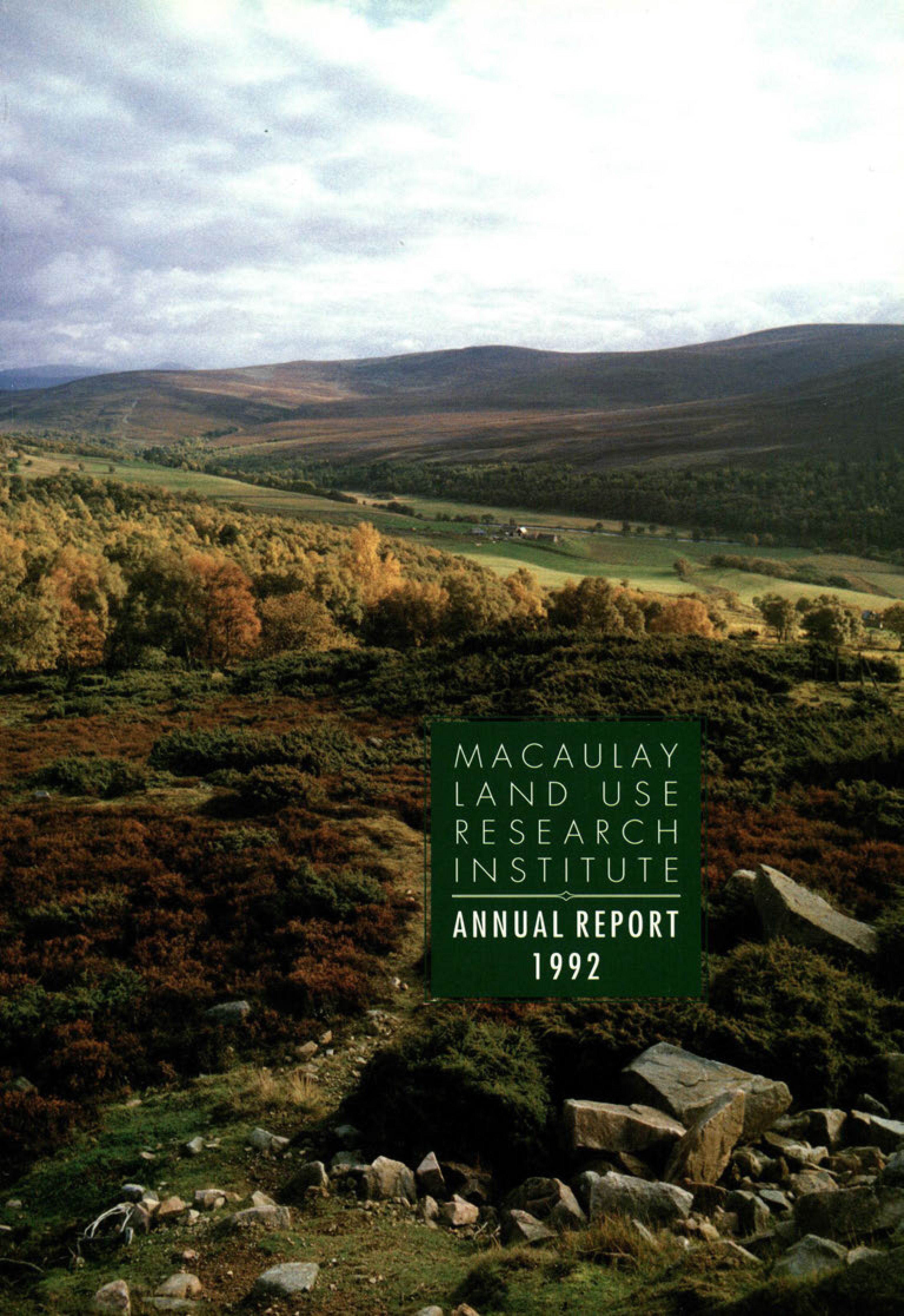


MACAULAY LAND USE RESEARCH INSTITUTE

ANNUAL REPORT 1992

MLURI

The Macaulay Land Use Research Institute was established by the Scottish Office Agriculture and Fisheries Department in April 1987 and is the only Institute in the UK with a specific remit to undertake research on land use.

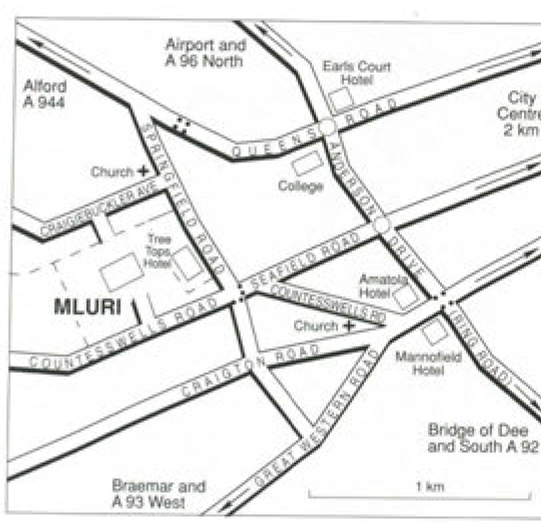
We are fundamentally concerned with understanding how our land resources can be used to achieve a range of different objectives. These objectives are not only associated with production, but also increasingly with conservation, amenity value, recreation and access to the countryside.

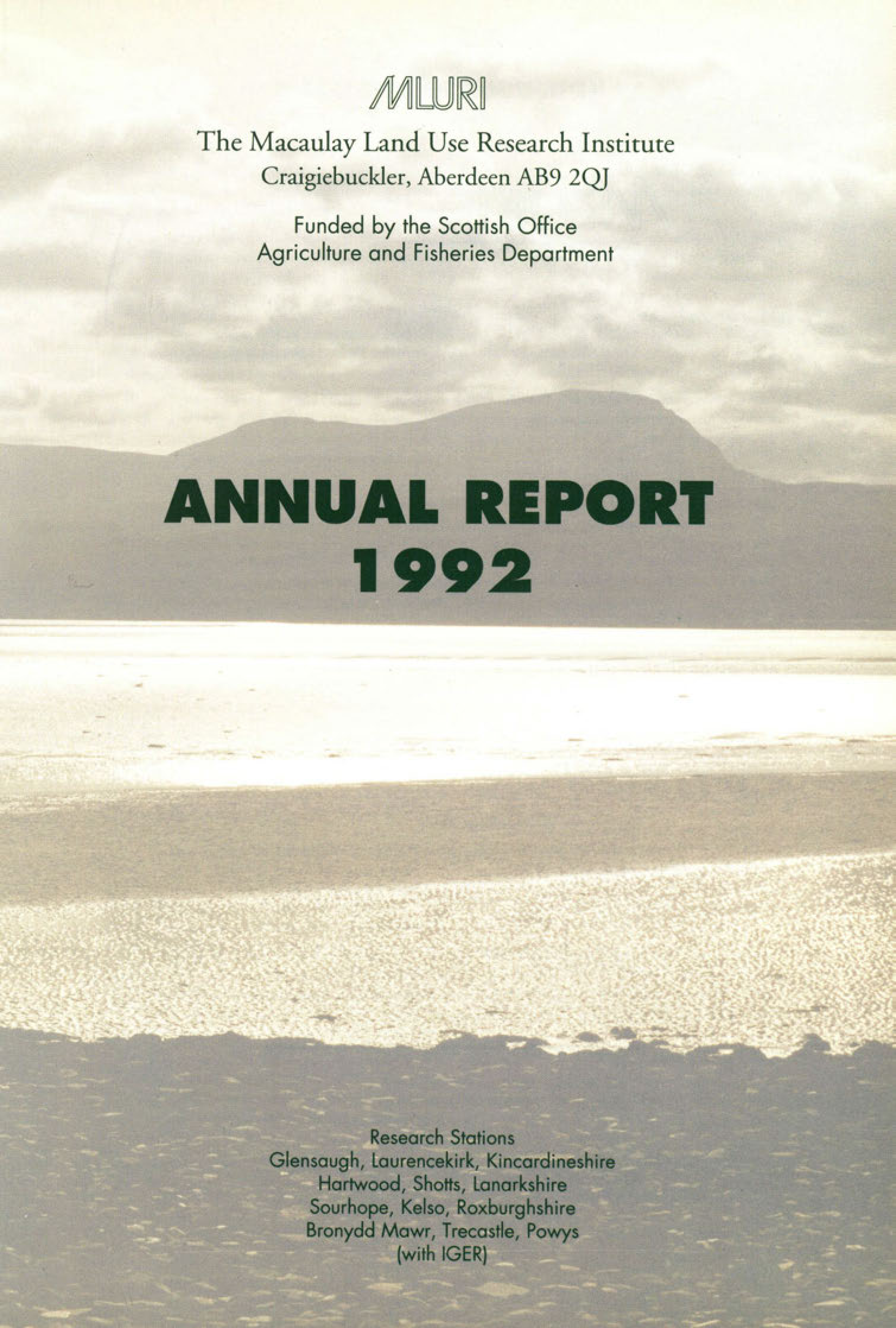
Our aim is to use our scientific understanding of land use systems and environmental processes to give policy makers objective information on the impacts associated with existing and alternative land uses.

In order to do this, we carry out research on the following:

- The impact of agriculture and related land uses on the environment
- The social and economic impacts of different land uses on rural communities
- The consequences of change in land use on our soil and water resources, and on the rural environment as a whole.

We undertake research for the Scottish Office, other agencies of central and local government and private contractors.





MLURI

The Macaulay Land Use Research Institute

Craigiebuckler, Aberdeen AB9 2QJ

Funded by the Scottish Office
Agriculture and Fisheries Department

ANNUAL REPORT 1992

Research Stations
Glensaugh, Laurencekirk, Kincardineshire
Hartwood, Shotts, Lanarkshire
Sourhope, Kelso, Roxburghshire
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MLURI

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DIRECTOR'S INTRODUCTION

The Annual Report of the Institute is a means of informing the public and our clients about some of the work that is undertaken which is of direct relevance to their interests and aspirations, indicating something of our main scientific achievements and recording the significant events of the Institute's life over the previous year.

There can be little doubt that the most recent significant event for the Macaulay Land Use Research Institute (MLURI) was the official opening of the new headquarters of the Institute at Craigiebuckler by the Secretary of State for Scotland, the Rt Hon Ian Lang MP, on Monday 22 March 1993. This was a historic occasion as well as being the culmination of a long period of planning and development which began in 1985 when it was decided, by the then Department of Agriculture and Fisheries for Scotland (DAFS), to create a new land use research institute by merging the internationally acclaimed skills of the Macaulay Institute for Soil Research based in Aberdeen and the Hill Farming Research Organisation, based in Edinburgh. Since that decision was taken it has become ever clearer that it was a decision of considerable foresight, imagination and of direct relevance to the needs of the 21st century.

The establishment of laboratory and office accommodation for the staff of the Institute on one site has been crucial to achieving improved efficiency and creating a working environment in which interdisciplinary and multidisciplinary research can prosper. The benefits can not only be measured in financial terms, but also in terms of the progress we are making in integrating our activities towards achieving an effective programme of land use science.

The building of a sophisticated, state-of-the-art laboratory and office block has been achieved successfully over a period of three years by the skill and dedication of many people and the financial provisions made by the Scottish Office Agriculture and Fisheries Department (SOAFD, formerly DAFS) and the Trustees of the Macaulay Endowment. We acknowledge and pay tribute to the wide ranging and invaluable contributions made by the Project Director, Dr Peter Newbould; the Project Manager, Currie and Brown; the Architects, Baxter Clark and Paul; the Management Contractors, GA Management Ltd; the Structural Engineers, Ramsay and Chalmers; the Services Engineers, Donald Smith, Seymour and Rooley; and the Quantity Surveyors, R Armour and Partners.

While SOAFD contributed towards the greater part of the cost of the building, the Institute continues to benefit from the generosity of Thomas B Macaulay, President of Sun Life of Canada during the 1930s, whose forebears came from the Isle of Lewis. I am sure T B Macaulay would have been pleased with current developments: he would have appreciated the remit of the Institute which bears his name and which addresses issues affecting directly the social, cultural and economic circumstances of the people for whom he had a particular concern, the people who constitute the basis of rural communities throughout the world: which brings me to the next most significant and recent event in the life of the Institute, the Land Use Science Conference held at our new headquarters on 29 and 30 March 1993.

This conference afforded the opportunity to hear from researchers involved in land use science, addressing issues which will be of importance and relevance to the development of the rural areas of Europe into the 21st century. It was an opportunity to begin to define more clearly the research that is required to aid decision-making at the farm, regional, national and European levels within the context of meeting rural industrial, social, economic and environmental objectives. The overall outcome of the workshops and conference discussions highlighted and confirmed the need for the continued development of more interactive decision support systems and information technologies, underpinned by relevant interdisciplinary research among the earth, biological, socio-economic and environmental sciences. It is this approach which lies at the heart of the Macaulay's research programme and which is reflected in the way we have reported our research in this issue of our annual report.

In 1987, when the new institute was created, it was implicit within its remit that the programme of work should include those aspects of economics research most relevant to land use policies and management with particular emphasis on the consequences of land use change and its impact on the environment. The research article on economics research outlines our current approach to meeting this requirement and how this relatively small but important activity in the Institute relates to other components of our programme.

A strong feature of current Government and EC policy with respect to agricultural land use is the belief that care for the environment need not conflict with efficient food production and policies have been introduced which aim to meet both of these objectives. Part of our programme, therefore, has focused particularly on the management of semi-natural vegetation, and the impact of agricultural activity on wildlife and water quality. We report on some of this work in the article 'Meeting Agricultural and Environmental Objectives'.

As part of its policy to encourage a reduction in the land used for agriculture, Government has introduced a number of schemes which together aim to increase the land devoted to the establishment of trees by some 33 000 ha per annum. We have responded by increasing the proportion of our research programme on plant-soil relations to address aspects of tree physiology in the context of tree-soil interactions, nutrient cycling, carbon partitioning and the rhizosphere; there are also strategic-applied projects which examine various forestry options, such as agroforestry, biomass production, and practices concerned with second rotation management; a substantial part of the research in these areas is concerned with gaining a quantitative understanding of the impact of trees on the environment. An overview of the work in this area of our research is presented in the article 'Trees and the Environment'.

In the article 'Soil and Surface Water Pollution' the importance that we give to research on land use and the environment is further emphasised. The land which is used for agriculture, forestry, water catchment and recreation, and sustains the habitats on which our wildlife and the quality of the countryside depend, is also subject to varying degrees of pollution. Government continues to develop policies to safeguard the interests of people and their environment; through SOAFD it supports a strong basic and strategic programme of research in the Macaulay Institute so that these policies can be formulated with increasing objectivity.

The 16th T B Macaulay Lecture 'Science from the Centre' which is presented in full in this Annual Report was given by Professor W D P Stewart, Chief Scientific Adviser to the Cabinet: Professor Stewart emphasised the need for a sound scientific basis regarding the environmental issues of Scotland and the way in which research should be undertaken and managed to meet that need. He stressed the importance of people in relation to the balance that has to be struck with respect to living in 'harmony with nature, with our environment, and with industry'. These are precisely the aspirations which the research in the Macaulay is designed to support.

Our unique combination of skills, our integrated research programme and our superb facilities are attracting scientists from all over the world to undertake short or longer term research projects at the Institute on a wide range of topics relevant to land use science. We are particularly pleased to have established a varied range of collaborative projects with research organisations in almost every country of the EC; this involves an ever-increasing exchange of ideas and a broadening of our perspective of land use issues in Europe.

Postgraduate training has become another important aspect of our work. MSc students from a considerable range of subject areas undertake projects at the Institute as part of their course in Aberdeen University with which we have a close association and where many of our staff give lectures. At present we have also over 30 postgraduate students carrying out work for their PhD who benefit from working alongside our scientists on current or future land use issues.

The Institute has also a well established Resource Consultancy Unit undertaking contract and consultancy work focusing on the application of soil data to land management and environmental issues. A suite of sophisticated techniques is available to customers and, if required, the full resources of the Institute can be dedicated to contract or consultancy work of a confidential nature or for dissemination within the scientific community.

I hope that you find something of interest in this our fifth Annual Report and should you wish further information about our work and our services, please don't hesitate to contact us or visit us at Craigiebuckler; you will be most welcome.

T J Maxwell, Director

CONTENTS

Introduction

ECONOMIC FACTORS are important in the decisions of those who own and manage land, and land use responds not only to technological change but also to changes in prices and support mechanisms. In addition, land use change is frequently associated with environmental effects - for example, to landscape, habitats and water quality. Economics has an important role to play in the prediction and valuation of environmental change and in assessing how external effects may best be taken account of in the development of land use policies. Frequently this is best achieved by an integrated approach to research with an inter-disciplinary team covering both biological and economic aspects of a problem - a *modus operandi* that MLURI is ideally placed to achieve.

Much of the programme of the Institute is devoted to underpinning strategic issues in land use and providing decision makers with a more comprehensive information base. Examples of such strategic areas are the impact of climate change and the development of environmentally friendly farming policies. Economics has a contribution in developing models and methodologies which will assist decision makers to evaluate the outcomes of different land use strategies.

Research in land use economics is closely linked to policy needs and this reflects the high level of public intervention in land use. This occurs through a great variety of measures that impact on agriculture, forestry, the environment, and even recreational access to the countryside. Examples of income support, incentives and regulation abound: from the intricacies of the EC Common Agricultural Policy to incentives for tree planting on farms and proposals to designate national parks. The breadth of such intervention in rural businesses and land use reflects the great range of output that the countryside produces and the intricate knock-on environmental effects that a change in land use can produce. It also reflects a concern with the well-being of farmers and the fragile rural communities which often depend greatly on farming for their income. There is a recurrent need to evaluate existing policy measures by determining whether they achieve their objectives, whether they provide value for money, and what their socio-economic impact is, as measured by income, employment and population change.

Structure

For the past three years the Institute has had a small economics input to its research programme as part of the Land Use Economics Unit, operated jointly with the Scottish Agricultural College, Aberdeen. From April 1992 a more substantial investment has been made in a new Environmental and Socio-economics group which should establish a critical mass in economics research. There remains considerable scope and a need to develop collaborative work with other Scottish institutions. To achieve this, links have been strengthened with the Universities of Aberdeen and Stirling (through joint supervision of research students) and with the University of Edinburgh (through the appointment of Professor Barry Dent as a consultant to the group).

To date, the research of the Land Use Economics Unit has concentrated on the appraisal of specific land use and forestry policies, economic aspects of environmental issues (including acid rain) and in understanding the effects of social and location factors in farm diversification and the uptake of environmental initiatives. Some selected results from this research are described below.

Evaluation of forestry policies

Afforestation of agricultural land has produced the most significant land use change in Scotland in recent decades and the environmental effects of this planting have been profound. Accordingly a considerable amount of research effort has been devoted to the assessment of forestry policy, in terms of identifying opportunities for planting, evaluating the grant structure and incorporating of a greater degree of environmental evaluation into policy. Central to much of this work has been the development of a MLURI forestry investment model which calculates the financial benefits from new planting at any site in Scotland where a set of site characteristics are available. The model has been applied to the whole of Scotland by using the Institute's National Inventory Point (NIP) database. This has identified the location and area of unplanted land where forestry is competitive with agriculture on the basis of expected forestry returns and agricultural land prices (Figure 1 on page 4). Investment potential is greatest on land of moderate agricultural capability (for example, Land Capability Classes 4 and 5) but where tree growth rates are above average and thinning is possible due to low windthrow risk.

Economics has rarely featured as a discipline at agricultural research institutes in the United Kingdom, yet MLURI is expanding its economics capability as an essential element in the overall programme of land use research.

Why is this?

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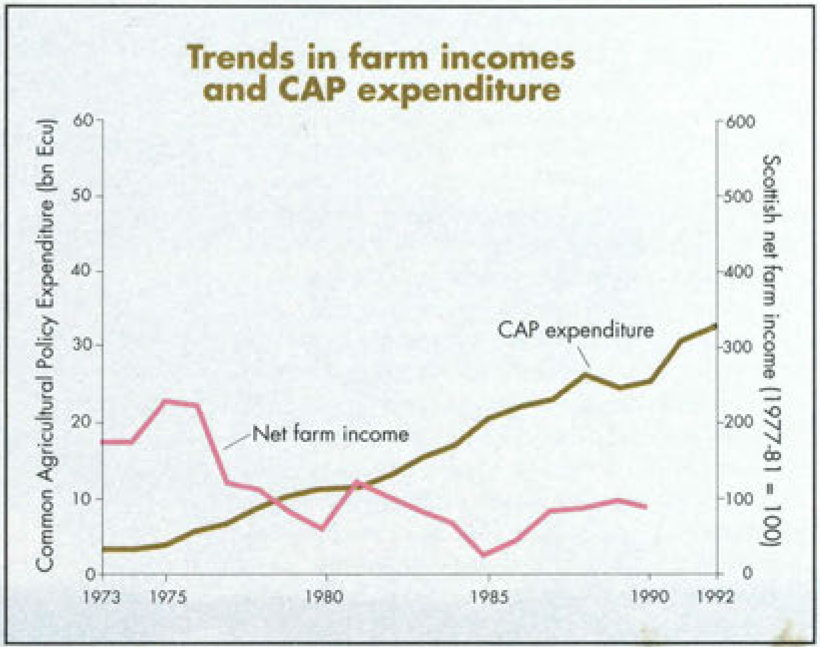
The rapid rates of afforestation in the Scottish uplands have led to increasing concern with the environmental effects of forestry on water quality and semi-natural habitats. Indicative Forestry Strategies are now being developed for each Scottish region in order to indicate the environmental sensitivity of new planting and hence shape the location of further afforestation. We have appraised the published strategies for a number of regions in the context of likely commercial planting pressure. Investment potential has been found to be proportionately higher in areas designated as Sensitive for new planting, due primarily to low land prices, and this could lead to a conflict between environmental and commercial interests. One method of shifting planting interest to less sensitive areas on better quality land is to redesign the payment differentials and the MLURI investment model has indicated how this could best be achieved.



