks; legislate for the Right to Roam. And so on.

It would take too long to comment on each of these attitudes. But I would have to say that changing management practices, providing positive financial stimuli, strengthening regulation where the voluntary approach is failing, involving people in collaborative management-orientated approaches - yes, all these are essential ingredients for getting there.

To me, introducing an integrated area-based approach is the way forward. What do I mean by that? I mean that there is no one, single solution or approach for the whole of Scotland. I mean that specific solutions must be tailor-made for specific problems for specific areas. I mean that we should not just consider the special places, the designated protected areas for landscape and wildlife. I mean what we should involve all the different interests - the crofters, the farmers, the landowners, the foresters, the fishermen, the local communities, the practical scientists, the environmental experts - in partnerships for the prosperity and health of the natural heritage.

Much of the work of SNH is, and has to be, devoted to protected areas, carefully selected on scientific and aesthetic criteria; but I think that in the past there has been an undue reliance, an obsession almost, with designated sites which could prove unhealthy rather than beneficial in the long run. We all have to give very careful thought to the priority we afford to the special or protected areas relative to the remainder of the countryside - what Roger Crofts, our Chief Executive, calls 'the 10/90 syndrome', where 10% of the country is designated and 90% isn't but an equal amount is spent on each. Of course, it is important to safeguard our most precious natural heritage assets, and we welcome the extra protection which they will enjoy under the European Birds and Habitats Directives. But nobody should be under any illusion that the cause of nature conservation will finally have prevailed when such bastions are finally in place.

Native pinewoods

'Islands' of protection can never be secure; moreover, the bulk of our natural heritage - whether we are talking about biomass or cherished local landscapes - will always lie outside such designated areas. These other areas (which we often refer to as the 'wider countryside', although they include the nature which finds a niche in our towns and cities) need and deserve just as much of our care and attention.

So our thinking in SNH now stresses the need to recognise that designated areas and the wider countryside are not separate entities; and we keep underlining the role of awareness, of the willing participation and involvement of a wide range of people (from the local community to more formal agency partnerships), and of an integrated land management approach based on positive stimuli throughout an evolving countryside.

But we still need a framework within which all these worthy aspirations can be brought to fruition. And that brings me to the nub of **back-casting**; because in SNH we have been engaged in a major exercise designed to enable us to sub-divide Scotland into a mosaic of natural heritage zones for strategic purposes.

The Natural Heritage Zones approach offers a framework within which it will be possible to consider much more rationally the geographical differentiation of policies and incentives. It provides a framework for strategies for managing a geographic space which contains one entire or several nested ecosystems characterised by landforms, vegetation cover and human culture and history. In such a system, designated sites and the wider countryside would be viewed together, and would play complementary roles, in securing environmentally sensitive management of the country as a whole. Within any one zone there would be a series of specific habitats with strict protection, core ecosystem areas preferably linked by corridors to allow expansion of these ecosystems and migration of flora and fauna between them, buffers to provide protection to the core areas, and habitat areas protected from indiscriminate development in the surrounding territory.

We are embarking on this new kind of approach already, it should be noted. In the Cairngorms, following the Report of the Cairngorms Working Party, the Government established a Partnership Board comprising a wide range of interests which has recently published its draft Management Strategy for the area, based on the idea that the Cairngorms represent what is basically a Natural Heritage Zone.

So I think of Vision in terms of a mosaic of possibilities to be explored, and back-casted. We need to home in on what is special and significant for specific zones. For instance, I am thinking of enchanting little animals like the red squirrel, now finding its last stronghold in Britain in our native pinewoods; of birds like the Scottish crossbill and the capercaillie and the evocative croaking of the corncrake which all add such distinctiveness to the Scottish scene; of the snub-nosed, inquisitive otter which finds safe harbour and haven in the north-western bastions of the land; of the chequered skipper butterfly and the habitats where it survives and can be encouraged; of the breathtaking underwater living seascapes of our sheltered sealochs; of freshwater pearl mussels which need healthy water and protection from indiscriminate treasure-hunters; of the power and majesty of our dynamic river systems; of the drama of salmon leaping and of red deer at the height of the rut.

We find, still, western oakwoods dripping with lichens, and gorges festooned with ferns - scenery which has probably changed little over the last 10,000 years. Arctic communities persist on the high hills and northern coasts, remnants of those landscapes which once dominated Scotland at the last retreat of the ice-sheets. Much of our inheritance of raised bogs and blanket peatlands still survives. All these can be localised and prioritised within their natural heritage zones.

Having created the picture of what we want to see, we back-cast to the present and work out how it can be achieved, zone by zone, mosaic by mosaic, to create the integrated vision within that framework of sustainability and its ancillary imperatives I described earlier.

4. How can we afford it?

With this, the fourth question I posed, I fear we are intruding into private political grief. But it seems to me to be incumbent on any visionary to be able to answer hard questions about the financial implications of a strategic vision. I cannot answer them: but pragmatism tells me that unless we can say 'This is measurably what it would cost to make this specific vision real, zone by particular zone, principle by particular principle and scheme by practical scheme', we haven't a hope of persuading those who control the purse-strings to shell out.

So we need the help of all the social scientists, of economists as well as environmentalists, of politicians and policy-makers at every level, of communities from top to bottom. Any vision can only be achieved through the integration of a variety of policy instruments embracing all sectors and activities which affect the natural heritage and all areas of assistance and subsidy; and any vision can only be fulfilled if it is seen to offer a proper balance between recognising the complexity of the environment and its interactions with human systems.

The ultimate deterrent, you might say, is also to be able to provide a properly costed alternative - this will cost so-so-much if we don't act, both preventatively and proactively, to manage the natural heritage properly and appropriately.

No one pretends it will be easy to work it out. But when has that stopped us? The real problem is to get the right ambience in which co-operation can flourish under the right leadership. And that leads me to my final Millennial Musing.

Envoi: The millennial role for science and technology

When I was in Iceland this summer, I heard a philosopher, Páll Skúlason, talk about the role of science and technology in helping us to identify our responsibility for the future and thereby to make the best decisions about the future. It was his thesis that a responsible attitude towards the future must concentrate on science and technology, and that science and technology need to play a greater role in creating what he called a new moral and ethical cosmopolitanism. In fact he was calling for a radical change of thinking in the world of research, of theories and innovation and creation.

The reason he called for this radical change was because for the last three centuries, science and technology have consistently and continuously isolated themselves from the rest of the world in order to concentrate exclusively on their own problems and theories. The reason, he felt, was clear: men of science and technology wanted freedom from all interference of political or religious authorities which had been telling them what to do since the Middle Ages. So they had made a deal: they said, 'If you, kings and worldly powers, leave us in peace, we shall not interfere in your domain; and moreover we shall pay you back by providing you with wonderful tools and instruments with which to do whatever you want in ruling the world, as long as you leave us to do what we want to achieve'.

This deal was the basis of the concept of the neutrality of science and technology: science and technology would be concerned only with the objective facts of reality, while politics and religion would settle disputes about the subjective values of people and society.

As a consequence, science and technology have stood for a non-responsible rationality, a rationality which refuses to assume responsibility for the decisions and consequences which are shaping our future. Men and women of science and technology still stand behind the screen of neutrality: they only imply what to do by telling us we can do. The time has come, he was saying, for people in the powerful and rational community of science and technology to accept responsibility and to work not only for results in their specific fields of research in isolation from the rest of reality, but also for the development of this 'moral cosmopolitanism', or 'ethical cosmopolitics' for the benefit of the state and the well-being of individuals.

And it might just happen, if for no other reason than the fact that the 300-year-old pact has been unilaterally broken - by the other side. The academic community is feeling more and more threatened by what is going on in the rest of the world. It realises that it has been losing its independence from the political and economic authorities, which are once again systematically and progressively trying to take over the running of science and technology - wanting to put them exclusively at the service of economic and political interests.

The only sensible reaction to this pressure is that the people of science and technology should recognise their social obligations and apply their rational critical thinking to the domains of politics and economics. What is needed, said Professor Skúlason, is a responsible, rational, scientific thinking which is developed systematically and globally within the decision-making process - a responsible rationality which tries to get hold of all the factors which determine the future of life on this planet; because as a philosopher he believes that the only people who are capable of leading the global rational discussion of what is to be done are the people who are trained to think critically: the men and women of true science and technology.

Ladies and Gentlemen: as we say in Iceland, 'I am selling it no dearer than I bought it'. But I submit that this challenge is worthy of consideration, at least, as science and technology think about their millennial role for the management and enhancement of the natural heritage, in Scotland and everywhere.

ANALYTICAL SERVICES

The integration of the requirements of Research Groups for chemical and physical analysis of diverse types of materials is effected through a centralised Analytical Group specialising in analytical chemistry. Comprehensive facilities ranging from highly specialised isotope ratio mass spectrometry to manual routine methods are available. On an annual basis, over 100K samples are submitted by Research Groups for analysis providing results for about 1000K determinands. To allow the throughput of a high volume of samples, emphasis is placed as far as possible on automated analytical methods using modern instrumentation.

The delivery of high integrity data necessitates that quality control of analytical results is a prime requirement. Within the Analytical Group there is a strict formal quality assurance scheme whereby all work is undertaken in accordance with defined standard operating procedures. Extensive use is made of reference materials as primary standards or as calibrants for in-house secondary references so that data can be traced to certified values. The Group also participates in analytical proficiency testing schemes.

The organisation of the analytical work is enhanced by a laboratory information management system developed in-house. The database records work submitted and the type of analyses required and from that information work allocation and prioritisation can be set. All analytical work is costed in terms of labour and recurrent expenditure and there is a component within the information management system which allows the reporting of financial data for submitted analytical work to Heads of Research Groups.

Services

The analytical facilities available to underpin the research programme include:

- **inductively coupled plasma-optical emission spectroscopy and atomic absorption spectroscopy in the graphite furnace mode** for the measurement of trace and major inorganic elements.
- **thermal ionisation mass spectrometry** for the analysis of heavy (inorganic) isotopes.
- **gas isotope ratio mass spectrometry** for the estimation of light (D, ^{13}C, ^{15}N, ^{18}O) isotopes.
- **gas chromatography linked to mass spectrometry** for the structural identification and the determination at low levels of organic compounds and the estimation of stable isotopes in intact molecules.
- **chromatography (gas-liquid, high performance and ion)** for the analysis of alkanes, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, amino acids and anions such as nitrate, chloride, sulphate, phosphate and fluoride.
- **flow injection and segmented flow analysis** for the determination of soluble reactive phosphate, alkalinity, nitrite/nitrate and total nitrogen and phosphorus and biochemical intermediates.

- **non-dispersive infra-red spectrophotometry** for dissolved inorganic and organic carbon.

In addition, resources are available to undertake the physical characterisation of soils, the proximate analysis of animal feeding stuffs and the pre-analysis preparation of materials.

Commercialisation

The extensive suite of analytical facilities is unique within the immediate locality and this feature is exploited in offering the facilities on a commercial basis to external customers. Commercial work can only be undertaken within the restraints of the requirement for analysis from core-funded work but income is generated from a range of commercial concerns which require low volume highly specialised analysis and data interpretation to solve specific industrial problems.

The areas of speciality include:

- chemical analysis of soils, contaminated land, plants, waters, oils and inorganic and organic materials
- characterisation of clays, minerals and other fine grained materials
- stable isotope analysis of plants, soils and waters
- characterisation of inorganic and organic compounds in materials, including oil production treatment fluids and organic polymers, derived from the oil related sectors
- development of analytical methods on a contract basis

The commercial services are used by the following customer base:

- oil service companies
- waste disposal companies
- local authorities
- land development companies
- environmental and engineering consultants

Future

The analytical facilities which are required are of necessity dictated by the needs of the research programme. However, there will be a continuing emphasis placed on increasing the extent of automated analysis. This will increase the effectiveness and efficiency of the analytical work thereby reducing the unit cost of analysis. The possibility of converting current manual methods of analyses to automated methods is currently under investigation.

Many grant awarding bodies are demanding evidence of a formal quality assurance scheme or accreditation for sample analysis and the successful application for NAMAS accreditation is seen as a priority. Indeed, accreditation is essential if income from commercial analytical work is to be increased.

COMPUTING AND INFORMATION SERVICES

Much of the work of the Institute requires the use of large spatially-distributed datasets, and the computing resources to hold and manipulate them efficiently. There is a related need to be able to present the results of research, often involving complex maps and diagrams, in an effective and easily understood form. There is an increasing need for high speed access to the international data network, and for use of information-retrieval services such as the Web.

The Computing and Information Services Group provides a range of services within the Institute, to address these needs. It comprises 3 sections:

- Computing Support
- Graphics Services
- Library

Services Provided

Computing

The Computing Support Section maintains and develops the Institute's core computing and network infrastructure.

A key aspect of the Institute's computing needs is fast, efficient access to computational, data and information resources on the global data network. MLURI has a fast, efficient Local Area Network with access from every office and work area. This is connected to a high-bandwidth Metropolitan Area Network, linking the Universities and Research Institutes in Aberdeen, and thence to the UK Academic Network, and the International Network.

Increasingly, the World Wide Web is an important medium for information retrieval and technology transfer. The rapid growth of this facility has placed additional demands on the capacity of the data networks at all levels. The Institute uses its own Web site for making information accessible to the outside world, as well as for distributing information within the Institute.

The Computing Support Section provides the following services:

- Management and development of the Local Area Network, data communications links with MLURI's research farms and the link to the external network.
- A basic, general-purpose computer service, based on UNIX work-stations.
- Management of site access and data security measures, including protection against unauthorised access, anti-virus measures and data backup.

Trouble-shooting on a PC

- Management and development of an ORACLE Relational Database Management System, with client-server access from PCs and UNIX work-stations.
- Data entry, data manipulation and reporting for research and administrative requirements, based on the ORACLE RDBMS.
- Development of ORACLE applications for research and administrative needs.
- A basic support service, for users of PC and UNIX platforms. This service covers assistance with purchase of hardware and software, resolution of problems associated with the core facilities provided by CIS, and general assistance with computing problems and issues.
- Management of Institute information accessible via World Wide Web facilities.

Graphics

Effective dissemination of the output of the Institute's research requires excellent presentation in the form of graphics for papers, conference presentations and via electronic media.

The Graphics Services Section provides a high-quality graphics service over a range of media, including computer-readable, film and paper. The section uses powerful desk-top publishing software, operating on networked Mac computers, and has well-equipped photographic and developing facilities. The core pages of the Institute's Web Site were created by the Graphics Services Section. As a part of their portfolio of services, they also create special web pages, as required by individual research projects.

The section provides the following services:

- All aspects of design
- Creation of text/graphics on computer and output on paper, film, or transparencies
- Scanning of documents for incorporation into computer-manipulated documents
- Photography for a wide range of purposes outside, in the laboratory or elsewhere in the workplace
- Photographic development
- Liaison with outside firms for report printing or laminating posters
- Design and creation of pages for the World Wide Web

Recent Developments

- A major increase in bandwidth for the external network link has been achieved with the introduction of the Aberdeen Metropolitan Area Network (AbMAN). This links all the universities, colleges and research Institutes in Aberdeen, and thence the other major Scottish research centres via recently-installed high-speed inter-MAN links.
- A powerful Silicon Graphics REALITY work-station has been installed to enable studies of landscape visualisation.
- The computing resources of the Graphics Services Section have undergone a major overhaul, to provide full network connectivity, fully up-to-date versions of software packages, and new Mac processors. A new A0 colour plotter has also been installed.
- A World Wide Web site has been created.

Library

The role of the library is changing, as new network-based information sources become increasingly important. A growing number of on-line information sources are now available. An important part of the library's function is the management of access to these facilities.

The library provides a comprehensive range of traditional services, combined with access to on-line information sources.