The focus for forestry research is now more firmly on environmental impacts. The investment model has been adapted to allow cost-benefit appraisal of public investment in forestry, accounting for those recreational and environmental effects for which valuations can be made. This version has been used to investigate replanting strategies which are especially relevant now that much planting in the early post-war years is reaching clear-fell stage. Site types have been identified that fail to produce the government required rate of return of 6%, after taking into account all the measurable non-market benefits including recreational value and carbon-fixing (Figure 2 on page 4). It is difficult to justify public investment (direct or through planting grants) for the replanting of these sites but further research is needed to identify how the sites may best be used in the future.

Achieving conservation objectives

Where government wishes to change land use in order to achieve a specified economic or environmental objective it has a range of approaches which might be considered. In collaboration with economists in the Scottish Agricultural College and Manchester University we examined alternative approaches to achieving conservation objectives in the countryside. Nine of the most important policy instruments used in achieving landscape and nature conservation were evaluated. These were :

- management agreements (individually negotiated with landowners)
- standard incentive payments (as used, for example, in Environmentally Sensitive Areas)
- public land purchase
- grant-aided land purchase
- capital grants
- capital tax relief
- cross-compliance (in which agricultural support is dependent on adherence to a conservation prescription for a farm)
- covenants

The most obvious framework for the comparison of these instruments was cost-benefit analysis. In this, the costs and benefits associated with the application of each instrument are calculated and the net welfare change attributable to the instrument is calculated. However, valuation methods for non-market goods (such as environmental improvement) are not well developed and

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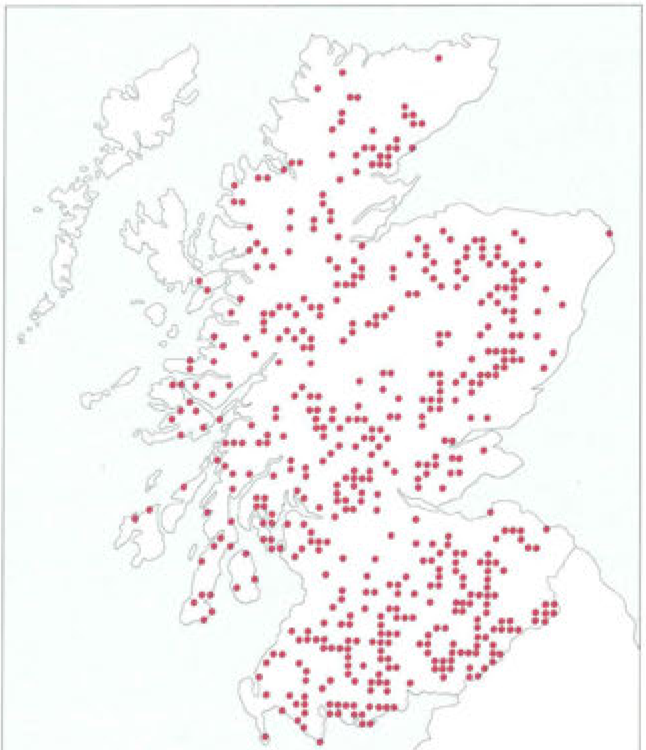

Figure 1. Distribution of unplanted land where forestry is competitive with agriculture.

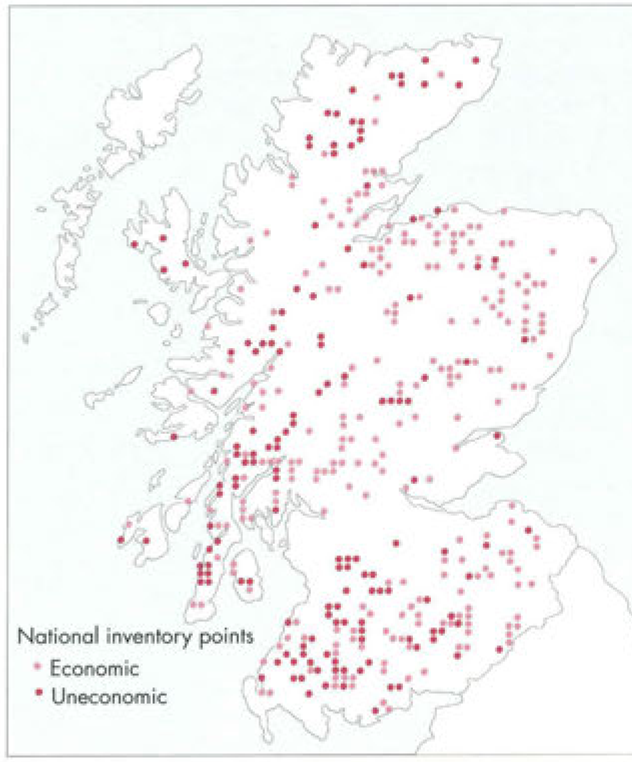

Figure 2. Distribution of uneconomic replanting in Scotland (under central assumptions and values).

this approach was therefore impracticable. To circumvent the valuation problem a number of different criteria such as cost efficiency, monitorability, timeliness, and targetability were established and each instrument assessed against each criterion. This was done both using the theoretical characteristics of the instruments and by examining the performance of instruments in a range of situations in which they had been applied. It was found that no simple ranking could be made - different instruments performed more or less well according to the criterion in question. For example, on cost efficiency alone, direct or grant-aided public purchase of land often proves to be a highly cost effective policy as compared with many other approaches. However, if public intervention in the land market is politically or socially unacceptable then other methods of intervention would need to be examined. Instruments need to be carefully selected and targeted for maximum effectiveness. For example, cross-compliance has been proposed as a way of providing a basic level of environmental protection. Under this approach, which is not at present incorporated into policy, farmers would receive income support from agricultural policy measures only if they farm in an environmentally friendly way. While potentially effective for giving a minimum level of environmental protection, it is inappropriate for environmental enhancement or the creation of new conservation interest. Standard incentive payment systems were found to be much more effective for enhancing conservation interest and providing new landscape or wildlife features. Their increasingly widespread use reflects these desirable properties. It was concluded that specific conservation objectives are frequently best achieved not with a single instrument but with an appropriate mix of different instruments.

Incentive payments - Set-aside and Farm Woodlands

Although standard payments are used for conservation they are also widely used to effect other changes in land use, with set-aside and farm woodland planting being two examples. In such schemes, a set payment is made (usually per hectare) to farmers who adhere to defined farming practices (for example set-aside) or undertake specified investments (for example, tree planting). In the ESA scheme there are a variety of standard payments linked to a number of different activities associated with protection and enhancement of the environment. The standard payment concept could hardly be simpler and its voluntary basis makes it attractive to land managers since it leaves decisions firmly in their hands.

We have evaluated this type of policy instrument both in theoretical terms and as regards its performance in a range of situations. The payments can be viewed as compensation for the acceptance by a farmer for restrictions on normal farming practice or for the cost of additional investment. The approach does, however, suffer from a number of possible disadvantages on efficiency grounds. Some farmers will be over-compensated, in the sense that they would enter a Scheme at a lower rate of payment, and the higher the target uptake level (and corresponding payment level) the higher the over-compensation that occurs. It is the prospect of gaining additional income from payments that attracts many farmers into such schemes. In evaluations of the Set-aside and Farm Woodland Schemes, however, this inefficiency does not seem to have been too serious. The table shows the payments made to farmers under the two schemes and their income foregone by converting the land to a new use. On average, farmers

NET INCOME EFFECTS ON FARMS

	Annual payment (£ per ha)	Farm income foregone (£ per ha)	Net annual income (£ per ha)
Farm Woodland Scheme			
Lowland	190.0	239.6	-49.6
All land	138.7	162.5	-24.2
Set-aside scheme			
Fallow	191.2	261.3	+5.4
Non-agricultural use	149.6	106.6	+158.9

PUBLIC EXPENDITURE EFFECTS

	Exchequer cost (£ per ha)	Exchequer saving (£ per ha)	Net Exchequer cost (£ per ha)
Farm Woodland Scheme	157.5	99.3	58.2
Set-aside Scheme	169.3	137.6	31.7

Net income and UK public expenditure effects of Set-aside and Farm Woodland Schemes in Scotland (per year, 1988/89 data).

planting trees suffered an income loss but this was offset by enhanced amenity, sporting and other benefits from woodlands. Farmers setting-aside land into fallow achieved a small income gain on average, whereas those establishing non-agricultural enterprises (for example, golf courses, riding schools) benefited more.

While farm income effects are important in terms of uptake and efficiency, the central criterion in evaluation is the net cost to the UK Exchequer in relation to the benefits achieved. The table above indicates the net annual cost per hectare after taking into account the Exchequer savings from reduced agricultural support on displaced activities when land is planted or set aside. In both cases the schemes had a net cost in 1988/89. The Scheme could only be justified in the economic evaluation by the benefits to wildlife and landscape that it produced. However, there were difficulties in objectively valuing these benefits because economic valuation techniques for environmental goods are not well developed. It will be part of our future programme to research how relevant valuation techniques might be developed.

Countryside access

Not all land uses earn an income from the market or receive compensatory payments from government. Public access to land for recreational use is a case in point. There, damage and disturbance from public access may result in costs to land managers. As part of a Countryside Commission for Scotland study a survey of Scottish farmers and estate owners was conducted in order to determine the costs and benefits associated with recreational access. Virtually all estates and 70% of farms experienced recreational access, but there were marked regional differences. Costs from damage, disturbance and interference (including vandalism) averaged almost £1,800 per estate, rising to nearer £3,000 where access was substantial. However, when expressed on a per hectare basis it was farms that had higher costs and especially those in near-urban areas. The costs were very substantial in some cases. To some extent landowners were able to derive income from recreational activities but this was restricted to the more specialised types such as shooting, fishing, riding and orienteering. Walking and less specialised activities offered fewer income possibilities. The study explored the feasibility of establishing a standard payment incentive scheme to enhance recreational access provision in Scotland. Such a scheme appeared attractive as a way of targeting public expenditure to those situations where enhanced access offered most benefit to local residents or tourists.

Future developments

It is increasingly clear that one core area of public interest is the environmental impact of different land uses and the assessment of alternative policies for environmental protection and enhancement. We aim to develop the methods available for measuring the output of environmental goods and evaluating them. These will then be applied in the context of the appraisal of agricultural and environmental policy measures (such as Environmentally Sensitive Areas) with a view to identifying how new policy measures can best be structured and delivered. In addition to this environmentally orientated research there is a strong interest in identifying the economic and social impact of EC and government initiatives, and indicating where new measures might best be targeted. To achieve this a more locationally orientated approach will be needed and there is scope for using geographic information systems to facilitate spatial economic studies. The social element in this work will be particularly important both in terms of factors determining the uptake of new policies (such as extensification) and in terms of their socio-economic impact.

Acknowledgement

The studies described in this article benefited from collaboration with staff in the Scottish Agricultural College, The University of Aberdeen and the University of Manchester, and their contribution is gratefully acknowledged.

Meeting and Envi Objectiv

OUR COUNTRYSIDE provides, from some 80% of the land and a technically successful and versatile agricultural industry, a substantial part of the nation's food requirements. Over the centuries, landowners, farmers and foresters have moulded, indeed created, much of what we see and experience in our countryside. It is only in relatively recent times, as agriculture has intensified and produced food surpluses and forestry has expanded, that significant conflicts have arisen between those who depend for their livelihoods on output from agriculture and forestry, and those who have an interest in wildlife conservation, landscape quality, countryside access, recreation, pollution control and environmental quality.

The EC and the British Government have responded to this concern: they believe that care for the environment need not conflict with efficient food production and have begun to introduce policies which aim to meet both of these objectives. Since its inception in 1987 MLURI has developed a programme of research that has sought to provide information which allows these objectives to be achieved by those who own and manage the land. Part of the research programme, therefore, has focused particularly on the management of semi-natural vegetation, and the impact of agricultural activity on wildlife and water quality. The well-managed integration of such a diverse range of activities, however, requires a logical and rational approach so that land use options, planning and management can be explicitly examined. Research concerned with developing computerised decision-support systems on the one hand and developing alternative systems of production on the other are central to meeting such an objective.

Management of semi-natural vegetation

A substantial proportion of the land under agriculture is classified in the agricultural statistics for 1991 as rough grazing (70% in Scotland, 12.5% in England and 3.15% in Wales). Such land is used predominantly within hill and upland farms for the grazing of sheep and suckler cows. It is dominated by a mosaic of semi-natural plant communities that provide habitats which contain many species of plants and animals of high conservation value: some of these areas are protected by being designated Sites of Special Scientific Interest (SSSIs) and National Nature Reserves. Clearly, the management of these important natural resources and their utilisation by domesticated livestock have an impact on their conservation value as well as creating and maintaining the pattern and colour which the vegetation cover contributes to the scenic quality of our hill and mountain environments throughout the changing seasons of the year.

Our ability to manage semi-natural vegetation in a manner which is acceptable to both agriculturalists and conservationists is dependent upon providing information from research on a range of topics, a selection of which are described in this article.

Understanding the impact of foraging strategy of herbivores grazing semi-natural vegetation

A major limitation in our ability to manage hill vegetation to meet agricultural, amenity and conservation objectives is our lack of understanding of the foraging strategy of herbivores, both within specific vegetation communities and when given a range of communities to choose from. Hill vegetation varies in its species composition, structure and digestibility. Previous research at MLURI (Hodgson *et al.*, 1991) has shown that the nature of the vegetation community determines the nutrient intake which herbivores can achieve. One of our research aims is to develop and test a generalised theory for the foraging strategy of herbivores grazing mosaics of indigenous hill vegetation.

Current research is examining the effects of differences in sward height and quality on the foraging behaviour and diet selection of sheep and goats grazing a relatively simple two-component system of indigenous grasses comprising a mosaic of *Nardus* and *Agrostis-Festuca* vegetation communities (Tables 1 and 2 on page 8); the aim is to gain a greater understanding of the factors affecting vegetation community choice. The results of these studies show that the preference sheep have for communities depends upon the relative nutrient intake rates on those communities. Sheep show a preference for the *Agrostis-Festuca* community, whereas goats show a preference for the *Nardus* community. Although the data are still in the preliminary stages of analysis, this differential preference probably reflects species difference in intake rate on the two communities. Future research will look at the factors affecting move-

> The type of landscape and wealth of flora and fauna to be found in the British countryside is an asset which is much valued by both the rural and urban dweller.

ment and sampling by sheep foraging across vegetation communities distributed as patches within a mosaic.

Generally, however, it can be concluded that *Nardus stricta* (moor mat grass) is a tussock grass which is avoided by sheep. When it is not grazed it can become the dominant species, leading to a reduction in plant species diversity and a decline in the nutritive value of the sward. Work in the Institute has shown that, unlike sheep, cattle will consume *Nardus* if the grazing pressure is high enough; but at high grazing pressures, when a significant amount of *Nardus* is consumed, the level of performance from lactating cows and their calves is relatively low (Table 3 on page 8). However, any penalty in cattle performance may be offset by an improvement in the nutritive value of the sward for sheep (or other animal species). This is being examined as part of an EC-funded project on mixed grazing in which four countries are taking part. At this Institute, *Nardus*-dominant swards are being grazed either by sheep alone (ewes and lambs) or by sheep plus cattle (yearling steers) at two different grazing pressures. Early results are encouraging, in that after grazing for only one season when sheep and cattle were grazed together, levels of *Nardus* utilisation were higher and lamb weaning weights were 5 kg heavier than when sheep grazed alone. Thus, mixed grazing of cattle and sheep may offer scope for combining the agricultural objective of maintaining agricultural output, while at the same time increasing plant diversity and preventing *Nardus* dominance.

In some circumstances the foraging strategy of a particular species of animal can be used to advantage to eliminate plants which are of minimal agricultural and conservation importance. The soft rush *(Juncus effusus)* is often found in grassland in upland areas of the UK and may progressively dominate areas of pasture. Goats are willing to consume rushes even when grass is plentiful, and their use to control and reduce rushes has been examined.

Elimination of established rush tussocks requires the removal of at least 75% of the current season's growth for a minimum of two consecutive years. Offtake of rushes is the product of individual intake (which depends on the availability of the inter-tussock herbage) and stocking rate. High levels of rush offtake, however, need to be balanced with an acceptable level of nutrition and animal performance.

For example, from experiments conducted over a number of years it is possible to calculate that on *Agrostis-Festuca* dominant swards where initial ground cover of rushes is less than 3%, grazing by 30 mature non-lactating goats per hectare, at an inter-tussock sward height of 4-5 cm, from June to September annually, would eliminate the soft rush and animal performance would be maintained (Merchant, in press). Above an initial rush cover of 3% it is likely that mob-stocking with a minimum of 40-50 goats per hectare would be required to have a serious impact. The use of immature or lactating goats, at lower stocking rates and higher pasture allowance to provide adequate levels of performance and at the same time limit the spread of rushes or reinfestation from seed reserves, remains to be considered.

With the present state of knowledge it is necessary to augment experimentally derived information, such as that described, with computer models in order to predict the foraging behaviour of herbivores. The aim is to develop a model that will describe herbivore foraging within spatially and temporally heterogeneous ecosystems.

The theory of foraging strategy involving choices between plant communities which vary spatially and temporally is in its infancy. The general framework of optimal foraging theory has provided a starting point for the interpretation of simple rules derived from empirical work at MLURI which reflect the behaviour of herbivores when making choices about which community to forage upon. These rules have been used to describe the foraging decisions of ruminants in heterogeneous environments within a sub-model component of the Hill Vegetation Management Model developed at MLURI. This model describes the quality and seasonality of hill and upland vegetation communities which provide the vegetation resource upon which the ruminant feeds. Currently, however, the sub-model describing their foraging strategy is not yet able to describe that strategy in the complex spatially and temporally heterogeneous environments typical of the hills and uplands.

An alternative, largely heuristic approach, using an artificial intelligence rule-based system, has proved successful in a similar context to simulate the grazing of forest environments by moose (Saarenmaa *et al.*, 1988). This approach represents the ecosystem

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Treatment	Sward height Agrostis/Festuca	Sightings of sheep on Nardus community (%)		Proportion of Nardus leaves grazed		Mean length of Nardus leaves (cm) after grazing	
		July	Sept	July	Sept	July	Sept
Short Agrostis/Festuca	3	37.0	27.5	0.60	0.69	3.0	3.3
Tall Agrostis/Festuca	4.5	25.5	22.0	0.17	0.32	7.5	4.2

Table 1. Proportion of sightings of sheep on the Nardus community and grazing records for Nardus tillers on the short and tall Agrostis/Festuca treatment.

	Sightings of sheep on Nardus community (%)		Proportion of Nardus leaves grazed		Mean length of Nardus leaves after grazing (cm)	
Nardus treatment	**June**	**August**	**June**	**August**	**June**	**August**
Previously lightly grazed	24.5	22.5	24.6	17.1	10.3	6.5
Previously heavily grazed	39.6	31.0	38.3	27.3	6.4	5.1

Table 2. Proportion of sightings of sheep on the Nardus community and grazing records for Nardus tillers.

	Inter-tussock sward height	
	4-5 cm	6-7 cm
Cow live-weight gain (kg/day)	0.07	0.38
Calf live-weight gain (kg/day)	0.70	1.02
Proportion of tillers grazed (July)	0.86	0.61

Table 3. Effect of grazing pressure (defined as inter-tussock sward height) on cow and calf performance or Nardus utilisation.

as a hierarchical set of objects which can be examined systematically with respect to their mutual interactions and relative influence on the behaviour of the whole system. A geographic information system approach is used to represent the spatial distribution of foraging resource and the animal behaviour and foraging rules are encapsulated in an artificial intelligence system. Preliminary investigations of this approach show that it is likely to be ideally suited to describing the multivariate nature of the foraging strategy of ruminants in hill ecosystems: it is being developed in collaboration with the Wildlife and Fisheries Science Department of Texas A & M University.

The impact of grazing on plant physiology and the consequences for vegetation dynamics

Sustainable plant growth after defoliation by grazing animals relies upon internal cycling of nutrients, particularly when plant growth is constrained by low soil fertility in extensively managed hill and upland pastures. Under such conditions, the uptake of nutrients from soil can be restricted as a result of reductions in growth of roots and their ability to forage for nutrients. Information on the effect of selective defoliation, of both plant species and plant parts, on nutrient partitioning and internal cycling of nutrients, is required to understand plant competitive interactions which will ultimately affect the structure of plant communities.