It offers the following services

- Management of the Institute's book, periodicals and staff publications resource, including cataloguing and loans management
- Purchase of new books and periodicals
- Inter-library loans
- On-line searches of external databases
- Management of the computer-based open-learning facility

Future Developments

The computing infrastructure and support services provided by CIS are being expanded in two important areas:

- The bandwidth of the Local Area Network is being greatly expanded through the implementation of a set of high-speed switches and optical fibre backbone. The net effect will be to raise the current capacity by an order of magnitude.
- The computing support service staffing level is being increased, to enable more efficient handling of maintenance and development of the infrastructure, whilst improving the support service for users. This will also enable detailed statistics to be collected to establish the effectiveness of the service and enable further improvements to be made within the context of a Service Level Agreement.

MACAULAY RESEARCH & CONSULTANCY SERVICES

UNIQUE ENVIRONMENTAL RESEARCH & CONSULTANCY EXPERTISE

MRCS is the commercial arm of the Institute and undertakes a wide range of research and consultancy projects across many sectors of the environmental market.

These include:

Waste recycling to land	- development of land-based recycling strategies
	- comprehensive analysis of wastes
Contaminated land	- soil and site investigations
	- modelling pollutant movement in soils
Catchment management	- development of tools for water quality control
Natural heritage management	- vegetation surveys & habitat assessments
	- computer models to aid land management
Comprehensive analytical services	- competitive rates
	- fast turnaround time

MRCS has full access to the Institute facilities and to the accumulated knowledge and expertise of its staff. The close relationship that exists between MRCS business and the programme of research undertaken by MLURI is important for the future development of both organisations and is a major competitive strength of MRCS.

Global market

MRCS has a wide customer base and has shown steady growth in a year when some of its public-sector customers have been through major reorganisations. For the future, MRCS has its sights firmly set on developing its overseas markets, particularly those where organisations like the World Bank and ODA are funding projects. Once again, the symbiotic relationship between MLURI and MRCS will be vital to ensure success in these markets: MLURI staff have gained experience in many parts of the world including China, Zimbabwe and Korea and nearly all the countries of the EU. Opportunties have been identified in Southern Africa, the Indian sub-continent, Russia and Central Asia and South America. Plans are currently being developed for MRCS to actively market expertise in soil survey and land capability, GIS and spatial data analysis, and rangeland management in these areas of the world.

Dr Iain Gordon 'making friends' in Zimbabwe

Drs Derek Bain and Simon Langan meeting with colleagues in Korea

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. Its 30 graduate staff are based at BioSS Headquarters in the University of Edinburgh and in units in Aberdeen (at both MLURI and Rowett Research Institute), Dundee (at Scottish Crops Research Institute), and Ayr (at SAC and Hannah Research Institute).

BioSS has particular expertise in the areas of Environmental Modelling, Image Analysis, Mathematical and Systems Modelling, Molecular Biology, Plant Breeding and Variety Testing, and Food and Nutrition. Major projects in these areas call on the services of the relevant BioSS specialists. In Aberdeen, there are 9 BioSS posts, 5 of which are based in the Environmental Modelling Unit at MLURI. The primary duties of the Unit are:

- to provide a consultancy service to MLURI scientists
- to engage in collaborative research with scientists from MLURI and elsewhere
- to develop programmes of applied statistical research
- to undertake related contract work

The consultancy service is operated through a well publicised open door policy whereby a member of staff is available each afternoon of the week. Primary responsibility for the MLURI research groups is divided amongst the BioSS staff involved. The consultancy office was well-used throughout the year, with over 80 scientists, visiting workers and research students seeking advice on the application of a wide range of statistical and mathematical methods to a variety of scientific problems. Where the timetable for the consultancy office is inconvenient, meetings are arranged for the mutual convenience of all concerned.

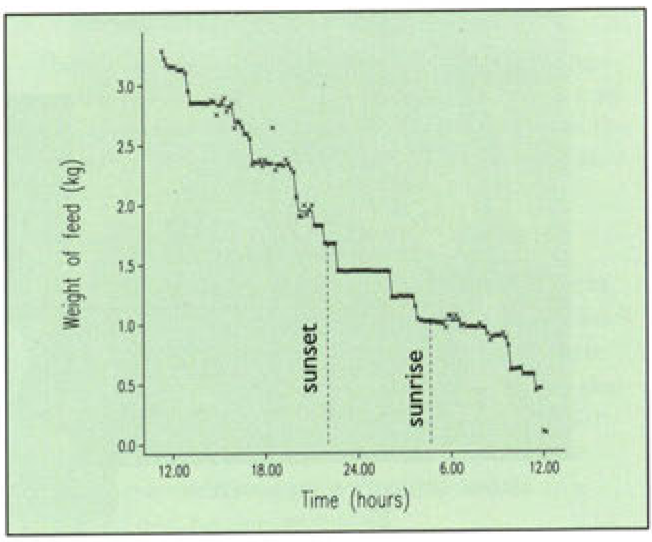
Collaborative projects arise out of contacts initiated through the consultancy service, and lead to joint publications with MLURI and BioSS co-authors. Examples of such collaborations with staff in the different MLURI groups are as follows.

- Ecology and Animal Science Group - model the correlations between animals within groups to reach a better understanding of the competitive interactions between sheep and deer; identify feeding bouts for red deer by fitting monotonic regressions to noisy records of weight of feed remaining in feed bins.
- Land Use Science Group - investigate the spatial distribution of sheep within an agroforestry system; use stated preference techniques to quantify the effect of hunting trip attributes on the preferences of deer stalkers.
- Plant Science Group - estimate the effect of location within patch on the growth of clover stolons in a grass-clover sward.
- Soil Science Group - investigate the potential for using near infra-red reflectance data to discriminate between the hyphae of different types of fungi; identify bacterial communities in soil samples using biolog plates.

BioSS and MLURI have a linked project to develop a Decision Support System for management of Red Deer on the open hill in Scotland. The main BioSS contribution has been to build a population dynamics model to integrate prior knowledge about closely studied deer populations with counts made at the locality for which management decisions are to be made. This model is now in place, together with a user-friendly interface for use on a PC. Additional research has lead to estimates of long-term changes in the spatial distribution of Red Deer on Rhum, and the development of techniques to estimate long-term changes in water chemistry.

BioSS provides training to scientists, both formally through computer-based short courses in Statistics and Mathematical Modelling, and also informally through discussions with individuals and small groups. This training raises the level of statistical awareness and abilities amongst scientists, allowing the statistical consultants to spend a greater proportion of their time on those projects which require the use of advanced statistical methods. During 1996, MLURI staff attended 10 different BioSS courses and received a total of 81 person-days of training.

Additional income of the Unit comes from external sources. A long-term contract involving BioSS, MLURI and ITE scientists at MLURI and ITE is monitoring the Scottish Environmentally Sensitive Areas. Another long-standing contract is for BioSS to provide a consultancy service to staff at ITE Banchory. Modelling work undertaken as part of this contract has lead to the establishment of evidence for travelling waves in the size of a Red Grouse population in Deeside.



Monotonic regression line (-) fitted to bin weight data as a precursor to analysing the feeding patterns of red deer

CHABOS

The Committee of Heads of Agricultural and Biological Organisations of Scotland (CHABOS) was formed in 1994 to promote an integrated approach to biological, environmental and agricultural research and development, technology transfer and policy support. The Committee's mission is ***'to use the unique scientific and technological strengths within CHABOS to enhance our under-standing of the natural world and to promote the utilisation of natural resources for wealth creation and the benefit and well-being of Society'.***

The organisations represented on CHABOS include the Scottish Agricultural and Biological Institutes *viz* Hannah Research Institute (HRI), Macaulay Land Use Research Institute (MLURI), Moredun Research Institute (MRI), Rowett Research Institute (RRI) and Scottish Crop Research Institute (SCRI), including Biomathematics and Statistics Scotland (BioSS), Fisheries Research Service (FRS), Forestry Commission Research Division (FCRD), Royal Botanic Garden Edinburgh (RBGE), Scottish Agricultural Science Agency (SASA), and Scottish Agricultural College (SAC). Together these organisations offer a unique blend and range of skills in microbial, plant and mammalian biochemistry and physiology, recombinant technology, aquaculture, animal and crop diseases, food technology, applied engineering, socio-economics, agricultural and land use systems, plant systematics and the management of biological collections.

CHABOS organisations are recognised as centres of excellence in their respective scientific areas with impressive records for high-quality research, education, advice, consultancy and scientific services. They are highly adaptable organisations and regularly realign their programmes to meet the changing needs of society and Government policy. They excel in recognising industrial needs, in developing strategies for effective technology transfer to the biotechnology, pharmaceutical, food, agriculture, aquaculture and forestry industries, as well as contributing to the means whereby Government policies can be implemented, evaluated and amended to achieve desired goals.

The CHABOS approach to science and technology marries well with Government policy and with the aims of the Technology Foresight Programme (TFP) to bring together business, academe and Government and identify key priority areas for research and development. Key priority areas currently include genetic and molecular engineering, health and lifestyle, environmentally sustainable technology, biomaterials, chemical and biological synthesis, bioinformatics, risk assessment and management, and modelling and simulation. CHABOS research programmes lie firmly in these priority areas.

These priority areas reflect the increasing complexity and nature of modern science. Significant progress now often depends upon co-ordinated input from scientists with experience in a range of disciplines. CHABOS is well placed to operate in this mode. Wide-ranging strategic and applied integrated research programmes are carried out by CHABOS. These integrated programmes achieve the highest international standards and contribute to science and technology within the life sciences in the widest sense. They involve not only CHABOS organisations but also scientists from other institutes and universities in Scotland, the rest of the UK and elsewhere.

Current initiatives funded by SOAEFD include co-ordinated programmes on Soil-Plant-Microbe Interactions, Animal Welfare, Fetal and Post-Natal Development, Plant Health, Vegetation Dynamics, Control of Helminths, the role of Lectins in Plant and Animal Biotechnology and Zoonotic Organisms. Other co-ordinated programme initiatives continue to be developed under four main themes, *viz* **Biotechnology** (peptides, membrane-antigen mapping, molecular tools for genetic characteristics of plants and animals, microbial communities and as diagnostic aids); **Food, nutrition and health** (microbial contamination, free radicals and antioxidants in food, control of adiposity, Bovine Spongiform Encephalpathy (BSE), meat production and health); **Animal production, health and welfare** (control of food intake); and **Biodiversity, sustainable systems and land use** (biodiversity: a conceptual and practical framework, economic and biological aspects of sustainability, environmental pollution/biological remediation/soil conservation).

In addition to its R&D programmes, CHABOS makes a crucial contribution to national S&T affairs, through involvement in policy advice, monitoring and representational work. This applies in particular to SASA and FRS.

CHABOS member organisations have pioneered the establishment of mechanisms for technology transfer and technology support which are geared to improvements in national prosperity and the quality of life. These operate at several levels; the provision of an extension and advisory service to farmers and land managers is undertaken principally by SAC. Technology transfer from many of the other CHABOS organisations is undertaken by subsidiary companies which operate closely with local enterprise companies to market scientific expertise and carry out applied research and consultancy contracts for industry, and for Government agencies and departments.

CHABOS plays a major role in advanced education and training in agriculture and the biological sciences. SAC is a major provider of vocational education and training for the land based sector. CHABOS contributes to undergraduate and postgraduate training: typically 230 M.Sc. students and about 400 Ph.D. students receive training at CHABOS establishments every year. Often with British Council or Royal Society support, some 300 scientists and students from outwith the UK also receive training or participate in collaborative research every year.

A prime objective of the organisations of CHABOS is to maintain and enhance the relevance and quality of their work. Many of their programmes are at the leading edge of science and technology. By harnessing this multidisciplinary expertise into fully integrated and co-ordinated programmes, the mutual benefits can be far reaching. The approach requires imagination and flare and the maintenance of the highest standards of quality control and quality assurance. The CHABOS members are committed fully to 'capitalise on the scientific expertise within the member organisations, to nurture their creative and innovative talents, and to carry out research of the highest international quality'.

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1 January 1997

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PLANT SCIENCE GROUP

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Mike F Proe, B.Sc., Ph.D.
Charles A Shand, B.Sc., Ph.D.
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ECOLOGY & ANIMAL SCIENCE GROUP

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Alastair J Macdonald, SDA, NDA
Stuart R McMillen, HNC
Nicholas Outram, M.Sc.
Jonathon Read, B.Sc.
Hilary L Redden, B.Sc.
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Glynn Stanworth, B.Sc., PG Dip.
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ANALYTICAL GROUP

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Lynda M Keddie

1. Inorganic Element Analysis
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Doris M McCombie

2. Mass Spectrometry
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Jennifer J Harthill, HNC
Keely P Taylor

3. Soil Analyses
Jason Owen, B.Sc., M.Sc., Ph.D.
Anne Dickson, B.Sc., M.Sc., MRSC
Kathleen H Davidson
June B McAdam

4. Radiochemistry
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5. Colourimetric Analyses and Chromatography
Alan Hepburn, C.Chem., MRSC
Susan M McIntyre, HNC
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Alistair Inglis, B.Sc.
Arlene M Murray, HNC
Gillian L Sim, B.Sc.
Donna McDonald
Gillian Martin
Maureen M Procee, HNC
Dawn Morley

6. Technical Services
Bert W Stuart, HNC
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Allan I A Wilson, HNC
David W Clark, HNC
David Sim
Gordon W Stott

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Ruth Penny
Nessie Rennie
Meg Walker
Marjorie Watt

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Jim A Steinson

COMPUTING & INFORMATION SERVICES GROUP

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Group secretary
Carol A Smith

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Lindsay Robertson, B.Sc. (database manager)
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Administrative Assistant
Kim Burnett

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Norman G McEwan (head shepherd)
John W Black (Jnr) (tractorman)
James Scott (shepherd)
June Scott (cleaner)

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A Robson Fawcett, AIMLS

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Craig A MacEachern

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Typist
Catherine Walsh

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Robert Graham (head stockman-cattle)
Jim C MacDonald, B.Sc. (stockworker-sheep records)
Robert Armstrong (stockworker)
Betty Farley (cleaner)

SOURHOPE

Officer-in-charge
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Patricia Gentry (recording officer)
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T Gavin Rogerson, Dip.FBOM (goats)
Pamela Tapson (shepherd)
Matthew Wilson (shepherd)
Dorothy H Wallace (cleaner)

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Sandra Denham (H)
Duncan Murray (G)
W Paul Leonard (H)

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Karen J Scott

Personnel Administration and General Office

Eileen J Cockburn
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Margaret W Forsyth
Iona M Shand
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May L Watson

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Wilfred F Wallace

Cunningham Building caretaker

Catherine Milne

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DURING 1996

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Dr Gaetano Pace, University of Naples, Italy.

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Professor Nikola Kostic, University of Belgrade, Serbia
Sebastian Meriau, Ecole Supérieure d' Agriculture d' Angers, France
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Alistair Pole, University of Aberdeen, Aberdeen Research Consortium
Patricia da Silva, University of Aberdeen, Spanish Government

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Ahmed Ayoub, Robert Gordon University, Self-funding

PROGRAMME OF RESEARCH
current projects as of 1 April 1997

Research projects in Programme Units 021 to 00C are funded by SOAEFD.