A qualitative and quantitative understanding of the mechanisms of partitioning and internal cycling of nutrients and root-growth potential in relation to severity of defoliation and level of nutrient supply is being developed. The range of species chosen for the experimental programme differ in growth form and thus in their response to defoliation. Initial experiments have determined regrowth capacity of grass species of different leaf morphology growing in monoculture under a single nutrient and defoliation regime. Experiments with monocultures are quantifying internal cycling of ^{15}nitrogen in relation to post-defoliation leaf growth under different levels of nutrient supply. Mosaics of two species will be used to determine the effect of selective defoliation and differences in ability to acquire nutrients on leaf regrowth and the partitioning of dry matter and nutrients. Such work will be used to interpret some of the effects which are being measured in the field where swards are being subjected to different levels of nutrient stress and which are responding in relation to differences in location and the degree of extensification being practised.

It follows that with extensification, changes in species composition of swards occur, particularly those managed with lower inputs of nitrogen fertiliser. In these circumstances competition for other plant nutrients, such as phosphorus, becomes increasingly important. In hill and upland soils most of the phosphorus in solution is contained within organic complexes, but their forms and concentrations are not well characterised. From the point of view of plant nutrition, particularly on such nutrient poor soils, it is important to have more information about these complexes and their dynamics in solution. The organically complexed phosphorus pool is often larger than the inorganic pool and may be an important source (directly or indirectly) of plant-available phosphorus. Nuclear magnetic resonance (NMR) is a non-destructive technique which can provide detailed information about chemical structures. Most of the speciation techniques used to date have been chemical and it is suspected that these cause changes to the compounds under study. Despite 100% natural abundance of the NMR responsive ^{31}phosphorus isotope, the principal limitation of 31P NMR is the inherent lack of sensitivity. Experiments using the NMR facility at Dundee University have shown the detection limit of the instrument to be of a few milligrams of phosphorus per litre

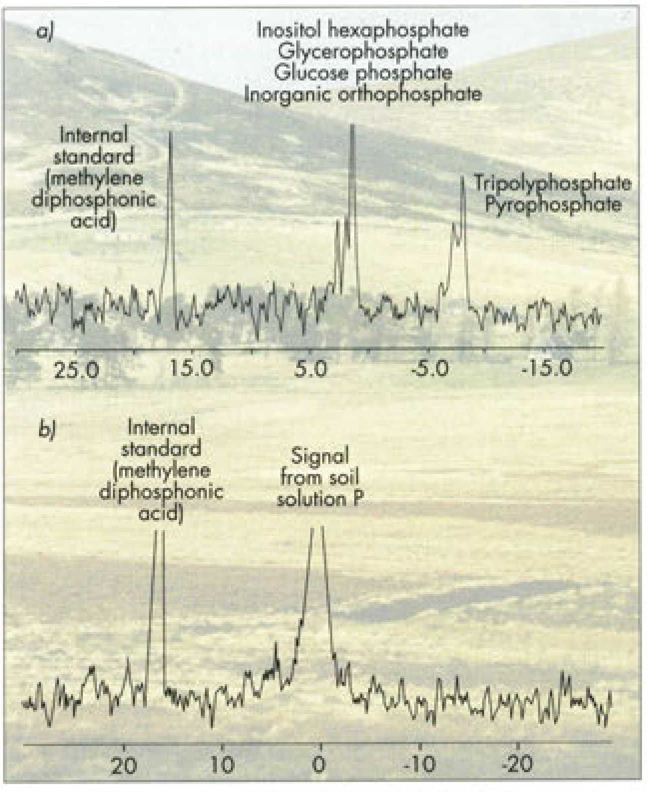

Figure 1. Phosphorus 31 Nuclear Magnetic Resonance spectrum of soil solution a) containing six different phosphorus compounds each at 10 mg/litre and b) concentrated (x100) by evaporation under nitrogen.

for a single speciation (Figure 1a). Methods for the concentration of soil solution to bring their phosphorus contents to near the determination limit have been investigated. The spectrum of a sample of concentrated soil solution obtained by simple evaporation under nitrogen showed a single broad envelope with a resonance position characteristic of orthophosphate and orthophosphate esters (Figure 1b). The total and organically complexed phosphorus contents of the concentrate were 25.3 and 9.7 micrograms per litre, respectively. Solutions concentrated by other means, including ultra filtration, gave similar results. The soil solution concentrate obtained by evaporation was shown by electron paramagnetic resonance to contain paramagnetic species of manganese, iron, carbon or oxygen, which may result in loss of resolution and broadening of the NMR signals. In addition signal broadening may also occur where phosphorus is associated with high molecular weight substances, which are known to occur in soil solution. Efforts to improve the resolution, and thus information that can be derived, are continuing.

Another important component of the competitive interactions between indigenous plant species is competition for light. Understanding how a range of indigenous grasses respond to the varying conditions of light and shade in terms of their capacity for carbon assimilation and growth is important for modelling competitive interactions within grazed swards which ultimately affect the structure of plant communities. The aim is to obtain a quantitative understanding of how indigenous grass species respond to shade within sward canopies and its consequences for carbon assimilation, partitioning and growth.

The above research on plant physiology and ecology which spans both fundamental and strategic science is also pursued in the context of providing information towards the construction of mechanistic models to determine suitable pastoral management systems. The models aim to predict changes from one vegetation community to another as well as changes in species composition within vegetation communities. The former will be done using rule-based modelling and will include probabilities of change. The latter will be based on the functional attributes of both plants (nutrient acquisition, internal cycling, photosynthesis, etc.) and grazers (foraging strategy, intake, digestibility, etc.) and will provide qualitative predictions of the likely direction of change under a given grazing regime. An example of predictions of interest at the community level is the likelihood of change from heather moorland to grassland or to woodland. At the within-community level interest focuses on the likelihood of an increase or decrease in the cover of trees, coarse grasses, mosses or rare species of flora and fauna.

So far, such models have been constructed on the basis of a good deal of empirical information and knowledge. They nevertheless have proved useful not only in determining where the information gaps are, but also in providing immediately useful predictions about the effects of a given stocking rate and management system on vegetation productivity. The first step in making this prediction is to determine the percentage of the annual production of each vegetation type which is eaten by the grazing animals. This is the utilisation rate. A computer model has been built to do this for sheep in the hills of the UK. The model uses basic information about the site, for example, its climatic zone and the altitude and area of each of the main vegetation types. The model predicts annual and seasonal production of each vegetation type and, given the number and average weight of the sheep on the hill in each month of the year, predicts how much of each vegetation type the flock will eat in each month.

Figure 2 on page 10 shows how offtake from each vegetation type on a typical hill farm varies throughout the year under two different stocking rates. At 200 sheep per hectare (Figure 2a) the sheep eat largely grass over winter, but when the stocking rate is doubled (Figure 2b), the amount of grass available to them over winter declines and the sheep are forced to eat more heather. The utilisation rates over the whole year under the two stocking rates are given in Table 4. At 200 sheep per hectare the heather will not be adversely affected, but at 400 sheep per hectare the utilisation rate is sufficiently high that the heather may decline in cover over the years.

Vegetation type	Annual utilisation rate (%)	
	200 sheep/ha	400 sheep/ha
Species-rich *Agrostis-Festuca*	57	78
Species-poor *Festuca-Agrostis*	36	60
Pioneer heather	11	44

Table 4. The effect of doubling the stocking rate on the utilisation rate of three vegetation types on a typical hill site.

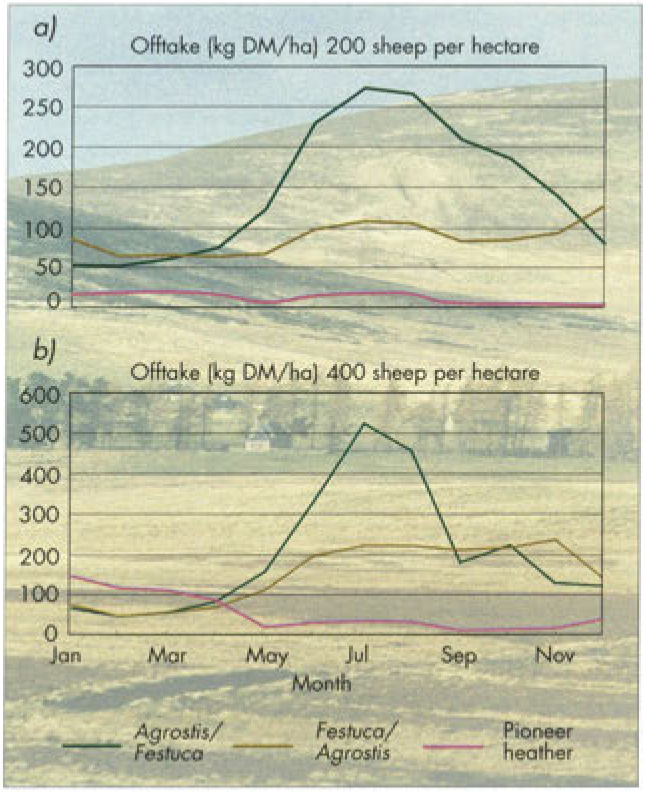

Figure 2. Offtake by the whole flock in each month from each vegetation type at two different stocking rates.

The model also predicts the quality and quantity of intake by an average sheep throughout the year. This information can be used to predict likely sheep performance and body condition. In the above example, the daily intakes at the end of January were 699 g and 640 g with 51% and 49% digestibility at the lower and higher stocking rates respectively. The sheep will therefore be in poorer body condition in the latter case.

Impact of agriculture on wildlife

Wildlife populations are distributed widely over farmland, woodland and forest and it is therefore not always either possible or relevant to consider wildlife in the context of a single land use such as agriculture. The range and type of wildlife habitat within these major land categories is very great: it includes the important areas of semi-natural vegetation, the crops of arable agriculture, broadleaved deciduous shelter belts and amenity woodland and the dominant conifer plantations of the state and economic forest industries.

Because conservation objectives are becoming more explicit in agricultural and forestry policies, there is an increasing need for information which describes the conservation value of different land uses. Traditional methods for conservation evaluation are most fully developed for individual sites, for example through procedures for SSSI designation. These methods, however, are not readily adapted to the provision of information for policy development and implementation since they cannot provide interpretation at broad regional scales and set locally important conservation sites in the wider regional, national and international context. The specific need is, therefore, for information and methods with which to address interests across large areas of land under a range of land uses. To date, the only evaluations of this type which have been attempted are inputs to Regional Indicative Forestry Strategies, these being directed towards a specific, single land use. There has been no attempt to produce a self-standing assessment of conservation interest nationally, regionally or for a local authority district, although this would have direct and immediate application in land use planning and environmental management.

One approach to producing such a wide area assessment builds on recent work in the Institute on habitat suitability and distribution mapping using data available from existing and historical sources such as field survey, atlas maps and classified satellite imagery (Aspinall, 1992). Methods have been constructed to take advantage of these data in the context of the spatial analytical tools offered by geographic information systems (GIS). The focus is to provide objective methods for inventory, monitoring and evaluation for a range of conservation objectives. The approach is based on integrating spatial analysis with species biology through applying principles of landscape ecology. In this way, species biology is related to structural, functional and temporal elements of landscape. In the approach adopted, GIS is used to measure spatial heterogeneity by objectively describing structure in habitat data. This provides a spatial description of local environmental conditions as well as identifying logical associations across larger geographic areas using networks and mosaics of habitats. An individual site is, therefore, placed in its appropriate district or regional context on the basis of both its internal characteristics and its (geographical) position as a functional link in a wider network of environments and habitats.

Habitat data are derived directly from analysis of environmental data (thematic maps and satellite imagery) and wildlife survey data using an analytical Bayesian probability method implemented within a raster GIS. This has the advantage of discerning associations between wildlife and environmental data from which hypotheses describing ecological relationships can be identified and tested. The methods have been applied to wading birds and moorland and grassland habitats in part of Grampian Region, north-east Scotland, and to species and community distribution in relation to climate across the whole of Scotland.

More direct impacts of agriculture on some species of wildlife are evident, however, as a result of growing crops which wild herbivores may use as a major feed source. For example, shortly after the widespread introduction of low-glucosinolate varieties of oilseed rape into Europe, there was an increase in roe deer mortality coinciding with a severe winter and shortage of other food sources (Onderscheka *et al.*, 1987). To test whether the ingestion of oilseed rape is harmful to deer, feeding experiments have been carried out with both roe and red deer. In two different experiments, oilseed rape was harvested daily and fed *ad libitum* to individually penned animals, as 60%, 80% or 100% of the diet for up to 7 weeks.

Fields of oilseed rape near Forfar, Angus.

carried out in collaboration with the Rowett Research Institute to determine if red cells from Finnish Landrace sheep phenotypes which have abnormally low levels of the antioxidant co-factor glutathione, are subject to a greater free radical burden as a result of exposure to the brassica-derived haemolysin dimethyldisulphide (DMDS) (McPhail *et al.*, in press). Results from ESR analysis of DMDS-challenged cells indicate that despite large differences in glutathione status, the induced free radical load was not significantly different between the two phenotypes. However, analysis of antioxidant enzyme activity revealed that animals of the low phenotype had significantly elevated levels of superoxide dismutase, catalase and glutathione peroxidase. This indicates that Finnish Landrace sheep with a genetic predisposition to low glutathione status may resist oxidative stress by compensatory adaptation of other antioxidant pathways.

When oilseed rape was fed as 60% of the diet, the roe deer developed a mild haemolytic anaemia after 2 weeks, but recovered by the end of the 6-week feeding period. None of the deer showed any other symptoms of ill health. However, roe deer were unable to tolerate a diet of 100% oilseed rape for more than a few days, although a diet of 80% oilseed rape is unlikely to lead to mortality in an initially healthy animal. Red deer are able to tolerate a diet of up to 100% oilseed rape for at least 6 weeks. Further work is planned to investigate the different susceptibility of roe and red deer to the toxic effects of oilseed rape.

Substances in plants which cause mild toxicity, induce a reactive physiological or behavioural animal response but appear to be of no direct benefit to the plant, other than as a defence mechanism, are often referred to as secondary plant compounds. It is thought that they are important in some circumstances in determining the foraging behaviour of both domestic and wild herbivores. A fundamental understanding of the physiological and biochemical processes involved could lead to a more careful choice of gene selection in plant breeding programmes or choice of animal species to utilise such crops. For example, the ingestion of forage brassicas by ruminants can result in the depression of voluntary intakes, low growth rates and the occurrence of pathological conditions such as haemolytic anaemia (McPhail and Sibbald, 1992). Such effects have been attributed to the presence of sulphur-containing compounds although the mode of action at the cellular and molecular level is not fully understood. Recent work at MLURI using electron spin resonance (ESR) spectroscopy has shown that such agents may act by promoting the formation of highly reactive, oxygen-derived free radicals within the cell. Living systems have evolved complex antioxidant pathways to limit free radical formation and damage. However, variations in cellular antioxidant capacity can occur and this may dictate the susceptibility of different animal species and genotypes to dietary-derived free radical stress factors. Studies have therefore been

Impact of agriculture on water quality

Considerable scientific and public interest exists in the link between modern agricultural practices and the quality of surface- and ground-waters. High amounts of nitrate in drinking water in particular are giving cause for concern on public health grounds, but relatively little attention has so far been devoted to the role of phosphorus with regards to water quality. Where phosphorus has been linked with eutrophication problems it is often as a result of localised gross pollution incidents, but phosphorus in rivers may originate from a range of domestic, industrial or 'natural' sources. In this respect approximately 200 000 tonnes of phosphorus fertiliser is applied annually by UK agriculture. Despite the often high solubility of this material only a relatively small amount appears to be leached from soil. This is primarily due to the series of dissolution/sorption reactions which rapidly occur once the fertiliser has been applied. There is evidence (Figure 3) that leaching of phosphorus may occur as other soluble organic/

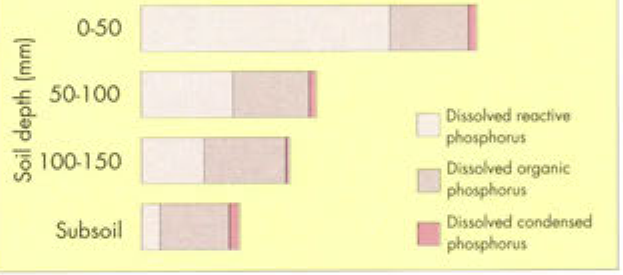

Figure 3. Variation in soluble phosphorus fractions with soil depth.

Fertiliser treatment		Phosphate	Nitrate
N	P	µg/ml	
0	0	0.025	0.20
1	1	0.06	0.74
2	1	0.04	69.2
Nitrogen	1 200 kg/ha/year 2 400 kg/ha/year		
Phosphorus	1 25 kg/ha/year		

Table 5. Influence of nitrogen and phosphorus fertiliser on soil solution chemistry.

polyphosphate components. One study has highlighted the possible importance of this organic-phosphorus fraction. From solutions isolated from soils with a range of pH and phosphorus status the organic fraction was a major (> 50%) component of the total phosphorus. In addition its concentration remained constant down the soil profile, in contrast to the orthophosphorus component which showed a sharp decrease.

Thus, nitrogen and phosphorus concentrations can vary considerably in response to the various chemical and biological processes operating in the soil/water system. The orthophosphate anion in contrast to nitrate is relatively immobile within the soil, being primarily the result of the greater affinity shown by surface sorption sites for the former. Any nitrate present in the soil is therefore susceptible to being leached and lost to the drainage system. The contrast in behaviour between nitrate and orthophosphate for solution removed from the topsoil of a long-term grass field experiment is shown in Table 5.

The regular annual application of nitrogen (as ammonium nitrate) and/or phosphorus (as triple superphosphate) influences soil solution chemistry especially as regards nitrate. It is possible to extrapolate observations from this experimental situation to the natural situation occurring within a river's system. The majority of a river's dissolved nitrogen load is present as nitrate. The concentration of orthophosphate is very small compared to nitrate (Table 6). Amounts of both nitrate and orthophosphate are greater for the River Don than for the River Dee in Grampian Region, Scotland. Concentrations increase downstream and appear to be directly related to differences in the pattern of land use in the river catchments (Edwards *et al.*, 1990).

The low levels of orthophosphate in rivers present major problems with regard to suitable methodologies of analytical detection limits. In an attempt to reduce this problem, an assessment is currently being made of the potential for using ion-exchange resins to concentrate ions preferentially. The resin membranes are placed in the river for various lengths of time and then analysed directly using X-ray fluorescence.

The upper reaches of the River Dee above Braemar.

	Concentrations (μg/ml)		Dominant land use (%)	
	orthophosphate PO_4^{3-}–P	nitrate NO_3^-–N	Cropland	Heathland
River Don				
1*	0.014	0.9	20	50
2	0.025	1.5	45	35
3	0.048	2.4	55	25
River Dee				
1	0.012	0.2	<3	60
2	0.007	0.2	<5	60
3	0.011	0.4	10	50
4	0.013	0.6	15	50

*Sampling sites progress from source (1) to estuary (3 or 4)

Table 6. Comparison of mean orthophosphate and nitrate concentrations (μg/ml) for various sampling points down the Rivers Dee and Don. (Chemical data supplied by North-East River Purification Board).

Land use options

The viability of agriculture will continue to depend upon the ingenuity of individuals to adjust the balance of use of land as between enterprises, introducing new technology and new enterprises or activities such as farm forestry, farming of goats and deer, or recreation and sport. In the future these will also have to be developed within a framework of known environmental impacts. The research programme therefore aims to develop decision support systems for assessing the land use options available to land managers and also to develop new animal production alternatives such as specialist fibre production.

Over the last five years, policies have evolved which are to encourage a greater proportion of land in upland agriculture to be converted to farm forestry and amenity woodland. This has implications not only for the immediate economic viability of a farm, but also for the longer term sustainability of the unit in terms of a balanced cropping regime, the spatial heterogeneity of wildlife habitats and therefore biodiversity. This requires a planning strategy which can often be complex. A decision-support model for the allocation of farming and forestry at the level of resolution of the individual farm is being developed (Butcher and Sibbald, 1991). The production potential of a range of agricultural enterprises, including livestock systems and arable cropping, and of a range of forestry alternatives, using conifer or broadleaved trees, is based upon a spatial description of the farm's physical resources. Individual crop yield modules are used to calculate costs and returns associated with each enterprise. These are then used to calculate a net present value for each crop, on those areas which have suitable physical resources, using standard discounting procedures for a discount rate and rotation length chosen by the user.

The land manager's objectives are represented by a set of decision rules relating to land allocation, for example stating minimum or maximum areas for particular crops. The rules are placed in a hierarchy which represents priorities, and may, for example, be used to set production or conservation priorities. The model runs through the hierarchy of rules to find solutions. These emerge as a range of land-use patterns, each of which satisfies the rules, with associated net present values. The manager may then re-run the model with a different rule hierarchy to assess the consequences of particular objectives.

The production of high value animal fibre constitutes an alternative use for land no longer required for food production. Animal fibre production enterprises have the potential for substantial import savings and offer a means of maintaining employment in rural areas; some types of enterprise would also accord with government policy on increased extensification, and some would bring aesthetic benefits in terms of landscape by the manipulation through grazing of certain vegetative types.