PROGRAMME UNIT 21

GEOGRAPHICAL AND RESOURCE ANALYSIS

Programme Unit Manager:
R V Birnie

021 339 An approach to modelling wildlife dynamics in hill grazing systems using grouse as a model (M Hare)

021 371 Decision support system for assessing land use options and impacts at the management unit level (K B Matthews)

021 373 Application of remote sensing and GIS for modelling distribution of short eared owls at landscape scales (R J Aspinall) [non commissioned research]

021 401 Integration of land cover and agricultural information from the Agricultural and Horticultural Census of SOAFD with the Land Cover of Scotland 1988 (LCS 88) to provide an enhanced, co-ordinated and multi-temporal Land Cover Database for Scotland (R V Birnie) [Flexible Fund]

021 439 A catchment /district scale model for assessing land use options and impacts with special reference to ecological modelling and conservation (R J Aspinall)

021 440 Development of a generic methodology for integrated impact assessment within a GIS framework (D R Miller)

021 443 Develop and evaluate the use of pedotransfer functions as a means of providing soil hydraulic data for process-based simulation models (A Lilly)

021 446 Spatio-temporal biophysical resource simulation modelling and representation for quantifying risks and opportunities in land use (G Hudson)

021 453 The development of visualisation techniques for landscape evaluation (D R Miller) [non commissioned research]

021 464 Modelling vole populations at a landscape scale (R J Aspinall) [non commissioned research]

021 477 Assessing the potential for short rotation coppice in Scotland (W Towers) [Flexible Fund]

021 556 Development of efficient, biologically sustainable and economically viable upland sheep systems (A R Sibbald)

021 557 The role of spatially distributed interactions in integrated land use systems (A R Sibbald)

021 558 Indicators of risk and resilience: a longitudinal study of sustainability in the UK hill sheep sector (A R Sibbald/R V Birnie)

021 559 Strategic development of RS Technology for characterisation at the field scale (G G Wright)

021 560 Development and testing of risk management methodologies with respect to organic waste recycling on farms (W Towers)

021 561 Application of knowledge-based systems for detecting land cover change (A N R Law) [non commissioned research]

PROGRAMME UNIT 22

SOCIO-ECONOMIC AND POLICY ANALYSIS

Programme Unit Manager:
J R Crabtree

022 384 Economic analysis of habitat and ecosystem restoration (D C Macmillan)

022 422 The relative importance of agriculture, pollution and climate in determining biodiversity on Scottish agricultural land (J R Crabtree) [Flexible Fund]

022 451 Economic appraisal of nitrate management at the catchment level (D C Macmillan)

022 461 The function and role of large estates in rural development (J R Crabtree) [non commissioned research]

022 462 Development of spatial economic analysis: sustainability indicators and demands on natural capital (D van der Horst) [non commissioned research]

022 505 To develop and apply the concept of environmental accounting to farming systems, with specific reference to assessing their sustainability (J R Crabtree/R V Birnie) [Flexible Fund]

022 562 Environmental benefits of traditional agricultural systems in European agriculture: a socio-economic analysis (D C Macmillan)

022 563 Choice experiments, cost-effectiveness and related valuation methods for assessing the benefits from investment in the rural environment (C H Bullock)

022 564 Multi-objective programming models of farmer responses to environmental incentives and constraints (N Barron)

022 565 Changes in land use, agricultural and rural structures: implications for rural sustainability (J R Crabtree)

PROGRAMME UNIT 23

ATMOSPHERIC DEPOSITION, LAND USE AND WATER QUALITY MANAGEMENT

Programme Unit Manager:
R C Ferrier

023 395 Predictive modelling of eutrophication within the river Ythan catchment and the development of an integrated management plan (P Domburg) [Flexible Fund]

023 434 Influence of weathering of calcium-bearing minerals on the sensitivity of catchments to acidification (D C Bain)

023 457 Distributed modelling of water quality at the river basin scale (S Dunn) [non commissioned research]

023 479 Nutrient cycling within semi-natural and managed ecosystem; consequences for water quality and catchment management (A C Edwards)

023 481 Impact and fate of nitrogen in atmospheric deposition: immobilisation and the characterisation of organic nitrogen released to soil water (B L Williams)

023 491 Critical loads of acidity to soils in relation to mineral weathering in different soil types (S J Langan)

023 492 Consequences of initial afforestation practices on catchment behaviour in northern Scotland (J D Miller)

023 500 The assessment of ground water quality in Grampian Region (A C Edwards) [non commissioned research]

023 530 Water resource modelling: impacts of global change, atmospheric deposition and land use change on soil and water quality (R C Ferrier)

023 531 Integration of soil hydrological information into existing physically-based catchment scale models (A Lilly)

023 532 Nutrient changes in soil hydrochemistry between extensively managed hillslopes and output streams (H A Anderson)

023 533 Contribution and pathways of soil-derived particles to the suspended loads of rivers (S J Hillier)

PROGRAMME UNIT 24

CONTAMINATED LAND MANAGEMENT AND WASTE UTILISATION

Programme Unit Manager: E Paterson

024 328 Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility (J R Bacon)

024 380 Influence of competitive interactions on the impact and fate of heavy metals in sewage sludge-treated soils (E Paterson)

024 431 Effects of mineral-humic interactions in relation to modelling metal retention by soils (D Lumsdon)

024 432 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 (J R Bacon)

024 517 Assessment of the biological impact and remediation of oil contamination in soils (C D Campbell) [non commissioned research]

024 535 Spatio-temporal modelling of opportunities and constraints associated with organic waste recycling on land (W Towers)

024 536 Sensitivity of Scottish agricultural and land use systems to atmospherically derived radionuclide pollution (C A Shand)

024 537 Impact of dissolved and particulate organic matter derived from farm animal wastes on soil drainage water (H A Anderson)

024 538 Soil ecosystem recovery in relation to organic micropollutants and heavy metals (C D Campbell)

024 539 Modelling diffusive-convective transport of reactive solutes in soils (J C L Meeussen)

024 540 Plant availability of phosphorus from sewage sludge amended soil and the influence of heavy metals (C A Shand)

PROGRAMME UNIT 25

SOIL QUALITY

Programme Unit Manager: E Paterson

025 433 Influence of heavy metal pollution on processes involving organic matter which affects soil fertility (M V Cheshire)

025 490 Use of existing datasets in national and regional assessments of threats to soil and water quality (S J Langan)

025 541 National assessment of factors and processes responsible for recent trends in the fertility of Scottish soils (A C Edwards)

025 542 Functional diversity of soil micro-organisms as an indicator of soil quality and its relationship to other soil properties (C D Campbell)

025 543 Microbial gaseous products as quality indicators of soils undergoing land use change (S J Chapman)

025 544 Contribution of clay mineralogy in soil structural stability and release of mobile colloids from soils (S J Hillier)

025 555 Development of clay database (S J Hillier) [Director's commissioned research]

PROGRAMME UNIT 26

LAND USE OPTIONS FOR PLANTS

Programme Unit Manager: P Millard

026 435 Development of methods to measure seasonal nitrogen translocation in trees and their application to quantify internal cycling (P Millard)

026 436 Sustainability of whole-tree harvesting of Sitka spruce as a sustainable land use on different site types within the UK (M F Proe)

026 438 Phenotypic and genotypic basis of population dynamics in heterogeneous species-rich grassland (U Bausenwein) [Flexible Fund]

026 463 Interactions between N status and carbon partitioning on the development of *Vaccinium* (P Millard) [non commissioned research]

026 480 Plant competition in grasslands in relation to defoliation, edaphic and environmental factors (B Thornton)

026 545 Consequence of defoliation for nutrient acquisition and root dynamics in a heterogenous soil environment (L Dawson)

026 546 Models of carbon and nitrogen allocation, growth and remobilisation in plants of extensively managed pastures (C P D Birch)

026 547 Canopy size, nutrient supply and assimilate partitioning in native Scots pine seedlings (M F Proe)

PROGRAMME UNIT 27

NATURAL HERITAGE MANAGEMENT - VEGETATION DYNAMICS

Programme Unit Manager:
R J Pakeman

027 205 Effects of sheep grazing intensity on the vegetation dynamics of a range of wet heather moorlands differing in vegetation structure and species composition (A Nolan)

027 450 Effects of pre- and post-burning management on the recovery of rehabilitated dry and wet heather moorland (P D Hulme)

027 487 Responses by tree saplings to browsing damage by cattle and red deer (A J Hester)

027 488 Influences on plant species balance in extensively managed grassland grazed by sheep and cattle (G T Barthram)

027 548 Extent and development of spatial aggregation of species in extensive grassland communities (C A Marriott)

027 549 Spatially explicit models of vegetation dynamics (C P D Birch)

PROGRAMME UNIT 28

NATURAL HERITAGE MANAGEMENT - HERBIVORE FORAGING

Programme Unit Manager:
I J Gordon

028 366 Antioxidant efficacy of dietary polyphenols in relation to diet choice in sheep (D B McPhail)

028 447 Develop a theoretical approach to optimal matching between habitat and free ranging ruminants (K D Farnsworth)

028 448 Effect of social behaviour on foraging by ruminants in heterogeneous ecosystems (A M Sibbald)

028 449 Effect of shelter and food supply on behaviour and energy status of ruminants in heterogeneous upland ecosystems (A J Duncan)

028 485 Measurement of the ranging behaviour of red deer using a Global Positioning Satellite system to aid development of computer based models (K D Farnsworth)

028 486 Functional basis for predicting interactions between red deer and natural vegetation communities (G R Iason)

028 489 Methods of estimating diet composition and intake by herbivores foraging in hetero-geneous ecosystems (R W Mayes)

028 506 Quantify the role of species interactions during foraging on the functioning of mammalian communities (I J Gordon) [non commissioned research]

028 522 Urinary metabolites as markers of dietary intake in free ranging ruminants (R W Mayes) [non commissioned research]

028 550 Conditioned food aversions and their influence on the foraging behaviour of free-ranging ruminants (A J Duncan)

028 551 Determinants of habitat selection by wild rabbits and their influence on fragmentation of *Calluna* moorland (G R Iason)

028 552 Effects of spatial aggregation of grass species on frequency dependent selection in grazing herbivores (I J Gordon)

028 553 Spatial and temporal variation in population demography of red deer in relation to density, climate and land cover (I J Gordon/G G Wright)

PROGRAMME UNIT 29

LAND USE OPTIONS FOR ANIMALS

Programme Unit Manger:
I A Wright

029 232 Cashmere production from goats and its improvement by cross-breeding and selection (M Merchant)

029 326 Sequential and mixed grazing of grass/clover swards by cattle and sheep (I A Wright)

029 367 Effect of rearing environment, management and genotype on the stress susceptibility of sheep in extensive systems (P J Goddard)

029 368 Relationships between behaviour, hormonal and immune responses to stress in sheep (S M Rhind)

029 397 Effects of pre-natal nutrition, colostral immunomodulators and lamb growth factors on aspects of innate and adaptive immunity in lambs (S M Rhind) [Flexible Fund]

029 399 Testing models of nematode larval intake by ruminants (J A Beecham) [Flexible Fund]

029 402 Object orientated modelling of mixed grazing systems (J A Beecham) [Flexible Fund]

029 426 Interaction of genotype and nutritional environment in grazing beef cows (I A Wright)

029 427 Mixed grazing of structurally heterogeneous swards (I A Wright)

029 482 Assessment of motivation in ruminants (P N Grigor)

029 483 Establishment of flocks of Cheviot sheep carrying the Thoka gene for prolificacy (S M Rhind)

029 484 Environmental influences on the quantity and quality of animal fibre production (M Merchant)

029 508 Pre- and post-natal development of the reproductive axis in the intrauterine growth restricted lamb

(S M Rhind) [non commissioned research]

029 554 Concentrations of environmental oestrogens (xenoestrogens) in tissues of domestic animals grazing pasture treated with sewage sludge (S M Rhind)

INTEGRATED PROGRAMME UNIT A

SOIL-PLANT-ANIMAL INTERACTIONS

Integrated Programme Unit Manager: P Millard

00A 398 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 (S J Grayston) [Flexible Fund]

00A 524 Influence of excretal urine-N on availability of soil phosphorus (C A Shand)

00A 525 Soil nitrogen dynamics in urine patches in extensively managed sheep pastures (B L Williams)

00A 526 Impact of grazing on microbial community structure and activity and the consequences for nutrient cycling (S J Grayston)

INTEGRATED PROGRAMME UNIT B

LONG-TERM MEASUREMENT AND MONITORING OF CHANGE

Integrated Programme Unit Manager: J A Milne

00B 333 Environmental Change Network: measure long-term environmental changes in soils, vegetation and wildlife populations at two upland agricultural sites in Scotland (D J Henderson)

00B 441 Integrating the LCS 1988 data set with satellite imagery to provide measures of vegetation heterogeneity, structure and examination of regional variation (G G Wright)

00B 493 Use of long-term monitoring sites and historical re-sampling strategies in the detection of environmental change (J D Miller)

00B 527 Development of the methodologies for use in LCS 2000 (R J Aspinall)

00B 528 Development of methodology for large-scale habitat assessment (A J Nolan/D J Henderson)

00B 529 Design of strategies for environmental and compliance monitoring (J R Crabtree)

INTEGRATED PROGRAMME UNIT C

DEVELOPMENT OF DECISION SUPPORT SYSTEMS

Integrated Programme Unit Manager: J A Milne

00C 400 Develop a Geographic Object-Oriented Simulation Environment for individual-based ecological modelling using GIS data (K D Farnsworth) [Flexible Fund]

00C 494 MLURI data model (R J Aspinall)

00C 495 Biodiversity management of upland landscapes (P Dennis) [non commissioned research]

00C 515 Development of a linked terrestrial aquatic data management system for lochs in the Scottish Standing Waters Classification Scheme (RC Ferrier) [Director's commissioned research]

00C 534 Construction of a Land Use Modelling environment to aid decision support tool development (A N R Law)

00C 570 Development of decision support tools for grazing systems (J A Milne) [non commissioned research]

MLURI EXTERNAL CONTRACTS

LAND USE SCIENCE GROUP

090 412 Silvicultural strategies for reducing damage to forests from wind, fire and snow: integrating tree, site and stand properties with Geographic Information Systems and regional environmental models to evaluate options for forest management (D R Miller) [EC]

090 420 Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning (A Lilly) [EC]

090 513 Integration of environmental concerns into hill and mountain farming (J R Crabtree) [EC]

090 569 Hydrology of alpine and high altitude basins (G G Wright) [EC]

SOIL SCIENCE GROUP

090 359 Characterisation, management and utilisation of red soil resources of southern China (M J Wilson) [EC]

090 474 Prediction of spatial and temporal variation in the solute chemistry of a major river system from the integration of models of terrestrial and hydrological processes (S J Langan) [NERC]

090 478 Dynamic models to predict and scale-up the impact of environmental change on biogeochemical cycling (R C Ferrier) [EC]

090 520 Trace element and phosphate extraction from sediments and soils (J R Bacon) [EC]

090 523 Ecological effects of land use changes on European terrestrial mountain ecosystems (R C Ferrier) [NERC]

PLANT SCIENCE GROUP

090 507 Total nitrogen and phosphorus losses from upland ecosystems: significance of instream processes (P J Chapman) [NERC]

090 514 Tree nutrition: Sustainability of wood production in relation to harvesting and remedial fertilisation (M F Proe) [EC]

090 568 The reduction of 137 Cs and 90 Sr uptake by grasses in natural meadows (C A Shand/M V Cheshire)

ECOLOGY AND ANIMAL SCIENCE GROUP

090 405 Research on the production of high quality cashmere from goats and its potential for agricultural diversification (A J F Russel) [EC]

090 428 The use of grazing as a management tool in natural woodland ecosystems (A J Hester) [EC]

090 473 Sustained conservation value through grazing: conservation management of priority upland habitats through grazing: guidance on management of upland Natura 2000 sites (J A Milne) [EC]

090 475 Transfer of heavy metals from feeding stuffs and environmental sources into meats, milk and other foods of animal origin (R W Mayes) [MAFF]

090 476 The role of domestic livestock systems in rural development in disadvantaged areas (J A Milne) [EC]

090 499 Selection of goats for resistance to gastro-intestinal nematodes (I A Wright) [Moredun Research Institute]

090 501 Research on the effect of goat management and endocrinology on cashmere fibre growth and quality (I A Wright) [British Council]

090 503 The influence of trituration surface and molar wear on assimilation efficiency and its relationship with fitness of Soay sheep (I J Gordon) [EC]

090 504 The herbivores dilemma: Trade-offs between nutrition and parasitism in foraging decisions (I J Gordon) [NERC]

090 511 Increasing competitiveness of high quality European animal textile fibres by improving fibre quality (J A Milne) [EC]

090 521 An integrated approach to radionuclide flow in semi-natural landscapes underlying exposure pathways to man (R W Mayes/ G R Iason) [EC]

090 566 European Livestock Policy Evaluation Network: development of protocols and methodologies for policy evaluation and impact on rural development (I A Wright) [EC]

MRCS CONSULTANCY DIVISION

090 415 Monitoring of Environmentally Sensitive Areas in Scotland (J H Gauld) [SOAEFD]

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FERRIER, R C, PATERSON, E, WOLSTENHOLME, R, DUTCH, J and DAVIDSON, J 1996. Evaluating the potential use of sewage sludge granules in forestry. *Growing Benefits, Newsletter of Grampian Region Water Services.*

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THORNTON, B 1996. Non destructive measurements: a cautionary note. *Pasture Ecology Group Newsletter*, 38, 17-18.