There are three main types of animal fibre production - from sheep, goats and camelids - which are potentially viable and merit research.

Wool is the most neglected agricultural commodity in the UK. Income from wool represents less than 5% of total returns, including subsidy, from sheep farming (Scottish Agricultural College, 1992) and this figure is likely to decrease in the foreseeable future. The opportunity to increase income from wool by changes in management or by genetic selection within existing UK breeds is extremely limited, and indeed any attempt to improve quality by breeding for finer wool is likely to reduce fleece weights and lead to lower returns.

Significant increases in returns require the production of high-quality wool which can be achieved only from certain types of Merino or Merino-crosses capable of producing substantial fleece weights with a fibre diameter of less than about 22 microns. Below this figure, the price increases rapidly for each unit decrease in fibre diameter. Research in the Institute identified the Saxon Merino x Shetland cross sheep as having the potential to produce this quality of wool (Saul *et al.*, 1992).

A small flock of Merino-Shetland crosses has been established at the Institute's Sourhope Research Station in the Scottish Borders. The mean fibre diameters of the 48 first-cross progeny sampled at 4 months of age (Table 7) were indicative of a quality which would

	No.	Fibre diameter (microns)		Fleece weight (g)	
		Mean	Range	Mean	Range
at 4 months					
Male	26	21.9	18.1-26.4		
Female	22	21.4	19.0-24.7		
at 14 months					
Male	6	19.1	17.6-21.4	2.8	2.3-3.2
Female	22	21.3	18.5-25.6	2.5	2.8-3.8

Table 7. Means and ranges of fibre diameter fleece weight of Merino-Shetland crosses as lambs or yearlings.

A Merino x Shetland ewe and lamb at Sourhope Research Station near Kelso.

command a significant price premium on world markets. The range in fibre diameter showed a potential for further improvement by selective breeding. The six ram lambs retained had exceptionally fine wool when shorn as yearlings (Table 7); the females showed no increase in mean fibre diameter from 4 to 14 months of age. The first-cross animals appear well able to cope with the climatically harsh hill environment at Sourhope Research Station and no management problems have been encountered.

Further improvements in wool quality and increases in fleece weight are being sought by selection within existing stock and by the crossing of the first-cross females with superior Merino rams, using semen imported from Australia. A planned element of the research will examine the economic potential of quality wool production from wether flocks of this genotype maintained under low-input extensive conditions.

The second type of animal fibre which merits consideration as an alternative enterprise is cashmere. Considerable progress has been made in improving the production of quality cashmere through a structured programme of cross-breeding and genetic selection, backed by basic research which has provided an understanding of the physiology of fibre growth and shedding in this species.

There is also interest in the UK in fibre production from South American camelids. Evaluation of quantities and qualities of fibre produced by llamas, alpacas or guanacos indicates that only the guanaco fibre has the characteristics which make it worthy of consideration as a possible alternative enterprise. Research on the biology of guanaco fibre production is currently in progress.

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Developments in farm woodland, Tomintoul, Banffshire.

TRE THE

Government policy on afforestation, farm woodland and farm forestry has developed quite radically since 1988, when the Chancellor of the Exchequer removed the fiscal advantages conferred on investors who were prepared to spend substantial sums on new planting; much of this planting took place in upland areas.

IN ENGLAND, this was followed in the same year by a decision that no further grants should be given for new planting in the uplands. Forestry policy was also influenced by the need to create incentives to remove land out of agriculture, in particular that contributing to surplus cereal production. Thus, since 1988, a number of schemes have been introduced, such as the Woodland Grant Scheme and the Farm Woodland Premium Scheme, which aim to increase the land devoted to the establishment of trees by some 33 000 ha per annum.

Because these policy initiatives have major implications for land use, MLURI has significantly increased its fundamental and strategic research on trees. The fundamental research addresses aspects of tree physiology, specifically in the context of tree-soil interactions, nutrient cycling, carbon partitioning and the rhizosphere. The strategic research examines various forestry options, such as agroforestry, biomass production, and practices concerned with second-rotation management.

The interactions of farm forestry and forestry with other land uses are also an important area of strategic research in the Institute. For example, the shelter effects of woodlands, silvopastoral systems and forests on animal behaviour and energy expenditure are measured, while the economic, social and environmental implications for land use change towards woodland and forestry establishment are examined, using landscape assessment and geographic information system technologies. Together, these initiatives culminate in the ability to examine the impacts of policy options from a range of viewpoints and on a range of activities.

While it is recognised increasingly that there are benefits other than the production of timber arising from the afforestation policies of Government, there is also considerable public concern about some of the potentially harmful effects that afforestation may have on the countryside. The Institute's research programme, therefore, has concentrated on developing a clearer understanding of the relationships between afforestation, atmospheric deposition of sulphur and nitrogen, and the implications of increasing acidification of surface waters.

ES AND ENVIRONMENT

Fundamental aspects of tree biology and nutrition

Despite the changes in fiscal policies and the introduction of new grant schemes, most afforestation, particularly in Scotland, continues to take place on nutrient-poor soils which contain high amounts of organic matter. An understanding of the mechanisms of organic matter turnover and nitrogen and phosphorus transformations in these soils is crucial in determining the appropriate management protocols for forestry crops on such land.

For example, planting spruce in mixture with pine or larch is prescribed as a means of establishing crops of Sitka spruce on nutrient-poor soils and avoiding inputs of nitrogen fertilisers. The mechanism of this effect is not known, but some mixtures of species appear to use the organic nitrogen of the soil more effectively than pure spruce. This has been demonstrated at a variety of different sites. In a study of the nitrogen dynamics beneath mixed species planted on *Calluna* heathland at Culloden forest, Inverness (Williams, 1992) the nitrogen capital of the humus and 15-year-old standing crop was 651 kg N/ha in Sitka spruce (*Picea sitchensis*)/Scots pine (*Pinus sylvestris*) stands compared with only 323 kg N/ha in pure spruce (Table 1 on page 18). A part of this difference is accounted for by the *Calluna* residues in mixture plots, but the balance could only have resulted from a transfer of nitrogen from the underlying soil by enhanced mineralisation of the soil organic nitrogen. Incubation studies in the field showed that net mineralisation of nitrogen in the humus was greater in the mixture plots. However, this result could have been a consequence of the better tree growth in the mixed plots, and not necessarily the cause. Similar results have been obtained on a deep peat beneath spruce/larch mixtures (Carlyle and Malcolm, 1986). Current work is directed at younger crops to discover if the enhanced mineralisation is the cause of the mixture effect. New experiments are using ^{15}nitrogen dilution techniques to measure rates of mineralisation and immobilisation. So far, measurements have been made in the laboratory at 10°C with humus from beneath mixed species 8 to 9 years after planting at Speymouth forest.

	Sitka spruce (kg N/ha)	Sitka spruce/Scots pine mixture (kg N/ha)
Tree crop	68	205
Humus	255	446
Soil	454	362
Total	*777*	*1013*

Table 1. Total nitrogen contents of the crop, humus and soil to a total depth of 10 cm in 15-year-old stands of Sitka spruce and mixed Sitka spruce/Scots pine stands at Culloden forest, Inverness.

Influence of soil physical conditions

Availability of nitrogen and phosphorus for plant uptake in upland soils is determined largely by the activity of soil micro-organisms. Soil physical conditions have marked effects on microbial activity and will influence nutrient availability by changing the rates of different nutrient transformations. New research is developing the use of undisturbed cores of peaty soils in laboratory experiments. In the first experiment, the physical conditions of moisture and aeration in the surface 5 cm of the peat cores were altered by the different water-table heights. Rates of nitrogen mineralisation and immobilisation were measured by the use of isotope dilution using ^{15}nitrogen labelled ammonium nitrate.

Water level (cm)	Air-filled pore volume (%)	Nitrogen-flush (mg/dm³ peat)
0	6.3	106
10	9.8	79
20	10.2	101
SED (n=6)		8.0

Table 2. Mean proportions of air-filled pore volume in the surface 5 cm of peat cores incubated at different water levels for 14 days and the total nitrogen extracted from the cores with 0.5 M K_2SO_4 after fumigation for 18 hr with chloroform.

Immobilisation in the soil microbial biomass was also measure from the flush of nitrogen extracted after fumigating samples with chloroform vapour. A significant effect of water-level on microbial-N was measured in the surface 5 cm of the core after 14 days (Table 2). This was attributed to the effects of fluctuations in the 10 cm water-level treatment on the activity and size of the microbial biomass at 5 cm depth. The implications of this effect for nitrogen dynamics in peat soils are being studied further.

Internal cycling of nitrogen

In addition to nutrients derived from mineralisation of soil organic matter, atmospheric deposition and fertilisers, trees rely upon the internal cycling of nutrients to meet their seasonal demand for growth. In order to develop appropriate management strategies for trees (particularly on more fertile soils) and to determine the impact of a range of environmental stresses (such as drought or nutrient deficiencies) on the sustainability of tree growth, it is necessary to understand the processes of internal nutrient cycling in a range of tree species. A project partly funded by the EC has been established in collaboration with the Instituto Superior de Agronomia (Lisbon) and the Universities of Salamanca and Bayreuth to study the processes of internal nitrogen cycling in a range of deciduous and evergreen trees with differing patterns of leaf and root demography in relation to nutrient supply.

Young trees are being grown in sand culture and their nutrients supplied by irrigation. In this way all the nitrogen supplied in any one year can be labelled with ^{15}nitrogen. The recovery of this

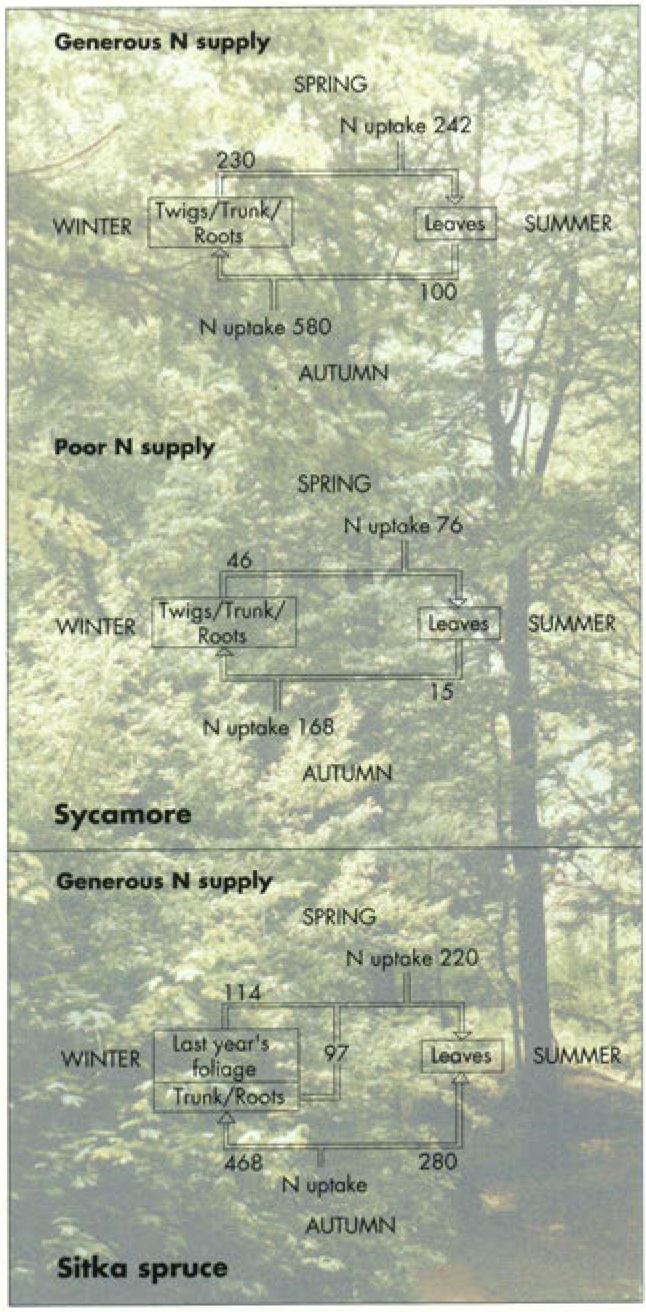

Figure 1. Seasonal internal cycling of nitrogen (mg/tree) in relation to uptake of nitrogen by roots.

N supply		^{15}N remobilised (mg/tree)	
Previous year	*Current year*	*Sycamore*	*Sitka spruce*
generous ^{15}N	generous N	238 ± 17.2	168 ± 22.0
generous ^{15}N	poor N	232 ± 20.0	209 ± 23.6
poor ^{15}N	generous N	46 ± 6.8	38 ± 2.2
poor ^{15}N	poor N	47 ± 11.0	42 ± 4.5

Table 3. The influence of nitrogen supply over two years on the remobilisation of nitrogen stored over winter for the growth of leaves in the spring.

tracer when trees are destructively harvested in subsequent years allows the processes of nitrogen storage and internal cycling to be studied in detail. The deciduous trees apple (*Malus domestica*), sycamore (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and birch (*Betula pendula*) have been studied, along with the evergreen Sitka spruce and eucalyptus (*Eucalyptus globulus*).

Figure 1 shows data for sycamore and Sitka spruce detailing the seasonal internal cycling of nitrogen in relation to nitrogen uptake by the roots. During leaf senescence in the deciduous tree, nitrogen was withdrawn for storage over winter. However, uptake of nitrogen by the roots in the autumn contributed more to storage than leaf senescence. Evergreen Sitka spruce stored nitrogen over winter in the roots and the foliage grown that year, with uptake in the autumn contributing directly to both these storage pools. In both species, spring remobilisation of nitrogen from storage pools occurred before rapid root uptake. The amount of nitrogen remobilised for spring growth was determined by the nitrogen supply to the trees in the previous year and was unaffected by the current supply (Table 3).

The partitioning and internal cycling of nitrogen in sycamore is being modelled in a collaborative project with the INRA Agronomy Station, Avignon, France. An existing model of nitrogen allocation, where sink needs (defined by carbon partitioning) were considered as driving forces for nitrogen partitioning has been extended to model withdrawal from senescing leaves, using a negative growth rate to allocate nitrogen back from leaves to other tissues. The model has been validated, using data from the second year of the experiment.

Carbon partitioning

An understanding and quantification of carbon partitioning in trees is fundamental to the modelling of tree growth and development. One aspect of carbon partitioning that is being worked upon is that resulting from water and nutrient stress, when a greater proportion of carbon is usually partitioned to the roots. The proportion of fixed carbon subsequently lost through respiration and root exudation may also increase when trees grow in harsh environments. Few, if any, process-based models of tree growth achieve an adequate representation of partitioning and loss of carbon, particularly through root exudation.

We are quantifying the effects of a range of environmental stresses on whole-plant carbon budgets including root exudation. For example, glasshouse experiments are determining the effects of nitrogen supply and coppicing upon the partitioning of fixed carbon within poplars and loss of carbon from respiring tissues.

The amounts and forms of carbon lost as root exudates are being assessed in several laboratory and field experiments. Such exudates affect soil fertility through interactions with micro-organisms. Studies using a farm forestry experiment at Lower Affleck farm, Grampian Region, have shown that Sitka spruce, hybrid larch (*Larixx eurolepis*) and sycamore all affect the cation contents in the soil solution (Table 4). Further investigations will determine how nutrient supply and the level of competition from weeds, or other trees, affect the amounts and forms of carbon loss from roots of different tree species.

Tree species	Ca	Na	K	Mg	Fe	Mn
	(μg/g DW soil)					
Sitka spruce	41.7	18.1	8.8	9.3	0.6	0.06
Hybrid larch	32.6	11.1	11.0	5.9	2.0	0.02
Sycamore	35.9	12.5	11.5	7.3	2.9	0.01
Fallow plot*	27.6	10.2	7.6	5.1	0.4	0.01
*May values						

Table 4. Influence of tree species on the cation contents of soil solutions from under three tree species at Lower Affleck, 5 August 1991.

Strategic issues, management options and some consequential effects

Many of our forests are reaching a stage of maturity when they will be ready for harvesting. The question now arises as to whether second-rotation forests should be established on these sites and if they are, how should they be managed. It is clear that the method of harvesting itself will have implications for future management. For example, increased mechanisation and utilisation of forest products has led to the development of new harvesting systems. Several of these systems now remove entire trees (excluding roots) from the site for processing at the road-side or outside the forest. The removal of entire crowns, rather than stems alone, increases

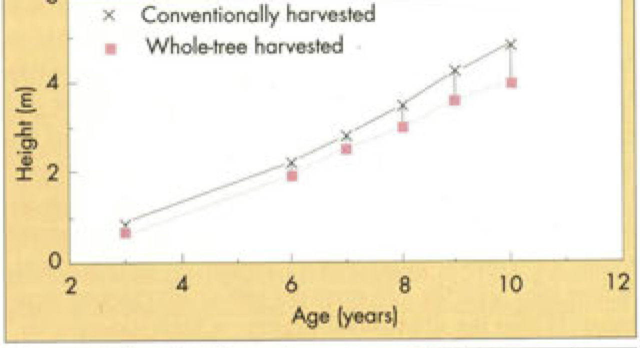

Figure 2. Effect of whole-tree harvesting on height in second-rotation trees.

	Component	Whole-tree harvested	Conventionally harvested	
		kg/ha	kg/ha	SED (n=4)
Dry weight	Foliage	7786	10380	1178
	Twigs	3763	5067	362
	Branches	4926	6621	447
	Stems	6942	10528	971
	Roots	7400	10300	-
	Total	*30817*	*42896*	-

Table 5. Effect of whole-tree harvesting upon component biomass in second-rotation trees aged 9 years at Kielder Forest, Northumberland.

the biomass yield by approximately 30 % in mature Sitka spruce. In contrast, nutrient removals may increase several fold (Miller *et al.,* in press).

Collaborative work with the Forestry Commission has shown that whole-tree harvesting on nutrient-poor soils in Kielder Forest, Northumberland, has reduced the height (Figure 2 on page 19) and dry matter production (Table 5) of second-rotation trees compared to those growing on adjacent sites which were harvested conventionally (Proe and Dutch, in press).

This work now aims to elucidate the mechanisms by which retention of residues on site improves tree growth. The relative importance of physical shelter, weed suppression and nutrient supply will be determined. Loss of nutrients beyond the rooting zone will also be quantified.

Agroforestry

The Government's financial incentives towards the establishment of forest plantations and woodlands on farms (farm forestry), has led to a consideration of silvopastoral systems. A network of silvopastoral experiments has been set up in the UK. The Institute is responsible, together with the Forestry Research Division of the Forestry Authority, for one of these experiments at Glensaugh Research Station. The treatments in the experiment, contrasting the growth of three tree species, are shown in Tables 6 and 7. There is also an agricultural control with no trees, and each treatment and control is replicated three times. The experiment has run for 4 years.

To date there are no significant differences between treatments in terms of pasture growth or animal performance. Sycamore and Scots pine were significantly taller at the end of 1991 in the silvopastoral treatments (where the trees are individually protected by tree shelters) than in the forestry controls (Table 6). However, hybrid larch, which had also been shorter in the forestry control plots than in the silvopastoral plots for the first three years, is now taller than the 100 stems per hectare silvopastoral treatment. Within the silvopastoral treatments, both sycamore and hybrid larch show a positive trend of height with planting density.

Tree planting density (trees/ha)		Tree height (cm) Sycamore	Hybrid larch	Scots pine
Silvopastoral treatments	100	200	218	-
	200	-	225	-
	400	234	251	141
Forest control	2500*	94	215	97

*all trees except those marked * are individually protected by tree shelters*

Table 6. Glensaugh silvopastoral experiment - tree height at the end of 1991.

Tree planting density (trees/ha)		Tree survival (%) Sycamore	Hybrid larch	Scots pine
Silvopastoral treatments	100	96	72	-
	200	-	79	-
	400	99	88	94
Forest control*	2500	100	100	99

*all trees except those marked * are individually protected by tree shelters*

Table 7. Glensaugh silvopastoral experiment - tree survival (%) during 1991.

Survival of trees over the year 1991 is less (but not significantly so) in silvopastoral plots than in the forestry control for both sycamore and Scots pine (Table 7).

It is believed that, on the silvopastoral treatments, the interaction of animals with trees, resulting from behavioural modification which causes the animals to shelter behind the tree shelters and to rub on them, is causing soil erosion and compaction around the trees. This effect will be exaggerated with low silvopastoral tree-planting densities. There appears to be a differential effect on tree species in terms of survival, hybrid larch being influenced more than sycamore. Hybrid larch and sycamore are both affected in terms of growth.

Short-rotation forestry

Despite there being a range of forestry and farm woodland grant schemes to encourage farmers to plant trees, a major disincentive to the establishment of farm woodlands is the time taken to see a return on investment. One solution is to manage trees on short rotations as fibre or energy crops. On better quality land, farmers may have the option of producing wood from single-stem trees or from coppice.

This research aims to quantify tree growth under coppice and single stem production systems established at our Hartwood Research Station. Detailed measurements of canopy structure, light interception (Figure 3) and photosynthesis (Figure 4) are being taken each year. Results will be used to model growth of different tree species, subjected to contrasting management treatments, in the context of short-rotation farm-forestry.