WILLIAMS, B L 1996. Forest soils discussion group. *British Society of Soil Science Newsletter.*

CONFERENCES and VISITS ABROAD

UK Conferences at which staff presented papers during 1996

LAND USE SCIENCE GROUP

ASPINALL, R J. Modelling in Applied Biology. Brunel University, 25-27 June.
ASPINALL, R J. The Spatial Dynamics of Biodiversity. Stirling, 1-9 September.
BULLOCK, C H. Agricultural Economics Society. Newcastle, 27-30 March.
BULLOCK, C H. The Spatial Dynamics of Biodiversity. Stirling, 1-9 September.
HARE, M. Workshop on A-life and the simulation of behaviour. Sussex University, 1-2 April.
JONES, K. GIS Research in the UK. University of Kent, 10-12 April.
MACMILLAN, D C. Non-market benefits of Forestry. Edinburgh, 24-28 June.
MACMILLAN, D C. The Spatial Dynamics of Biodiversity. Stirling, 1-9 September.
McALISTER, E. Measuring nutrient run-off from land to water. Leicester, 6 December.
MILLER, D R. Landscape perception and GIS. University of Leicester, 24-25 June.
SIBBALD, A R. The CAP and the Scottish countryside. Battleby, 23 May.
SIBBALD, A R. Annual meeting of UK Agroforestry Forum. SAC Craibstone, 1-3 July.
TOWERS, W. Soil Protection. Ayr, 19 March.
TOWERS, W. The Environmental Technology Industry. SECC Glasgow, 23 May.

SOIL SCIENCE GROUP

BAIN, D C. International Symposium on Geochemistry of the Earth's surface. Ilkley, Yorkshire, 22-28 July.
DUNN, S M. Measuring nutrient run-off from land to water. Leicester, 6 December.
HODSON, M. International Symposium on Geochemistry of the Earth's surface. Ilkley, Yorkshire, 22-28 July.

PLANT SCIENCE GROUP

EDWARDS, A C. Hillslope Processes. Bristol University, 20-22 May.
GRAYSTON, S J. Fungal Biodiversity and Mycology of the Future. University of Sheffield, 9-12 April.

ECOLOGY AND ANIMAL SCIENCE GROUP

BIRCH, C P D. British Ecological Society Annual Meeting. Durham University, 17-19 December.
BEECHAM, J A. British Ecological Society Annual Meeting. Durham University, 17-19 December.
DENNIS, P. The Spatial Dynamics of Biodiversity. Stirling, 1-9 September.
GODDARD, P J. Association of Veterinary Teachers and Research Workers. Scarborough, 1-4 April.
GORDON, I J. The Spatial Dynamics of Biodiversity. Stirling, 1-9 September.
FARNSWORTH, K D. Modelling in Applied Biology. Brunel University, London, 25-27 June.
HESTER, A J. Native Woodlands Discussion Group Annual Meeting. Pitlochry, 30 May-2 June.
HULME, P D. British Ecological Society Annual Meeting. Durham University, 17-19 December.
PARTRIDGE, L W. British Ecological Society Annual Meeting. Durham University, 17-19 December.
READ, J. British Ecological Society Annual Meeting. Durham University, 17-19 December.
WRIGHT, I A. British Society for Animal Science Winter Meeting. Scarborough, 18-20 March.

Conferences abroad at which staff presented papers during 1996

LAND USE SCIENCE GROUP

BROADGATE, M L. Presentation to DGVI, EC. Brussels, Belgium, 3-5 July.
CRABTREE, J R. Global Warming Mitigation. Trento, Italy, 22-25 May.
MACMILLAN, D C. Ecology, Society and Economy Conference. Paris, France, 23-25 May.
SIBBALD, A R. European Society for Agronomy. Wageningen, The Netherlands, 7-11 July.
TOWERS, W. 4th International Symposium on Livestock Farming Systems. Foulum, Denmark, 22-23 August.

SOIL SCIENCE GROUP

CAMPBELL, C D. Substrate use for characterisation of microbial communities in terrestrial ecosystems. Innsbruck, Austria, 16-18 October.
CHESHIRE, M V. 8th Meeting of the International Humic Substances Society. Wroclaw, Poland, 9-14 September.
HILLIER, S J. 33rd Annual Meeting of the Clay Minerals Society, Gatlingburg, USA, 15-21 June.
HODSON, M. Mineral Weathering. Brno University, Czech Republic, 2-4 December.
LANGAN, S J. Impact of Acid Deposition. Tsukuba, Japan, 10-12 December.
MEEUSSEN, J C L. Hydroinformatics '96. Zurich, Switzerland, 9-12 September.
WILSON, M J. EUROLAT '96. University of Aveiro, Portugal, July.
WILSON, M J. 14th Conference on Clay Mineralogy and Petrology. Slovakia, 2-6 September.

PLANT SCIENCE GROUP

DOMBURG, P. Information and Communication Technology Applications in Agriculture: state of the art and future perspectives. Wageningen, The Netherlands, 16-19 June.
PROE, M F. IEA Workshop on Whole Tree Harvesting. Jyvaskyla, Finland, 9-13 September.
SHAND, C A. Interactions of Soil Minerals with Organic Matter and Micro-organisms. Nancy, France, 3-6 September.
SHAND, C A. 6th International Conference on Field Flow Fractionation. Ferrara, Italy, 7-11 September.
THORNTON, B. European Society for Agronomy. Wageningen, The Netherlands, 7-11 July.
WILLIAMS, B L. International Peat Congress. Bremen, Germany, 27 May-2 June.

ECOLOGY AND ANIMAL SCIENCE GROUP

DENNIS, P. International Congress of Entomology. Florence, Italy, 25-31 August.
FORSTER, J. Spanish Pastures Conference. Logrono, Spain, 4-8 June.
HESTER, A J. Nordic Sub-arctic Sub-alpine Ecology Group Annual Conference. Faroe Islands, 3-5 August.
MAYES, R W. Joint meeting of Pasture Ecology and Animal Intake Groups. Dublin, Eire, 24-25 September.
SIBBALD, A M. Joint meeting of Pasture Ecology and Animal Intake Groups. Dublin, Eire, 24-25 September.

Staff visits abroad during 1996

LAND USE SCIENCE GROUP

BROADGATE, M L. EC Workshop. Umea, Sweden, 22-27 October.
BERGEZ, J-E. EC project meeting. INRA, Avignon, France, 29 April-3 May.
BERGEZ, J-E. EC project meeting. University of Thessaloniki, Greece, 29 May-1 June.
BIRNIE, R V. Sabbatical. CSIRO, Australia, September-December.
CRABTREE, J R. International Ecological Economics Conference. Boston, USA, 4-7 April.
CRABTREE, J R. Seminar on Integrated Environmental and Economic Analysis in Agriculture. Copenhagen, Denmark, 3-4 June.
CRABTREE, J R. European Association of Environmental and Resource Economists. Lisbon, Portugal, 27-29 June.
CRABTREE, J R. EC project meeting. University of Thessaloniki, Greece, 18-21 September.
CRABTREE, J R. EC project meeting. Paris, France, 16 December.
HUDSON, G. Deriving soil hydraulic parameters for simulation models. INRA, Orteans, France, 10-12 October.
LILLY, A. Soil and water quality at different scales. Wageningen, The Netherlands, 7-9 August.
LILLY, A. Land Information Systems for planning the sustainable use of land. Hanover, Germany, 20-23 November.
MACMILLAN, D C. Rural Development and Forestry. Vienna, Austria, 15-18 April.
MILLER, D R. EC project meeting. Brussels, Belgium, 3-5 July.
MILLER, D R. Application of remote sensing in European forest monitoring. Vienna, Austria, 13-16 October.
MILLER, D R. EC project meeting. Umea, Sweden, 22-27 October.
SIBBALD, A R. EC project meeting. University of Thessaloniki, Greece, 29 May-1 June.
SIBBALD, A R. 4th International Symposium on Livestock Farming Systems. Foulum, Denmark, 22-23 August.
SIBBALD, A R. EC project meeting. INRA/CIRAD, Montpelier, France, 28-30 November.
TOWERS, W. Environmental impact of biomass for energy. Noordwijkerhout, The Netherlands, 4-5 November.

SOIL SCIENCE GROUP

BAIN, D C. Atomic Spectroscopy Symposium. Dublin, Eire, 27-29 March.
BAIN, D C. Clay Minerals in the Modern Society. Oslo, Norway, 19-21 May.
BAIN, D C. Clay Minerals Conference. Granada, Spain, 19-21 September.
BACON, J R. EC project meeting. Barcelona, Spain, 23-24 October.
CHESHIRE, M V. EU Proposal reviews. Brussels, Belgium, 15-19 July.
CHESHIRE, M V. Lecturing. University of Lausanne, Switzerland, 10-13 October.
CHESHIRE, M V. Thesis examination. INRA, Montpelier, 5-8 December.
FERRIER, R C. EC project meeting. Amsterdam, The Netherlands, 27-28 February.
FERRIER, R C. TERI Committee meeting. Paris, France, 11-12 April.
FERRIER, R C. Collaboration. ISPRA, Italy, 21-23 October.
FERRIER, R C. Ecosystem Research, Global Change and the European Environment. De Bilt, The Netherlands, 11-12 November.
HELLIWELL, R C. EC project meeting. NIVA, Grimstead, Norway, 9-11 December.
LANGAN, S J. Mineral Weathering. Brno University, Czech Republic, 2-4 December.
MEEUSSEN, J C L. Modelling workshop. Strasbourg, France, 10-14 June.

PLANT SCIENCE GROUP

GRAYSTON, S J. Substrate use for characterisation of microbial communities in terrestrial ecosystems. Innsbuck, Austria, 16-18 October.
GRAYSTON, S J. INRA Twinning Workshop, Clermont-Ferrand, France, 10-13 December.
MARRIOTT, C A. INRA Twinning Workshop, Clermont-Ferrand, France, 10-13 December.
MILLARD, P. EC project meeting. Barcelona, Spain, 15-18 February.
MILLARD, P. INRA Twinning Workshop, Clermont-Ferrand, France, 10-13 December.
PROE, M F. INRA Twinning Workshop, Clermont-Ferrand, France, 10-13 December.
WILLIAMS, B L. INRA Twinning Workshop, Clermont-Ferrand, France, 10-13 December.

ECOLOGY AND ANIMAL SCIENCE GROUP

BARTHRAM, G T. Joint meeting of Pasture Ecology and Animal Intake Groups. Dublin, Eire, 24-25 September.
DUNCAN, A J. Establishing collaborative links. India and Pakistan, November.
FARNSWORTH, K D. Collaboration. University of Minnesota, USA, July.
GODDARD, P J. Livestock Farming Systems Symposium. Foulum, Denmark, 22-23 August.
GORDON, I J. Collaboration. Zimbabwe, August.
GORDON, I J. 1st International Symposium on the Physiology and Ethology of Wild and Zoo Animals. Berlin, Germany, 18-21 September.
GORDON, I J. Recent advances in small ruminant nutrition. Rabat, Morroco, 24-26 October.
HULME, P D. Collaboration. University College, Galway, Eire, 20-23 May.
LAKER, J. Forum on Nature Conservation and Pastoralisation. Cogne, Italy, 18-21 September.
MAYES, R W. Collaboration. Agricultural University of Norway, Oslo, Norway, 18-19 July.
McPHAIL, D B. 8th Biennial Meeting of the International Society for Free Radical Research. Barcelona, Spain, 1-5 October.
MILNE, J A. Livestock Farming Systems Symposium. Foulum, Denmark, 22-23 August.

ANALYTICAL GROUP

MIDWOOD, A J. Collaboration. Texas A&M University, 20-31 May.

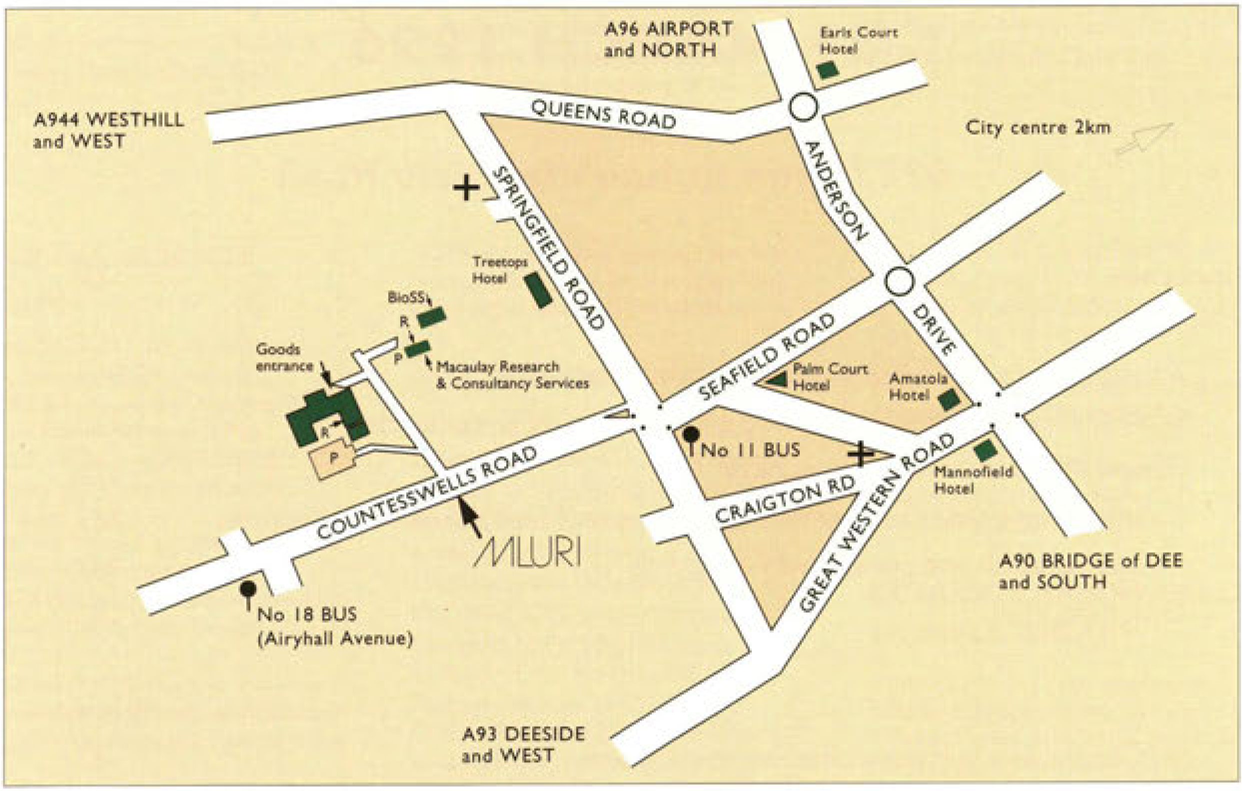
ANNUAL FINANCE STATEMENT for the YEAR ENDING 31 MARCH 1996

Income	£k
Scottish Office Agriculture and Fisheries Department	5,842
SOAFD Flexible Research Funding and other SOAFD contracts	1,325
European Union research contracts	379
Funding from other Government Departments, Public Bodies and Agencies	383
Private research and consultancy contracts	242
Other income	143
	8,314
Less Equipment purchased from revenue grants	-67
Total income	**8,247**
Expenditure	
Staff costs	5,156
Research expenditure including Research Station costs	1,574
Other operating costs	1,202
	7,932
Surplus (deficit)	315

The capital funds received from SOAEFD totalled £382,959 of which £203,817 was for capital works.

During the year the turnover of the Macaulay Research and Consultancy Services was £648,465.

MLURI CONNECTIONS



MLURI 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.