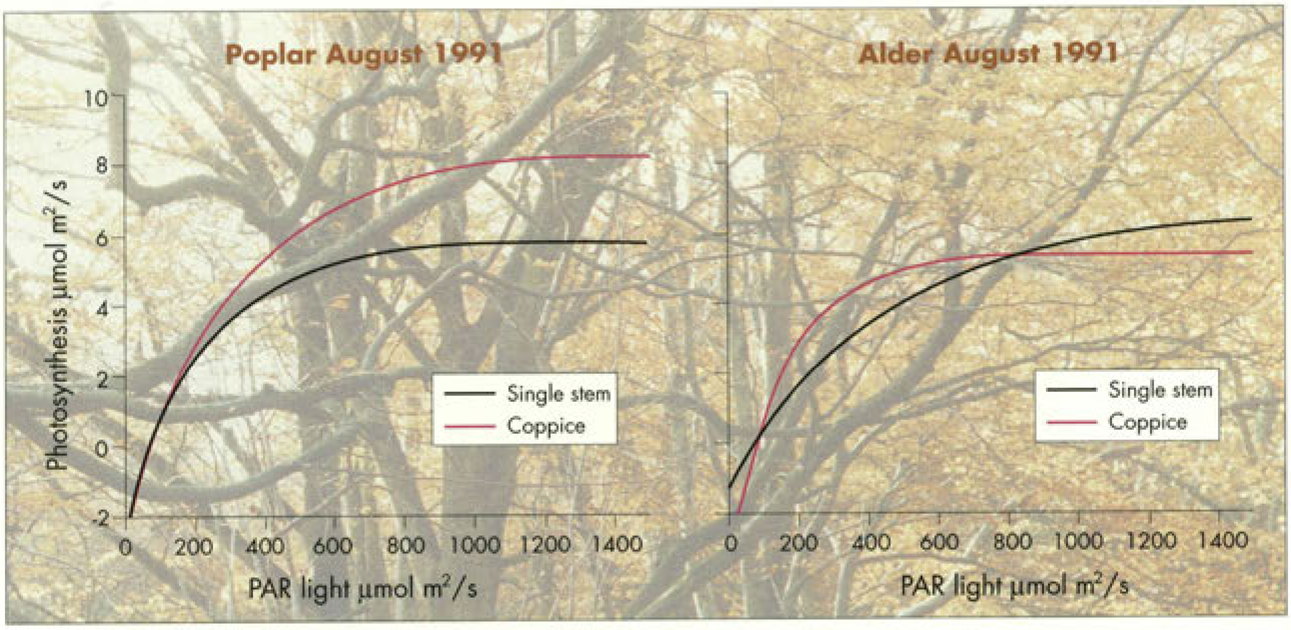

Figure 3. Proportion of incoming light intercepted by contrasting short-rotation forest canopies. (PAR = Photosynthetically active radiation)

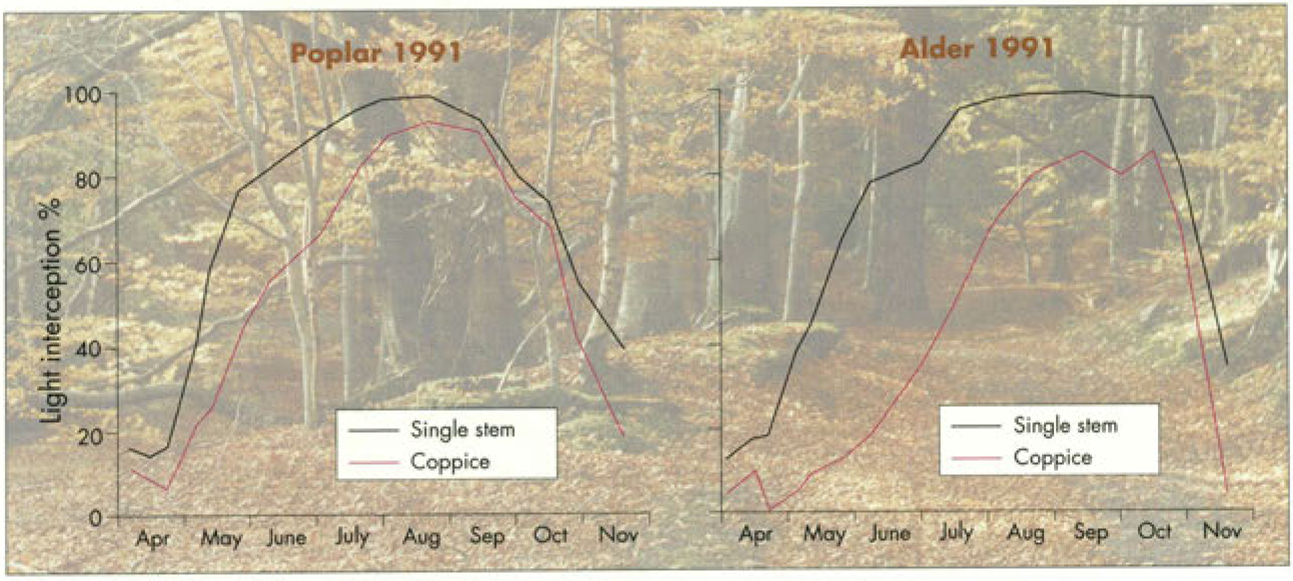

Figure 4. Photosynthetic response to increasing light levels in contrasting short-rotation forest canopies.

Tree-animal interactions

Farm-forestry and silvopastoral systems also have the potential advantage of increasing the amount of shelter provided to grazing animals. This has implications for the energy and financial costs associated with animal production systems and for animal welfare, as well as the cost-benefit of introducing trees into pastorally based agriculture.

The development of new techniques for measuring energy expenditure in the field allows the quantification of the effects of shelter in undisturbed free ranging animals for the first time. Different genotypes or breeds may react differently to the provision of shelter because of intrinsic differences in their metabolism or in their shelter-seeking behaviour.

This hypothesis was tested in an experiment in which the energy expenditure of the Scottish Blackface and Dorset Horn sheep was measured by exposing fully fleeced adult sheep to different degrees of shelter for three periods of a week during the winter of 1990/91. Shelter was provided by a combination of a shelter belt of trees and an artificial shelter. Energy expenditure was derived from carbon dioxide production rates, measured using an isotopic dilution technique. The isotope was infused into the animals and blood samples taken automatically so that the animals were undisturbed.

Mean CO_2 production rates (g C/day/kg$^{0.75}$ (SE))			
Treatment	Dorset Horn	Scottish Blackface	Mean
Sheltered	14.3(1.72)	18.2(1.72)	16.2(1.16)
Exposed	17.8(1.72)	20.5(1.72)	19.2(1.16)
Mean	16.0(1.16)	19.3(1.16)	

Table 8. Mean carbon dioxide production rates for Dorset Horn and Scottish Blackface sheep grazing exposed or sheltered plots.

The results given in Table 8 show that the mean carbon dioxide production rate was 19% lower on the sheltered than exposed areas, indicating the degree to which shelter can reduce energy expenditure. The Dorset Horn sheep increased their carbon dioxide production rate by 24% in the exposed compared to the sheltered area, while the Scottish Blackface sheep increased theirs by only 13%. The Scottish Blackface breed appears to be more adapted to exposure, perhaps because its metabolic rate is higher than that of the Dorset Horn. As well as quantifying the effects of shelter, these results are also important for developing an understanding of the factors affecting the foraging strategy of sheep.

Relationships between atmospheric deposition of pollutants, trees and stream water acidification

Vegetation, particularly mature trees, intercepts atmospheric pollutants in either gaseous, liquid or solid phases. Foliar adsorption and exchange processes as well as direct deposition of pollutants on to tree canopies can, therefore, lead to decreases in atmospheric concentrations of pollutants, with the potential for the transfer of these pollutants into and through soil/water systems. Mature coniferous trees, especially after canopy closure, have the capacity to capture both particulates and gases close to pollution sources, as well as to intercept marine-derived sea sprays near coasts. If these increased loadings are transferred to the soil, then this too could lead to soil or water acidification, especially where changes in the hydrological transport of these inputs through the soil are imposed by the drainage necessary for much of the recent new afforestation.

Currently, work is being carried out at both plot and catchment scale on the consequences of afforestation, including interception of airborne components. Sites range from Rumster in the north, via Loch Ard in central Scotland, to Galloway in the south-west. This research is in parallel with long-term monitoring sites at the Institute's research stations, so that any short-term changes due, for example, to tree planting or clear felling of areas, could be assessed against long-term observations.

Recent work at MLURI has linked mature Sitka spruce forests with the capture, and subsequent transfer, of atmospheric sulphate aerosols (Miller *et al*, 1991). These particular aerosols are possibly derived from sulphur dioxide combined with ammonia, and their interception by tree canopies can lead to increased concentrations of sulphate in throughfall under this species compared with other coniferous trees. This increase in sulphate, as a mobile anion, can in turn lead to both soil and surface water acidification, depending on its accompanying cation.

When compared with the foliage from mature Norway spruce, that of Sitka spruce contained larger concentrations of soluble sulphate. Indeed the total sulphur contents of Sitka foliage of all ages was also larger than those of Norway spruce (*Picea abies*). However, these patterns were not reflected in the contents of cysteine and methionine, the major sulphur-containing amino acids, and those of arginine, a main organic nitrogen component (Table 9). Larger amounts of these amino acids were detected in the Norway spruce foliage and surface litter (to 1 cm depth). However, below this depth, within the microbially-modified LF horizon, the Norway and Sitka spruce forest floors contain similar contents of the respective amino acids.

		Cysteine + methionine	Arginine
Norway spruce	Foliage	14.4	25.7
	Surface litter	48.5	65.4
	LF horizon	21.3	22.6
Sitka spruce	Foliage	11.1	19.2
	Surface litter	14.0	21.6
	LF horizon	24.5	22.7

Table 9. Contents of sulphur-containing amino acids (cysteine + methionine) and arginine (µg amino acid/g dry tissue)

Since previous work showed that the sulphur-containing amino acids are major components of the carbon-bonded fraction of plant and soil sulphur, the 'excess' sulphate extractable from Sitka foliage must be present either simply as sulphate anion, or as easily-hydrolysed sulphate ester.

Studies are also underway on the biological mechanisms by which atmospheric sulphate sulphur becomes incorporated into other soil sulphur fractions within forested ecosystems. This involves the activity of the microbial biomass which itself is one form of labile sulphur. Immobilisation into soil organic fractions is one route by which sulphate sulphur is transformed. In two studies, ester-sulphate accounted for 20-70% of the total sulphur content. This may be an important form in which sulphate becomes organically bound. In very wet or waterlogged systems, anoxic conditions can bring about microbial reduction of sulphate. Below the aerobic surface layers of peaty soils, sulphide concentrations may equal or exceed those of sulphate. Other reduced forms such as pyrite and elemental sulphur may also be generated and these are under investigation.

Much of the information currently being gathered from monitoring sites and from detailed experiments in the field and the laboratory is required to enhance our understanding of the processes involved in acidification as well as providing data for model validation and development. It is important that even at

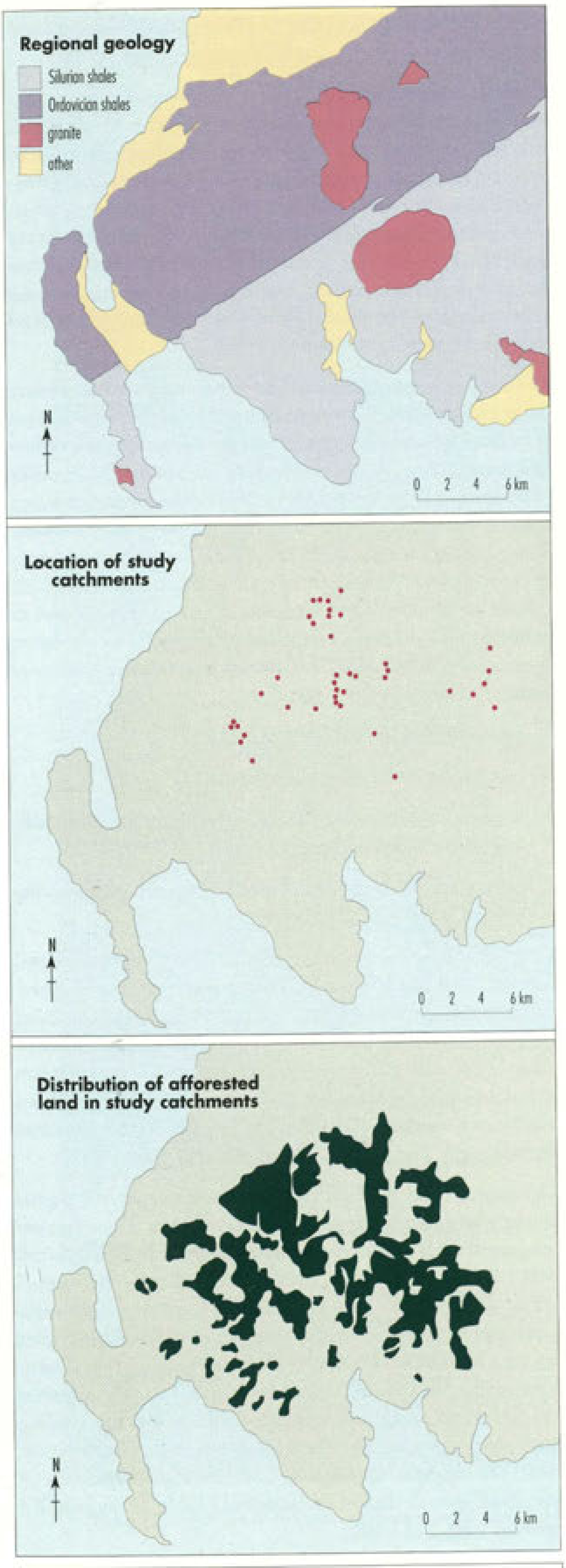

Figure 5. Galloway: study catchment and geology.

this stage we should be able to assess the regional impact of atmospheric deposition on tree crops.

For example, the Galloway region of south-west Scotland is classified as an acid-sensitive environment. Within the region, decades of acid deposition have resulted in acidification of surface waters and damage to fish populations and other aquatic organisms (Harriman *et al.*, 1987).

Extensive afforestation in Galloway has in many cases exacerbated the problem by increasing the total acidic loading through interception of pollutants (Miller *et al.*, 1991), and the removal of base cations from the soil by the growing forest. The water and soil quality model MAGIC (Model of Acidification of Groundwaters In Catchments) has been calibrated to water quality surveys carried out in 1979 and 1988. The calibration included detailed information on the afforestation histories for all the individual catchments (Wright *et al.*, in press). The location of the study catchments used in the regional analysis, the underlying geology, and the extent of afforestation (in 1988) are shown in Figure 5. Application of the model allows for investigation of the long-term regional response in water chemistry. Figure 6 shows the frequency distribution of regional alkalinity predicted by the model. The model predicts a large shift in the distribution from pre-acidification (1853) to recent times (1988). The observed and model-predicted alkalinities for 1988 are in close agreement (Wright *et al.*, in press). This shift in regional alkalinity is extremely important for aquatic life, as ALK=0 is the value where aquatic systems become damaged.

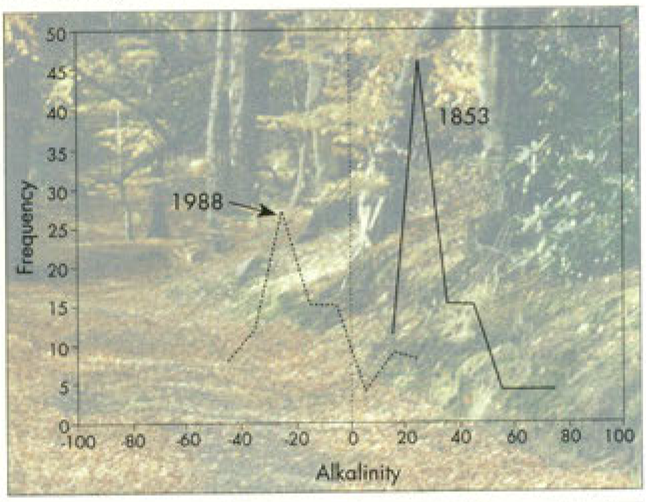

Figure 6. Frequency distribution of regional alkalinity predicted by the MAGIC model.

The calibrated model was used to examine the effect of future land use and deposition scenarios on water quality (Ferrier *et al.*, in press). The scenarios included constant or reduced deposition (based on the emission proposals of the convention on long range transboundary air pollution) and forestry strategies including the sequential removal of forests upon maturity (at 50 years) and the increased planting of all appropriate land within the catchments studied. Figure 7 shows the forecasted frequency distribution for the alkalinity of a number of lochs under two different scenarios for the year 2038. Scenario A represents constant deposition

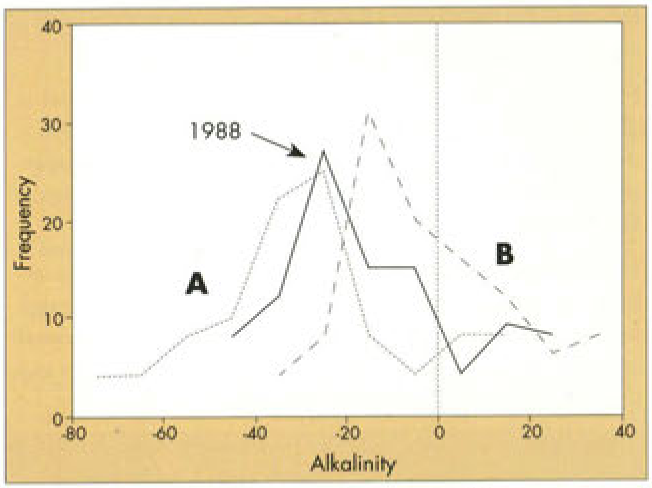

Figure 7. Frequency distribution for regional alkalinity as predicted by MAGIC for the year 2038. See text for details of scenarios A and B.

combined with further afforestation, and scenario B reduced deposition and sequential removal of the forest upon maturation. Only under scenario B is there a recovery of water quality within the region, although the majority of lochs are predicted to remain below the critical ALK=0 threshold.

The calibrated MAGIC model can be used to assess the regional effect of land use change and deposition both individually and in combination, and hence is an invaluable tool for policy development and management.

While the impact of acidification on water quality is naturally an issue which dominates discussions about the impact of trees on the environment, the direct effect of acid deposition on tree growth is also important, since acid deposition has also increased the amount of nutrient ions as well as pollutants in the atmosphere. Experiments have been performed to test the hypothesis that the treatment of Sitka spruce with acid mists containing ammonium and nitrate ions, as well as leaching ions from leaves, can deliver nitrogen by exchange across leaf surfaces, with consequences for internal cycling of nitrogen. Such an effect would fertilise the trees. The outcome of these experiments, performed during the 1991 season, awaits completion of $^{15:14}$nitrogen ratio determinations.

Policy impacts, economics appraisal and forestry indicative strategies

Between 1919 and 1988 forestry policy in Great Britain was driven by strategic needs. Similar strategic needs drove agricultural policy, and particularly in the post-war period to 1986, priority was given to the protection of prime-quality arable and the better hill land. As a consequence, forest expansion was channelled onto marginal agricultural land. Latterly, in the 10 years up to 1987, forest expansion was about 24 000 ha per year of which 21 000 ha was in Scotland. The total forest estate in Scotland is now 11 200 km^2 or 14.5% of the land area (Dargie and Briggs, 1991) which is still less than half the potential area as defined by the Land Capability for Forestry classification (Gauld *et al.*, 1989).

The post-war period was characterised by rapid forest expansion on marginal agricultural land in Scotland. Much of this land was perceived as having high conservation, recreation or other value (such as the generation of hydroelectricity). However, because forestry, like agriculture, lay outside the planning system (Mather, 1986) only the relevant regulatory bodies had powers over development control. This situation led to a degree of conflict, typified by the debate over the afforestation of the peatlands of Caithness and Sutherland (Nature Conservancy Council, 1987).

The conflict between forestry and conservation led to a more integrated approach to forest planning through the introduction of Indicative Forestry Strategies and the encouragement of forestry expansion in 'an environmentally acceptable way' (Scottish Development Department, 1990). It also led to an earlier recognition of the need for more basic information to inform discussions of countryside change and to provide a context for decisions on particular sites (Scottish Development Department, 1989). As a result, in autumn 1986, Scottish Office ministers decided to instigate a national land cover mapping programme to be based upon aerial photography. The aim was to produce a land cover database which would provide:

1. census of present land cover in Scotland
2. baseline for establishing past changes
3. baseline for monitoring change in the future and for modelling potential future changes
4. data source for case studies of specific areas and issues relating to particular types of land cover.

Aerial photography was acquired for the whole of Scotland between 1988 and 1989, at 1:24 000 scale. Photographic interpretation was carried out in the Institute, based upon a hierarchical classification system. Over 120 land cover categories were identified (Table 10) using conventional air photo interpretation techniques. Interpreted information was transferred from photo overlay to a standard 1:25 000 O.S. Pathfinder map base, and then digitised. The project was completed in August 1992.

The output from the land cover mapping project is a digital dataset with a nominal spatial resolution of 20 m. These data are being used largely within geographic information systems (Aspinall *et al*, 1990) to assist in the formulation of policy by the Scottish Office. The Scottish Office Environment Department, the main sponsor of the project, has, for example, now funded two pilot exercises to look at historical land cover changes in the Cairngorms and in the Central Valley of Scotland. The main objective was to examine actual land use changes in the context of prevailing rural policy instruments. The Cairngorm study (Gauld *et al.*, 1991) for example, highlighted both the rapid expansion of woodland and the decline in moorland (Table 11 on page 26) between 1946 and 1988.

Principal features	Major features	Main features	Sub-categories based on
Semi-natural ground vegetation	Heather and dwarf shrub heathland	Dry heather moor Wet heather moor Undifferentiated heather moor	Muirburn Rock outcrop Scattered trees
	Undifferentiated coarse grasslands	Undifferentiated coarse grasslands	Rock outcrop Scattered trees
	Smooth grasslands	Smooth grasslands with rushes Smooth grasslands with low scrub Undifferentiated smooth grasslands Undifferentiated bracken	Rock outcrop Scattered trees
	Blanket bog and other peatland vegetation	Blanket bog with dubh lochans Undifferentiated blanket bog	Erosion Scattered trees Mechanised exploitation Domestic exploitation
	Undifferentiated salt marsh	Undifferentiated salt marsh	
	Wetlands	Wetlands	Scattered trees
	Dune lands	Bare dunes Partially stabilized dunes Links with grassland Links with heathland	
	Montane vegetation	Undifferentiated montane vegetation	Rock outcrops
Woodland	Coniferous woods	Plantations Semi-natural	Mapped areas Lines of trees Clumps of trees
	Broadleaved woods	Broadleaved woods	
	Mixed woods	Mixed woods	
	Undifferentiated low scrub	Undifferentiated low scrub	
	Management features	Management features	Recently ploughed land Former woodland recently felled Open canopy young plantation
Agricultural land	Agricultural land	Improved pasture Arable land	Rock outcrop Scattered trees Scattered farmsteads
Farms and developed rural land	Isolated farmsteads and other buildings	Isolated farmsteads etc.	With trees With no trees
	Miscellaneous developed features	Factories, Airfields, Golf courses, Cemeteries	
Bare ground	Miscellaneous bare ground	Cliffs, crags & screes, Quarries, Bings, Paths, Hill roads, Water	Mapped areas, lines or points
Miscellaneous features	Built-up land		
	Transport features in a rural context	Road Rail	
	Cloud-obscured areas		
	Snow-obscured areas		

Table 10. Land cover features interpreted in the Land Cover of Scotland mapping project.

Sixty-one km^2 of 'present' woodland is located in areas which were moorland in 1946, representing a 14% loss of the total 1946 moorland area. The vast majority of 1988 woodland is coniferous

		Moorland	Woodland	'Other'	Total (1946)
	Moorland	318.35	61.13	16.29	395.77
1946	Woodland	6.30	88.60	5.98	100.88
	'Other'	9.91	9.96		
	Total (1988)	334.56	159.69		

Table 11. Matrix of change, moorland to woodland 1946-1988, figures in sq km.

plantation which has increased as a cover type from 10 km^2 in 1946 to 89 km^2 in 1988.

Whilst the national land cover project provides census information to support better informed debate and rural policy formulation, it has to be recognised that the information is limited by its scale. More detailed information on, for example, land use or ecology is being gathered through the National Countryside Monitoring Scheme, now sponsored by Scottish Natural Heritage, and the Countryside 1990 project being conducted by the Institute of Terrestrial Ecology (ITE) on behalf of the Department of the Environment. Both these programmes use a stratified random sampling approach. Very detailed information is collected on a limited number of representative sample sites, generally based on the O.S. grid (for example, ITE surveyed 508 1km squares for Countryside 1990 over Great Britain). Recognising the strengths of both approaches, MLURI and ITE are now pursuing a joint initiative to investigate how the land cover and ecological information from the MLURI and ITE surveys can be combined to provide an enhanced and co-ordinated land cover database for Scotland. This research is being funded by the Scottish Office Agriculture and Fisheries Department under their flexible funding arrangements.

While it is important that the Institute can critically assess the consequences of policy on historical land use change, it is equally necessary to develop models which predict likely consequences of present policies and analyse the potential for modifying policy to better achieve objectives.

In a current project, the water quality model MAGIC has been coupled with a spatial database. Water catchment sensitivity to changes in land use can now be mapped, and forestry planning policy, therefore, evaluated and its impact on water quality assessed. Digital representation of soils, terrain, stream network, land cover and land cover changes over a forty-year period for the River Feshie catchment in the Cairngorms was compiled in a geographic information system. Vertical weighting of soil characteristics for input to the MAGIC model was carried out for each soil type using horizon depths and bulk densities. Spatial aggregation of soil chemistries was carried out using three techniques for assessment of the catchment. These were, firstly, whole catchment proportions, secondly, flow pathway prediction derived from digital terrain data, and thirdly, analysis of proximity to streams. Changes in woodland land cover were used to re-assess the spatial weightings based upon exposure and forest edge effects.

Three hundred lochs across Scotland have been sampled and the spatial database and relational databases for those catchments compiled. Output from the water quality model was used in conjunction with the spatial database to produce a map of catchment sensitivity. This provides a new aid to the assessment of multiple sector land use planning which includes agriculture, and the forestry industry, against which an economic appraisal can be made.

An important component of economic appraisal is the return on capital invested in forestry. The forestry investment model developed in the Institute (Macmillan and Chalmers, 1992) appraises commercial afforestation schemes to identify the Internal Rate of Return (IRR) for capital invested, since this has a critical influence on the decision by both state and private sectors as to whether to invest in forestry or not. In this type of commercial appraisal, timber is the only major marketed output of forestry incorporated. However, forestry generates a far wider range of outputs for which no market exists, including recreational opportunities, carbon storage and biodiversity. Cost-Benefit Analysis (CBA) attempts to quantify, in money terms, the economic values associated with these outputs so that a clearer indication of the net economic benefit of forestry to society can be obtained. While considerable uncertainty surrounds many of the techniques and values used, research continues to develop the potential of CBA as a means of ensuring an appropriate balance between forestry and other land uses is achieved and that the right trees are planted in the right places.

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Mixed woodland on the upper Findhorn, Moray.

SOIL AND WATER P

SOIL AND SURFACE WATER POLLUTION may be the product of industrial or other activities often taking place at some considerable distance from where the pollution ultimately occurs. It can also arise directly from agriculture through the inefficient use of fertilisers, and it may involve forests too, insofar as trees may scavenge acidifying pollutants from the atmosphere, thus concentrating sources of acid deposition to soils and subsequently affecting the acidity and aluminium content of stream waters.

The public are becoming increasingly aware of the wide-scale damage that is being caused to the environment, and realise that the control of pollution is necessary if the quality and safety of our primary resources of soil and water, and the food that they produce, is to be assured.

Government continues to develop policies to safeguard the interests of people and their environment, and the Scottish Office Agriculture and Fisheries Department is supporting basic and strategic research in this Institute so that these policies can be formulated with increasing objectivity.

The land which is used for agriculture, forestry, water catchment and recreation, and sustains the habitats on which our wildlife and the quality of the countryside depend, is also subject to varying degrees of pollution.

Evaluation and risk assessment

Continuing industrial development, the concentration of people into major urban centres, and the continuing need to maintain the competitiveness of British agriculture, all give rise to issues which have an important bearing on soil and environmental pollution. The concentration and fate of heavy metals that have arisen from the application of sewage sludge to soils, the relative efficiency of nitrogen and phosphorus fertiliser use and the subsequent impact on stream waters and on estuarine and marine habitats all need to be evaluated and assessed both locally and regionally.

Land evaluation for sewage sludge disposal

Three million wet tonnes of sewage sludge are produced each year in Scotland. About three-quarters is currently disposed of at sea, but this method will be prohibited by 1998 (EEC, 1991)Disposal on land is seen as one of the main alternatives as sewage sludge contains organic matter, nitrogen and phosphorus which would be beneficial to plant growth. However, because sludge may also contain toxic heavy metals such as cadmium, copper and zinc, it is necessary to take into account many different factors in determining the suitability of the land disposal option..

Current research aims to:

- ☐ identify the principal climatic, topographic and edaphic characteristics and their interactive effects which determine the suitability of land for the disposal and utilisation of sewage sludge (Figure 1 on page 30).
- ☐ compile a draft classification for the suitability of agricultural land for the application of sewage sludge, using the Food and Agriculture Organisation (1976) methodology. A series of decision rules has been established for each of the environmental characteristics identified above, incorporating existing knowledge and taking into account current legislation. Examples of decision rules, using soil type, slope and topography are given in Table 1 on page 30.
- ☐ test the classification on a range of soil, topographic and climate datasets from Grampian Region to identify the location and extent of suitable classes (Figure 2 on page 31).

This work is being developed using a geographic information system and the analyses will address questions such as land availability and distance from sewage treatment plants.

The capacity of a soil to neutralise incoming acidity depends not only on the chemical status of the soil but also on the length of time that the soil solution resides within the chemically and biologically reactive soil horizons. This residence time is a function of the soil porosity and the antecedent moisture content. The soil macropores are important in determining the saturated hydraulic conductivity as well as providing preferential pathways for the movement of water and, therefore, pollutants, leading to the phenomenon of by-pass flow.

SURFACE
LLUTION

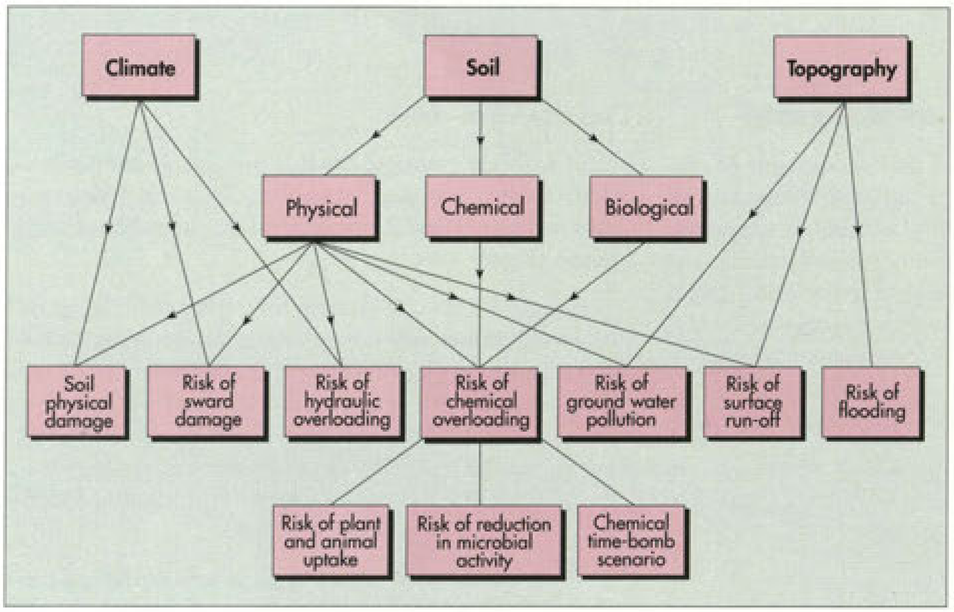

Figure 1. Relationship between environmental parameters and potential risks.

The HOST classification (Hydrology of Soil Types) provides a 29-class system of soil hydrological response based on the dominant pathways of water movement through the soil and highlights those soils in the UK where by-pass flow is important, thus indicating the soils where there will be little opportunity for the amelioration of polluted inputs. This classification, developed by the Institute of Hydrology, MLURI and the Soil Survey and Land Research Centre, provides a means of refining existing models of soil buffering capacity, which are based largely on soil chemical properties, and is applicable throughout the UK.

Current work is focusing on the need to establish more precisely where, when, and for how long, soils are in the saturated state, in relation to soil physical conditions and climate.

Nitrate loadings in surface waters

Modern agricultural practices have been strongly linked with increased nitrate loadings in surface waters. Nitrate loading (defined as concentration x discharge) which is, in turn, related to marine eutrophication, is a major environmental issue for countries bordering the North Sea. By 1995, EC legislation (EEC, 1980; UK DOE, 1987) will require a 50% reduction in such loadings, possibly achieved by the introduction of agricultural restrictions in nitrate-sensitive areas.

Few predictive studies have examined the relationship between agricultural intensity and nitrate concentrations on a regional basis. In simple terms, nitrate leaching increases as primary

	SUITABILITY CLASS/ENVIRONMENTAL RISK			
Parameter	Unsuitable/ unacceptable	Marginally suitable/ high	Suitable/ moderate	Highly suitable/ low
Soil type	Lithosols, peat Regosols Saline alluv. soils Rankers Rendzinas Peaty podzols Subalpine podzols Alpine podzols Saline gleys Peaty gleys Ground water gleys	The remaining soil types are classified according to the rules below		
Slope	>15° 11-15° where topsoil has >18% clay	11-15° where topsoil has <18% clay 7-11° where topsoil has >18% clay	7-11° where topsoil has <18% clay 3-7° where topsoil has >18% clay	0-7° where topsoil has <18% clay 0-3° where topsoil has >18% clay
Topography	Moderately-extremely rocky	Slightly rocky	Non-rocky	Non-rocky

Table 1. Excerpt from land suitability/risk assessment classification for sludge utilisation on agricultural land.

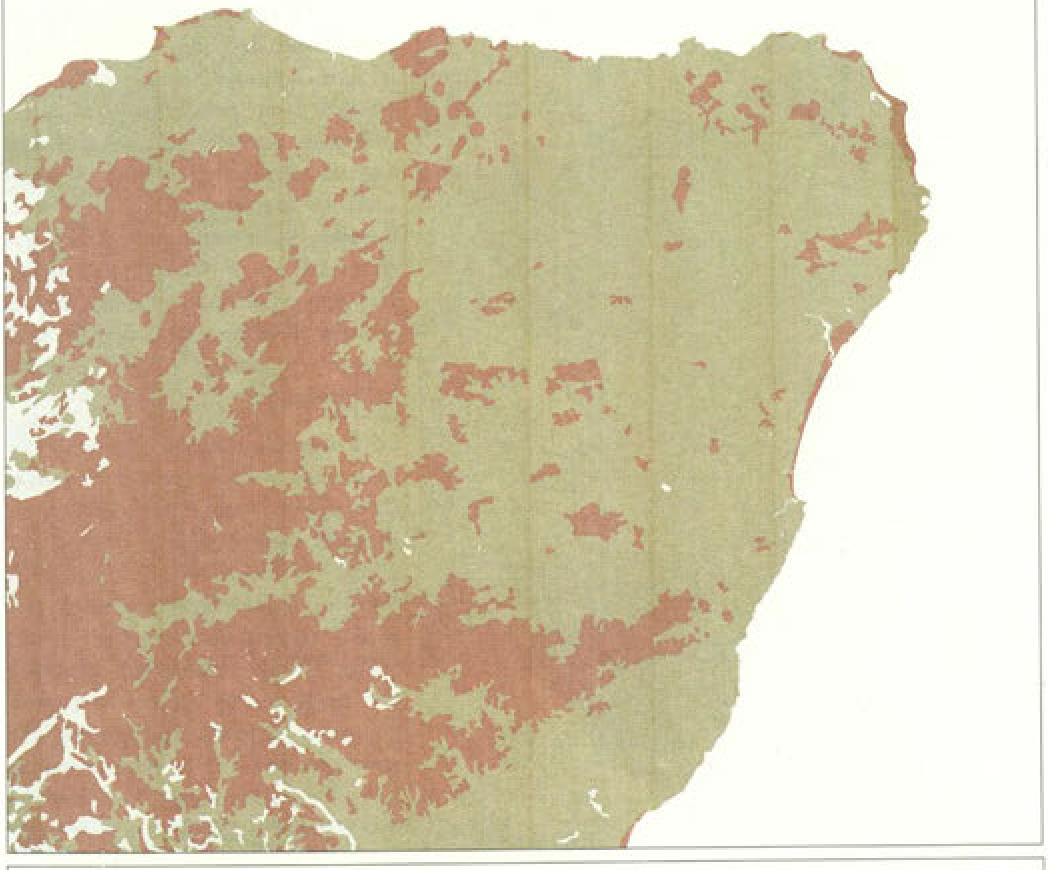

Figure 2. Land suitability, based on soil type only, for sewage sludge utilisation on land in Grampian Region. Areas coloured pink show unsuitable land.

Before this technique can provide an operational means of monitoring agricultural intensity and nitrate loading, further examination of national fertiliser practice, soil types and seasonal rainfall patterns are required. However, initial results put Scottish losses at nearly 60 000 tonnes annually, worth approximately £18 million.

land use changes from moorland to forest or grassland to arable agriculture, with variation due to time of year and site or soil characteristics. Preliminary analysis of data for Grampian Region has indicated that the type of land cover is probably of more significance than rainfall or soil type in determining nitrate concentrations in streams and rivers.

Grampian river catchment statistics linked with land cover classifications based on high resolution satellite data suggest losses of 1.6 kg N/ha/year from non-agricultural land and 29 kg N/ha/year from agricultural land (grassland, spring and winter crop combined) (Wright *et al.*, 1991). Individual catchment or site characteristics may account for some ±20% variation on these figures.

Low resolution (long-term) satellite data provide the means to extrapolate these losses nationally. In the case of long-term data, the classes produced cannot be attributed to pure land cover types, but to dominant types. Test area comparisons with high resolution data are made, agricultural class percentages assessed and nitrate losses thus calculated (Figure 3).

Pollution climate of Scotland

Although Scotland might be considered as being relatively unaffected by atmospheric pollution, soil and vegetation samples taken from sites across the length and breadth of the country show clearly, particularly in the central belt, the influence of industrial and other activities. This is well shown by the distribution of heavy metals. Thus, the lead and zinc contents of peaty soils are relatively low in two south-west to north-east transects in the north of Scotland, but increase markedly in similar soils in the Midland Valley with some (at present) unaccountably 'high spots' (Figures 4 and 5 on page 33). The soils in the most southerly transect also contain relatively high amounts of heavy metals, possibly reflecting to some extent the influence of industrial activity in England. Persistent organic micropollutants, such as polychlorinated biphenyls (PCBs) show a similar pattern (Figure 6 on page 33). These distributions represent the accumulated result of long periods of atmospheric pollution from anthropogenic sources. On the other hand, pollution by radiocaesium represents the effect of one single incident at Chernobyl, and the pattern of precipitation over a few days in 1986. In the transects studied (Figure 7 on page 33), the highest levels of radiocaesium pollution occur in those areas which were unfortunate enough to receive heavy rainfall at that particular time, so washing the radioactive particles from the atmosphere.

More detailed research on these sources of pollution is reported on the following pages.

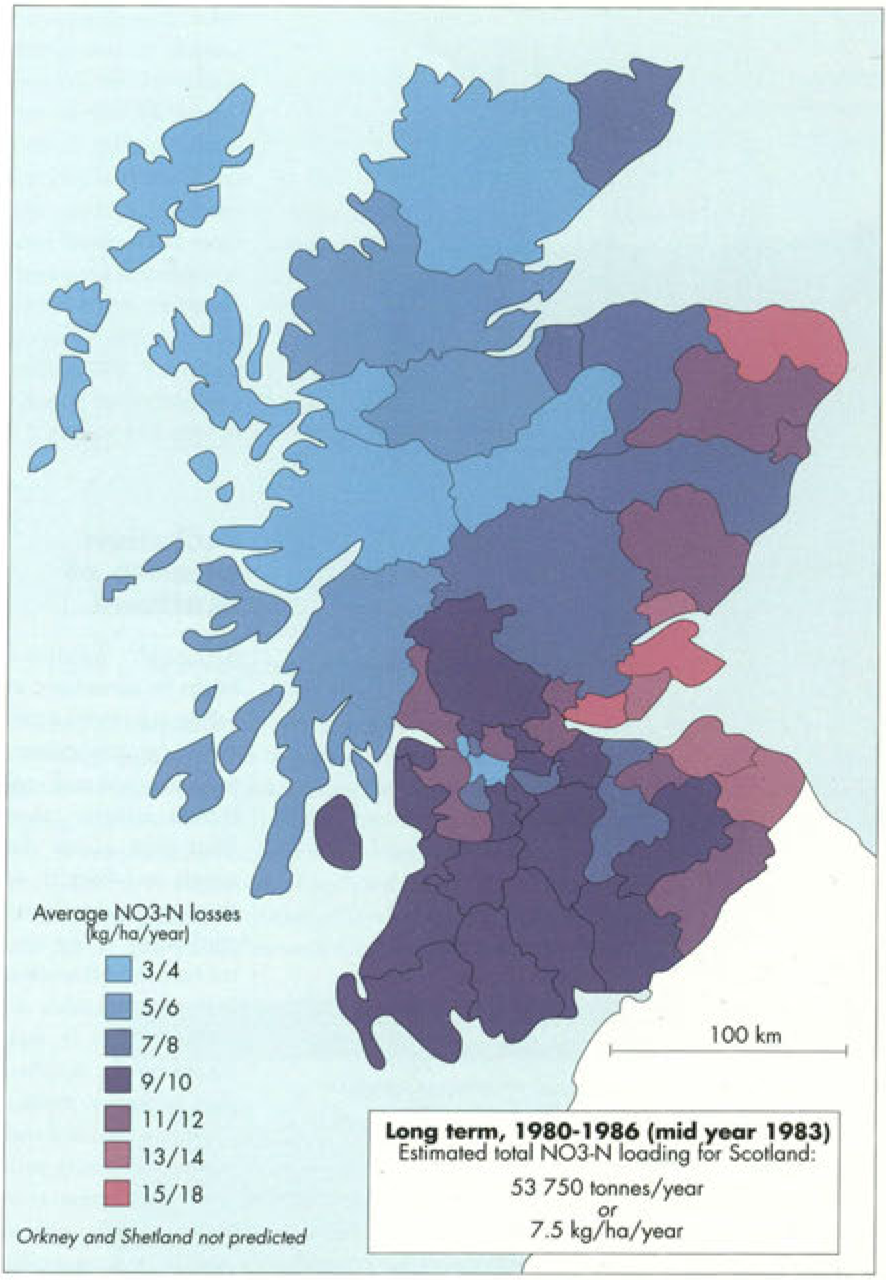

Figure 3. Average long term, 1980-1986 (mid year 1983), nitrate (NO3-N) losses, estimated using AVHRR satellite imagery and Grampian Region NO3-N regression estimators.

Sources of lead pollution

The isotopic composition of lead varies according to the source and history of the individual sample and consequently can be used to give an indication of its source (Bacon *et al.*, 1992). Typically the lead isotope ratio (^{206}Pb:^{207}Pb), generally used in environmental studies, varies from 1.04 in old ores to over 1.30 in newer deposits with an average of about 1.20. Slag-heaps, streams and sediments from the vicinity of the former lead-mining areas of Scotland have ^{206}Pb:^{207}Pb ratios of 1.171 to 1.175, and tap-waters have ratios of 1.17 to 1.18. Petrol additives used in Britain in the recent past have much lower ratios of about 1.09, but this is variable, depending on the proportions of the different ores used; recently there has been a move towards importing some American additives with higher ratios.

Rain-water samples collected from the three Institute Research Stations (Table 2 on page 34) regularly show low ^{206}Pb:^{207}Pb ratios consistent with most atmospheric deposition having origins in petrol additives. Greater variation is observed at the Hartwood site, indicating a greater proportion of lead derived from other industrial sources such as metal-smelting and coal-burning. A noticeable perturbation was observed at all three sites during November-December 1990; this was greatest at Hartwood, where it took longer to return to the normal background level.

Lead accumulations are commonly observed at the surface of peaty soils, even in the remotest areas. Lead isotopic analysis shows that these accumulations have significantly different isotopic composition from the underlying geochemical lead, and a consistent pattern of lower ^{206}Pb:^{207}Pb ratios is observed, suggesting that much of this lead has an anthropogenic origin (Table 3 on page 34). The ratios observed and the dates of sample collection are beginning to form a picture that is consistent with data from Edinburgh University on dated peat cores, and the historical nature of atmospheric lead inputs is becoming better understood through the use of isotope methods.

Sorption and desorption of radiocaesium

The Chernobyl incident in 1986 resulted in an uneven deposition of radiocaesium over Britain. High rainfall resulted in relatively greater amounts being deposited on hill and upland areas where levels of radiocaesium in herbage have not diminished with time and some livestock restrictions still remain in force. All these areas have soils with highly organic surface horizons.

The ability that soils with higher organic matter content have to retain caesium in a form which remains available to plants may depend on the proportionately low amounts and nature of the mineral matter they contain, as well as the slow rate of transfer from the numerous organic exchange sites on which the caesium is initially retained (Cheshire and Shand, 1991).

Minerals differ in their ability to bind caesium. For example, caesium was retained more tenaciously by metabentonite, a

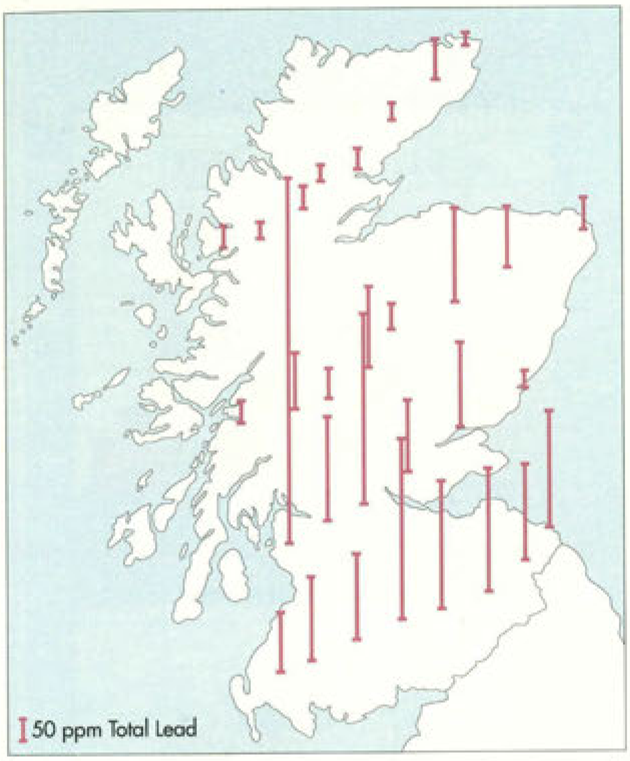

Figure 4. Total lead concentrations in surface soils.

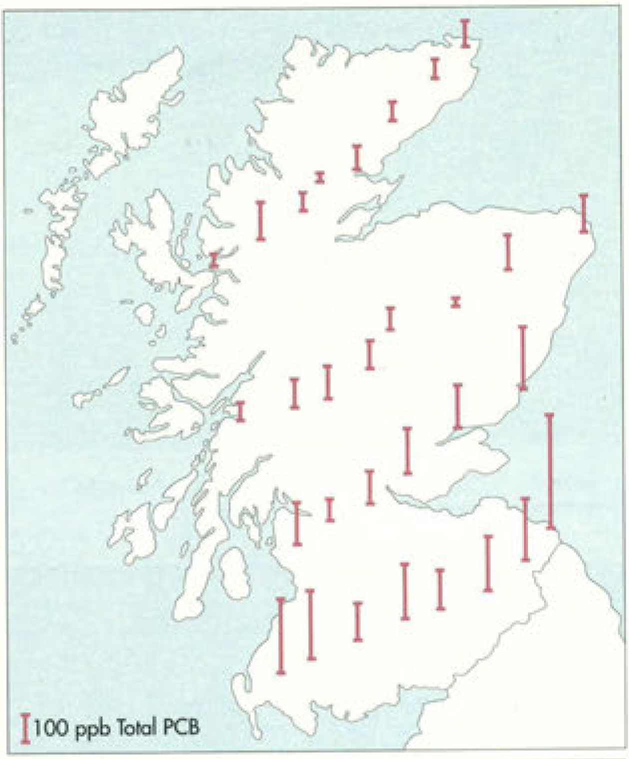

Figure 6. Total PCB concentrations in surface soils.

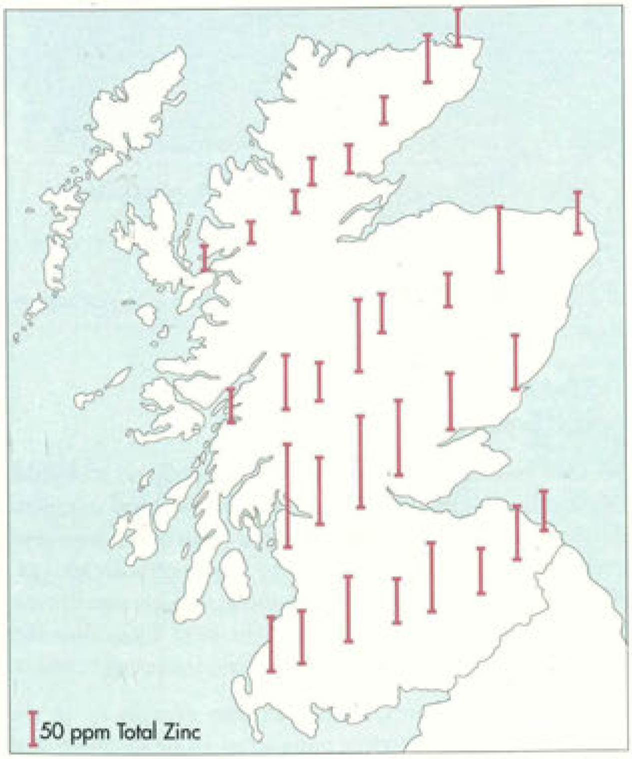

Figure 5. Total zinc concentrations in surface soils.

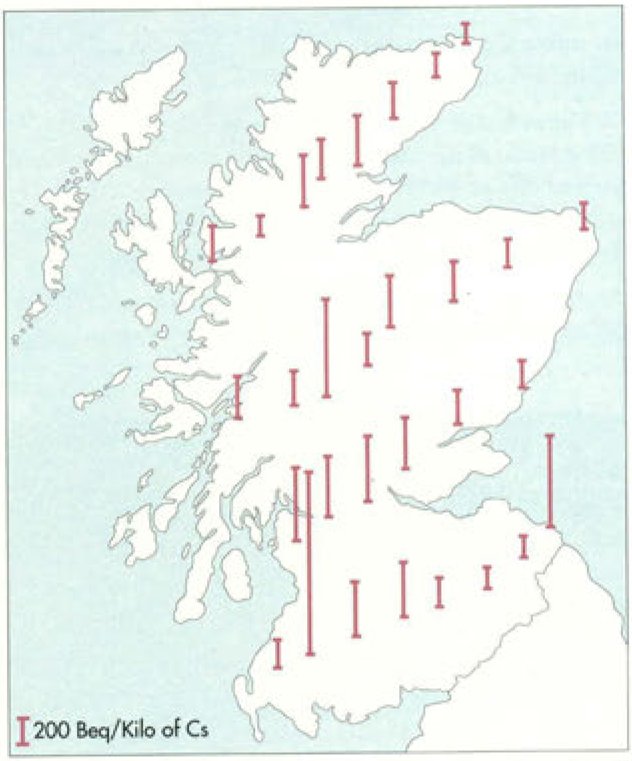

Figure 7. Radiocaesium concentrations in surface soils.

Date	Glensaugh	Sourhope	Hartwood
1/89	1.112		
2/89		1.06	1.126
2/90	1.114		1.115
7/90	1.113	1.116	1.104
8/90	1.114		1.126
10/90	1.117		1.120
11/90	1.131	1.132	
12/90	1.101	1.125	1.153
1/91	1.111		1.133
2/91		1.109	

Table 2. ^{206}Pb:^{207}Pb ratios in rain-water samples from the Institute's research stations.

Profile	Surface horizon	Deeper horizon
Listonshiels No. 3	1.147	1.174
Cairnsmore of Fleet No. 4	1.160	1.202
Easter Cringate No. 2	1.154	1.170
Kelty No. 1	1.134	1.167
Kelty No. 4	1.147	1.174
Kelty No. 9	1.145	1.174
Glensaugh	1.154	1.163

Table 3. ^{206}Pb:^{207}Pb ratios in surface and deeper soil horizons.

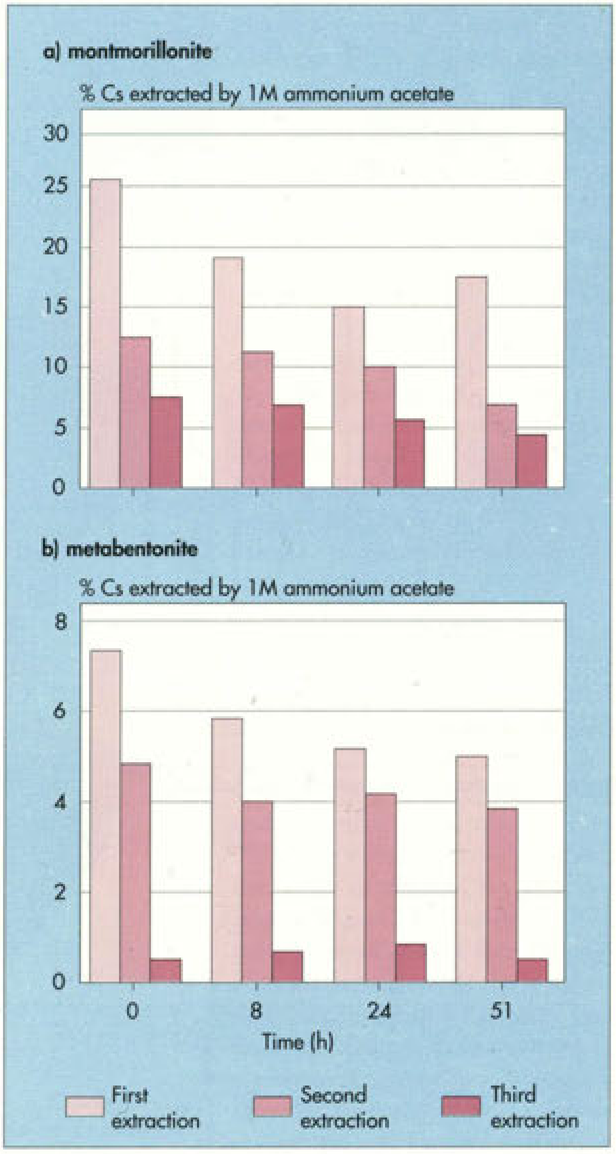

Figure 8. Sequential extraction of Cs (a) from montmorillonite and (b) from metabentonite.

clay material consisting of interstratified illite-smectite, than by pure montmorillonite clay (Figure 8).

Six soils with organic surface horizons developed on a range of parent materials have been studied, and in all cases the initial extractability of added caesium by ammonium acetate was quite high although there was some variation between the soils (Table 4).

However, this extractability falls rapidly with time and further studies are being undertaken to determine how mineral content and composition influence the availability of radiocaesium to plants and subsequently to animals.

Soil Association	Parent material	Initial extractability of added caesium (%)
Hatton	Old Red Sandstone	100
Durnhill	Quartzite	95.6
Countesswells	Granite	96.1
Ettrick	Greywacke	80.2
Darleith	Basalt	90.4
Strichen	Schist	95.9

Table 4. Initial extractability of caesium from selected peaty soils.

PCBs in organic soils

Polychlorinated biphenyls (PCBs) are synthetic industrial organochlorine compounds, common in electrical components: these toxic compounds were released into the environment until statutory restrictions were introduced over a decade ago. PCBs are stable to decomposition and are widely distributed. Furthermore, as they pass through the food chain they can concentrate in the fatty tissues of animals, including humans.

In the soil environment, PCBs partition strongly on to the organic matter, and therefore peats act as strong absorbers and accumulators, especially in upland areas which are subject to higher precipitation and higher deposition rates.

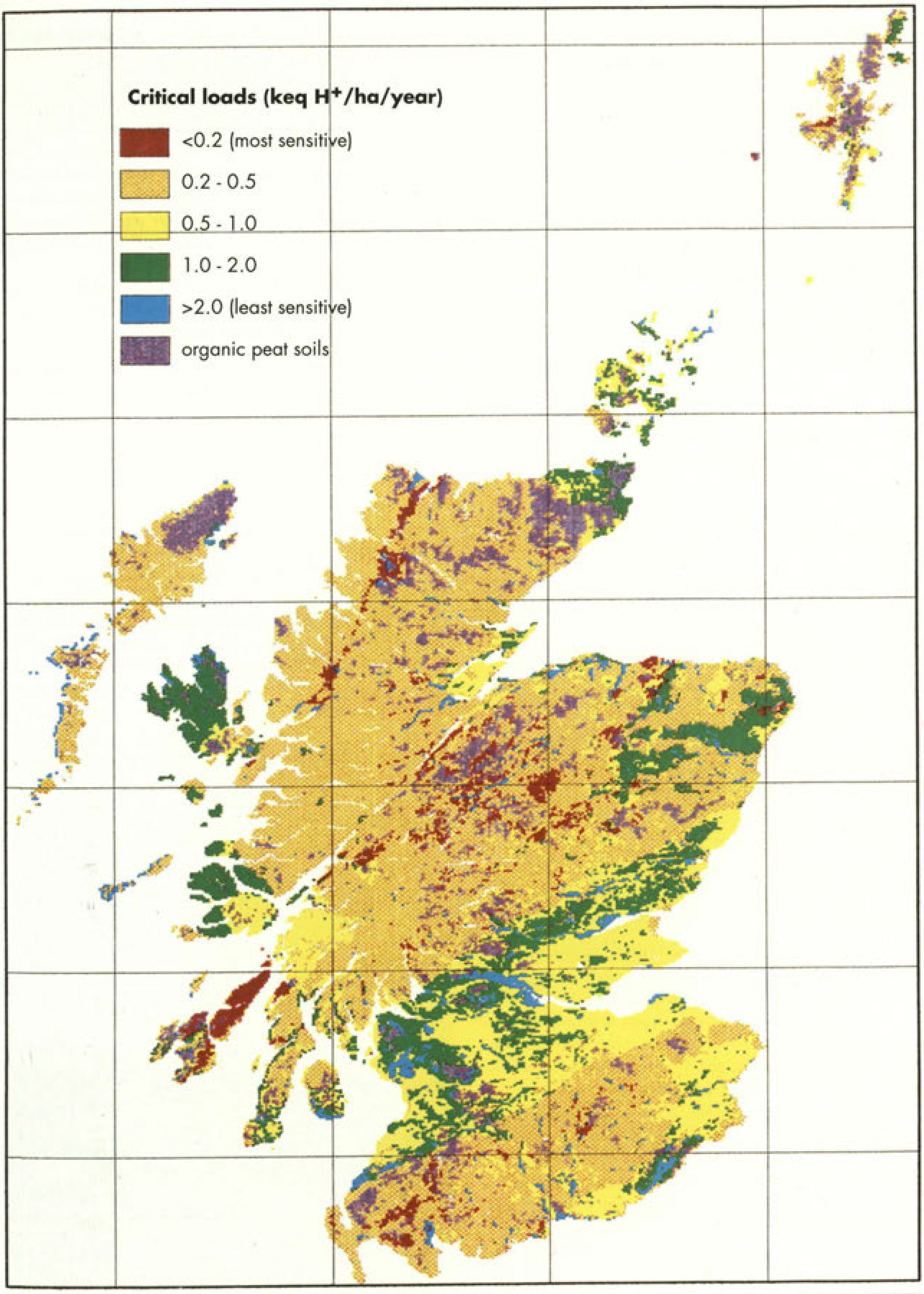

Figure 9. The distribution of different soil critical load classes across Scotland.

In the survey carried out, the top 5 cm of soil, excluding raw vegetation, was sampled at various sites covering four east-west transects (Figure 6). The samples were extracted and PCB levels estimated using a combination of gas chromatography and gas chromatography/mass spectrometry. In one site, samples were taken to a far greater depth: PCB levels below 5 cm were not substantial. The overall level of PCBs, expressed on a dry-weight basis, was generally higher than those found in previous UK studies, but this is likely to be a function of the highly organic nature of the soils studied.

A marked increase in amounts of PCBs, from north to south is evident, and is commensurate with the increasing level of industrial activity towards the south. The two northern transects (transects 1 and 2, Figure 6) are similar and may represent the general background unaffected by industrialised areas. PCB levels in the peaty soils of the Midland Valley (transect 3) are about double the levels found in the most northerly transects. Transect 4 shows similar levels, though the area is less densely industrialised; it may be influenced by sources further south as well as the Central Valley.

An east-west U-shaped distribution is evident. The higher values on the west side probably correspond to the higher precipitation that these areas receive, but it is not yet known how the higher values found in the east coast soils can be accounted for. From the viewpoint of PCB volatilisation and uptake by plants and grazing animals, the important parameter to measure is the total PCB burden of the land; this can be expressed as the amount per unit surface area of deposition if the field bulk density and moisture content of the soil are known. Results obtained, in terms of grammes per hectare, generally show a close parallel with the precipitation pattern. It is evident that such a mode of expression is essential if valid comparisons with other areas and studies of long-term temporal trends are to be made.

Acid deposition to soils

National scale critical load and exceedance maps

The impact of acid deposition on soils and surface waters is of considerable concern, particularly in northern Europe and North America. To reduce this impact considerable effort has been made to reduce acidifying pollution at source, particularly by controlling and limiting the sulphur component of these emissions. In 1985, the European States under the auspices of the UN-ECE agreed a sulphur protocol by which emissions were to be reduced by 30% (of 1980 levels) by the member countries. In 1993 this European sulphur protocol is due for revision and renewal. One method of assessing the effectiveness of different abatement strategies for limiting the impact of acid deposition is to use a critical load approach (Bull, 1991). A critical load can be defined as: 'a quantitative assessment of one or more pollutants below which significant harmful effects on specified elements of the environment do not occur according to present knowledge' (Nilsson and Grennfelt, 1988). National critical load maps (Figure 9) and the areas in which these are exceeded (exceedance maps) have been produced by the Institute using information from the 1:250 000 Soil Survey of Scotland maps and the detailed soil descriptions held in the Institute's soils database. This information has been passed on to the Department of the Environment and incorporated into the United Kingdom critical load programme as a basis for negotiation of the new sulphur protocol (DOE, 1992). The work is also being developed for use by the Scottish Office in an indicative forestry strategy context, in particular to identify areas where further afforestation is likely to lead to increased soil and water acidification.

Critical loads for catchments and regions

To improve our estimates of critical loads and the damage to ecosystems where they are exceeded, it is necessary to understand more fully the complex interactions between the atmospheric input, vegetation type, soil type and hydrological pathways which transfer the acid deposition through a catchment to the water body. Research at the Institute is centred on providing better estimates of the processes and linkages within this transfer. For example, in Galloway two catchments contrasted by their vegetation types are being studied in detail. Calculation of weathering rates for the catchment soils has been undertaken. This is vital to the work on critical loads as the weathering rate is the primary variable driving the critical load sensitivity. The monitoring of precipitation inputs and stream water outputs in the catchments have been used to calibrate the MAGIC model routine for predicting the consequences of different emission and forest planting scenarios. Further work on the role of organic acids as a modifier to critical loads is also being undertaken. The final product of all of these research initiatives will be a better understanding of catchment sensitivity to acidification and the production of more detailed regional critical load maps.

Acid soils of the Cabrach, West Aberdeenshire.

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The Ochil Hills, Carse of Stirling at Menstrie.

Introduction

It is a pleasure and a privilege to be in Scotland, at the Macaulay Land Use Research Institute (MLURI) to give the 16th T B Macaulay Lecture. I know the institute well. I served on its Board of Governors for a short period before moving south to become Deputy Chairman and Chief Executive of the Agricultural and Food Research Council, a post which I filled for almost three years. In the latter role, I maintained close links with MLURI and with the other institutes of the Scottish Office Agriculture and Fisheries Department (SOAFD) as part of the Agriculture and Food Research Service (AFRS).

Earlier today I met with Professor Cunningham, members of the Governing Body and staff. I was pleased with what I learnt and saw. To those who are responsible for guiding this new and evolving institute, let me make a point. We live in a rapidly changing world and there are increasing pressures - scientific, technological, social and indeed sometimes political - to do this and to do that. It sometimes seems easier to adapt to the whims of the moment. That is seldom a sensible way forward and it is especially difficult in an area such as science and technology where long-term judgement, vision and a measured approach are essential. My advice to those involved in shaping this restructured institute is to be like a good carpenter: decide what you want to do, measure twice and cut once and then get on with the job. That job may take another ten years, but the vision must be uncluttered and clear-sighted - MLURI must become the premier institute in the UK concerned with land use interactions - agricultural, environmental, economic and social.

SCIENCE FROM THE

The 16th T B Macaulay Lecture

Given by
Professor W D P Stewart, FRS, FRSE
Chief Scientific Adviser
to the Cabinet Office
20 November, 1991

Scientific advice

I have been Chief Scientific Adviser in the Cabinet Office since October 1990. I am a civil servant and the post is an apolitical one. I operate and provide advice at the heart of Government. My office is located in the Cabinet Office at the corner of Downing Street and Whitehall, with the Treasury on one side and the Scottish Office on the other. What better combination could there be! It is a great honour and privilege to hold the post. The issues which concern the Cabinet Office Science and Technology Secretariat are both domestic and international and the boundary between the two is diminishing. We now have the globalisation of competition, of markets, of science and technology and indeed of everything else. If the UK is to remain as an international leader, it must position itself increasingly for success in that global arena.

A major reason for the international emphasis is global population growth. The population of the world is expected to double in 30 years, with an annual increase of around 80 million. By the time this talk is finished there will be an additional 9,000 hungry mouths to feed on the surface of the Earth. Also, the pace of progress and the costs of science and technology are both escalating. Quite simply, no one country can afford to do everything on its own. Collaboration and internationally-shared facilities and programmes will increasingly be 'the norm', whether this be space research, nuclear fusion, particle physics, astronomy, human genome research, or environmental issues such as global warming.

Priorities have to be set by the UK and other countries in the type of science and institutes which can be funded. I do not believe that decisions on priorities should be made by politicians or administrators. The best decisions will be taken, surely, by the scientists themselves. There is no way out of priority setting. The costs must be analysed, the time scale for realistic funding established and most importantly the scientific and applied potential of the work must be key components of the decision-making process. The question of how many will benefit from the research topic being supported must also be addressed.

I do not make these points to be negative but to emphasise that as costs escalate even international organisations cannot fund all the scientific opportunities that are available. The European Community (EC) for example, is not the salvation to all our resource problems. It does not have the funding and does not and cannot fund all areas. For example, the internationally acclaimed CERN facility in Geneva is not an EC facility; the EUREKA programme on industrially funded research is not an EC programme. EC science and technology programmes, though important, do not provide all the funds for anything other than a small proportion of European programmes and they have to be focused on areas which complement rather than duplicate national programmes.

Another major issue is the changing geography and politics of Europe. Who could have predicted a year ago the rapidity of change in eastern Europe? International markets and international competitors are changing. We are but a small country perched off the coast of continental Europe, remote from expanding areas of human population growth such as the Pacific rim, South America and Africa. We have no God-given right to success; no God-given right to an inordinate share of limited public funds and no God-given right to a high standard of living. Anything we get we must earn. Yet, the population of the world is expanding most rapidly in areas remote from the United Kingdom and indeed Europe. That does not help us to sell our products globally. Superimposed on that there is an additional problem for those of us here today: agriculture is poorly perceived - the supermarket shelves are bulging and UK food shortages of the immediate post-war years are a thing of the past. Concurrently, other extremely interesting and exciting areas of science and technology are emerging. That was a major reason why, as Secretary of AFRC, it was necessary to restructure and reshape the institutes. There was a need to position the Council for the changing scientific and global scenes. Perhaps we were ahead of our time, perhaps restructuring was overdue, or both, but we had to set out our stall to deal with the challenges of the next century. That, in macrocosm, is what MLURI must do in microcosm. In AFRC, we were successful, as the quality of the science being carried out and the international recognition given to AFRC scientists shows. Much was achieved, but there is more to do. I am sure that MLURI, likewise, will be successful as its longer-term planning achieves practical returns.

CENTRE

The picture shows Professor Cunningham (left), Chairman of the Institute's Board of Management and Professor Maxwell (centre), Director of MLURI with Professor Stewart before the 16th Macaulay Lecture at Aberdeen.

The need for a sound scientific base on environmental issues in Scotland

It is right and proper that the Scottish Office should have a major research institute concerned with land use and the environment and SOAFD should be congratulated on its foresight in establishing MLURI with its new remit. Today the environment is a matter of concern to all of us. Once it was regarded as the territory of the naturalist, the bird watcher and conservationist, all important in their own right, but until recently regarded, sometimes, as odd-balls, nuisances or even trouble-makers. Now everyone wants to sit round the table with them. There are several reasons why that is and should be the case. Put simply, society, by and large, has come to appreciate that environmentalists and conservationists - by and large - have genuine concerns and real points of importance to put over. I am not talking here of the vociferous lunatic fringe. The other reason is that mankind has come to appreciate that the environment is genuinely at risk and thus his own self-preservation may be at risk. What you have is self-preservation superimposed on conservation issues. We are concerned about the environment because we want to survive. In the United Kingdom we have no food shortages, a higher standard of living than ever before. We live in a global village and we are concerned about self-preservation - how it affects our lives, our jobs, our companies, our families, the family cat and before we know where we are industrialists including agriculturalists and environmentalists are working together to a common goal and high time too!

There is, however, a problem - the concerns about the environment are unending! Sometimes they are general concerns, sometimes they are concerns to only a small sector of society or to fringe groups or individuals. Usually they are real concerns, at least to some people. In recent times, for example, there have been concerns about global warming, desertification, ozone holes, nitrate levels in water, aluminium in drinking water, pesticides and herbicide levels in the soil; the state of the North Sea; the release of genetically manipulated organisms; the transportation of nuclear waste; leukemia clusters, PCBs, afforestation, deforestation and so on. It is essential that Government has scientific experts available who can deal with such issues and provide sound advice. In this regard institutes such as MLURI can have an important role to play - providing advice on tap so that statutory policy and regulatory issues can be properly addressed. They must also be able to do so in competition, on a level playing field, with other potential suppliers of research data - the universities, polytechnics and other research institutes in the public and private sector. To achieve competitive advantage and, because of the multiplicity of issues which arise, it is important that such organisations are staffed by scientists who, in addition to being scientifically excellent, are flexible and adaptable in their approach. The days are over when a scientist in a publicly funded research organisation can expect to continue with the topic of his PhD thesis until age 60 - unless he is truly outstanding!

Industry/Environmental interactions

The UK, generally, has one of the highest standards of living and one of the best social services in the world. Such benefits do not come lightly. They come from a secure wealth-creating base. That means, in general terms, a strong industrial base, be it in agriculture, high technology industries, manufacturing industry or natural resources. If we do not have products to sell in the global arena, or sell more valuable products than we buy, then the country will go into long-term decline. As Sir John Harvey-Jones, former Chairman of Imperial Chemical Industries, says 'industry creates the wealth'. I believe that we need as a central plank in the protection of the environment a strong industrial base to generate the necessary wealth. The worst thing that would happen would be for the environmental lobby to kill the industrial goose that lays the golden egg just as it would be equally irresponsible for the industrialist to ignore the real environmental concerns which industry sometimes generates.

In relation to Scotland, I do not subscribe to the view that people are unimportant even in the last wilderness of Europe. I do not subscribe to an environment for the future which is denuded of people. We have to plan for the needs of people, and for the needs of society, not in isolation but taking due account of both environmental and industrial concerns. We must live in harmony with nature, with our environment, with industry. It is sub-optimal to consider agriculture, industry, the environment, or social issues as discrete entities which survive depending on the success of pressure groups in promoting them. We must strive for consensus rather than conflict and for sensible planning which is beneficial to *Homo sapiens*. MLURI has an important part to play in aiding such planning and by interacting with planning groups and those interested in the social dimension both regionally and, nationally. I return later to the question of regional interactions.

One of the most important needs of industry, in relation to the environment, is an assurance that the standards of environmental protection being set and which industry has to meet - and which costs them money to meet - are soundly based. It is incumbent on the UK and the EC to ensure that its standards are scientifically based. That is one reason why the UK needs a strong research base. The UK, through its scientific contribution, must contribute to the shaping of European legislation on one hand and to protecting the UK from ill-thought-through and sometimes unnecessary legislation on the other hand. It is for reasons such as these that I am convinced that we need scientific foci such as MLURI, which provide, in the UK, truly independent and scientifically unassailable data and advice on a broad range of environmental matters.

Let me turn now to the environmentalist - and we should all be caring environmentalists. The major environmental groups, including some pressure groups are doing a good job and deserve much credit, not only for drawing attention to environmental issues of concern, but also for helping to promote realistic standards. For example the introduction of unleaded petrol in the UK was by the Royal Commission on Environmental Pollution Report on *Lead in the Environment*. Environmentalists and pressure groups have also helped to ensure the protection of some unique ecosystems. Such groups have a continuing and important role to play.

I am duty bound, nevertheless, as an environmentalist to urge a cautionary approach. The secret is to know when to make a 'song-and-dance' and when to keep quiet. Environmentalists, like others, have a social responsibility. There is a downside to crying 'wolf' too often. It is this. There is limited money in the public purse. If, as a nation, we accept that we have to be internationally competitive and defensively secure, then going over the top on environmental issues may force the diversion of public funds away from major and urgent social issues such as AIDS, drug abuse, care of the elderly etc. We have to be sure that we do not do a disservice to the very society that we are at pains to protect. We are back to the need for vision coupled with sound judgement. The question then is how do we address the increasing demands for financial resources. The Pearce Report promotes the 'polluter pays' principle. I support this concept. If the polluter pays principle is introduced there is an incentive to reduce the pollution and to develop environmentally benign products and processes. These can be expected to provide competitive advantages over more polluting products and processes and gain an increasing share of an environmentally conscious market.

The way forward for MLURI

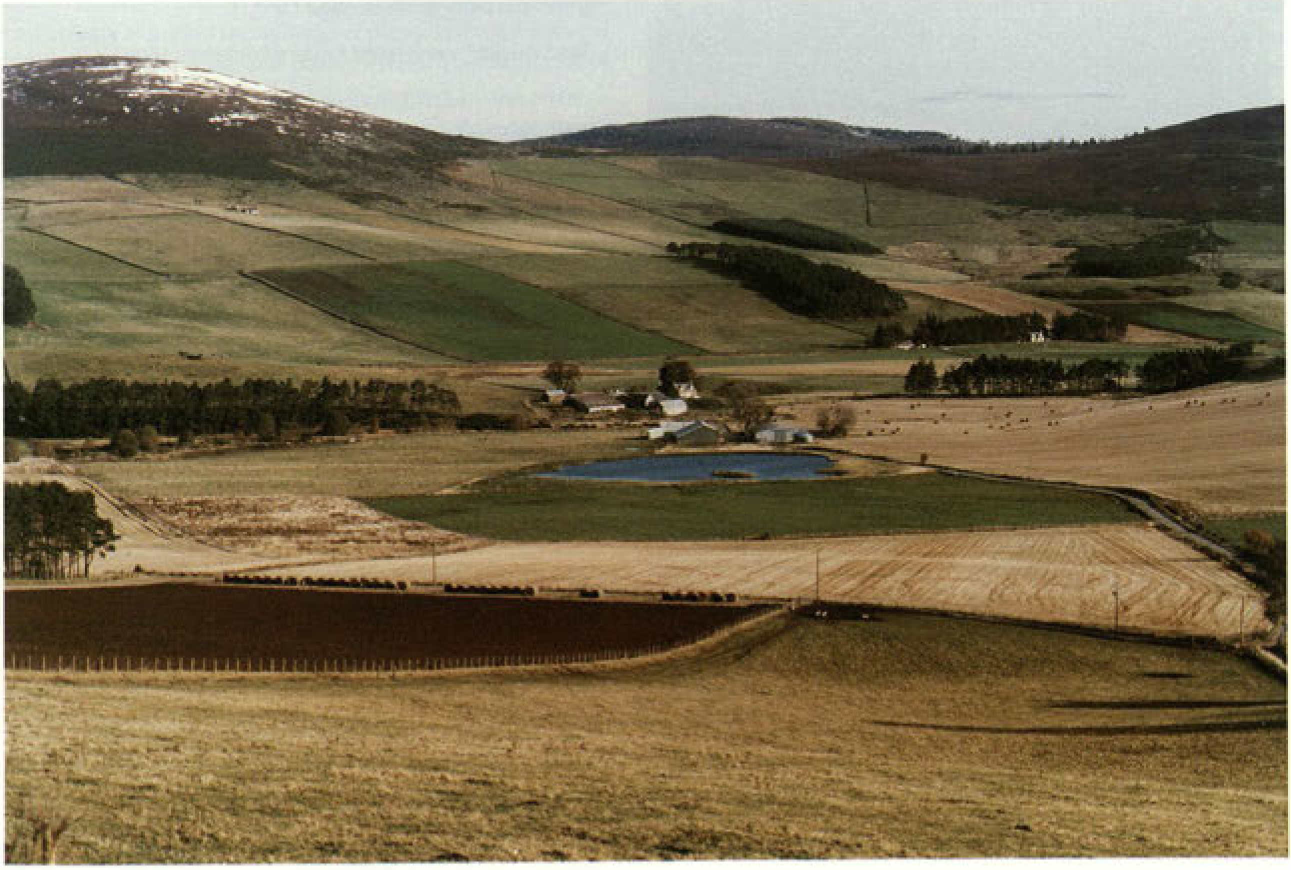
I am a strong believer in regional hubs. There is a need for centres of regional pride with universities, colleges and research institutes serving as hubs of training, skills and expertise able to retain local and surrounding industries and which attract national and international industries to the area. I do not see these hubs developing as top-down bureaucratic organisations, but as organisations which grow by building on their strengths and with the government providing conditions which enable successful hubs to develop. I know that this is a concept supported by Principal Irvine of Aberdeen University. In the Aberdeenshire area there is one of the greatest concentrations of high quality research establishments per unit of population anywhere in the UK: the Macaulay Land Use Research Institute; the Rowett Research Institute; the NERC Banchory Laboratory; the SOAFD Marine Laboratory and the MAFF Fisheries and Food Laboratory and two universities: one of the oldest in Scotland, the other likely to be one of the newest. Think carefully, before, in this area of the UK, you criticise the state and funding of UK education and science. You have much of which to be proud. There is a need to work together to couple the institutions in a communications network and to share facilities interactively and to advantage without losing the competitive spirit of each entity. Perhaps your Enterprise Board and the Scottish Office could be convinced of the need to help to ensure that this dispersed suite of facilities and resources are optimally interactive to keep ahead of the competition nationally, UK-wide, European-wide and globally.

Finally, a word about the primary focus of the science carried out at MLURI. In a rapidly changing world with increasing environmental, social and political concerns, MLURI, if carefully nurtured, can fill an important niche in the UK land-use scene. Its sciences must be founded in the basic sciences, but not necessarily basic science for its own sake. It must focus on strategic science underpinning the longer-term competitive base of broad industrial and environmental sectors, and the statutory, policy and regulatory needs of government departments. Both these general areas should be funded by the public purse. It must also provide advice to industry and the private sector on contract. Importantly the calibre and quality of the science must match the best in the world, but I dare to suggest that activity should not be particularly focused on global issues such as world ozone levels or the global carbon cycle. There is always the temptation to seek to research the topical issues of the moment, often because funds are available for work in such areas. That is a dangerous approach. I have seen too many laboratories jump, ill-equipped, into new areas of research and, being unable to compete, wither on the vine. I am convinced a laboratory should focus on areas and issues where it has uniqueness and where it has an important job to do. Play to your strengths and to your uniqueness in worthwhile areas. Your material strength and uniqueness is the majestic ecosystem of Scotland in which you operate; your intellectual strength resides in the staff. The job of this institute, as I see it, is to take account of the needs of the people of Scotland, the need to protect the ecosystem of Scotland, the need to work with the industries of Scotland, the need to protect the environment of Scotland and the need to promote the ecosystem of Scotland for the people of Scotland, the UK and internationally.

There are real questions to be answered: can energy, in economically sensible terms, be produced by forestry, or from peat, or hydro-electricity or from the nuclear industry? What effect, if any, will genetically engineered organisms have on the ecosystems of Scotland; how will the introduction of new plant and animal varieties affect the ecosystem of Scotland; what do we do about the agricultural landscape as more of it is transferred to purely environmental use as industrial projects are replaced by environmental projects? What effect will changed land use patterns have on the species and genetic resources of Scotland? Let me put it like this. I fully accept the need for academic excellence, for Nobel Prizes which provide recognition of international merit, of international prizes which show that the stature of UK science is still highly regarded internationally. These are worthwhile aspirations. It is also equally important in my view to focus with the same degree of excellence on the local issues of importance, networking nationally and internationally and giving global leadership in your area of expertise and competence.

Chairman, this new institute is still in its infancy. Set your sights firmly on the future, focus on your strengths and build on these. As I said earlier, measure twice and cut once. Bringing agricultural and environmental research together under one roof is a worthwhile and positive way forward. I wish the institute well - its Director and staff, its Governing Body and the Scottish Office which has protected and shaped its interests - as progress is made to a rapidly approaching next century.

Glenbuchat, Aberdeenshire.



Resource Consultancy Unit

Dr. J H Gauld, Head, Resource Consultancy Unit, demonstrates soil types and soil mapping techniques to students from Aberdeen University as part of their Soil Survey and Land Evaluation course.

The Macaulay Land Use Research Institute has an established reputation in soil research, exemplified by the national soil survey maps and the comprehensive soil databases built up over several decades. The potential range of soil survey applications to land use issues is appreciable, with soil data a principal component, not only of the Land Capability for Agriculture and Land Capability for Forestry maps rating land in terms of its flexibility for crop or tree growth respectively, but also of research currently being conducted at the Institute by specialist staff. Such applied research has traditionally been used also by staff at other research institutes, by Government agencies and by private clients. Given these strengths, the Resource Consultancy Unit (RCU) was created in 1991 to undertake contract and consultancy work focusing on the application of soil data to land management and environmental issues. The Unit also contributes to research within the Institute.

Much is known about the soil and land resource of Scotland; indeed, staff formerly with the Soil Survey of Scotland form the backbone of this new Unit, bringing their accumulated field expertise to service the needs of all interested parties. Besides this field experience, techniques available to potential customers include analysis of satellite images and aerial photographs, geographic information systems, land use modelling and standard analytical methods to characterise soil properties. Consequently, the full resources and expertise of the Institute can be dedicated to contract or consultancy work of a confidential nature of for dissemination within the scientific community. Where necessary, multidisciplinary teams will be established to focus specifically on the client's needs. At all times independent and impartial advice will be provided.

The services currently on offer include:

Services to Government

Impartial advice to Government is supplied on many environmental issues to assist in the formulation of policies. Current research and assistance includes:

- research into alternative land use systems
- environmental impact studies associated with changes in land use
- land cover assessments based on aerial photograph interpretations
- monitoring biological change within the Environmentally Sensitive Areas.

Services to local government

Both Regional and District authorities require comprehensive advice relevant to current and future planning and resource utilisation. MLURI has an established history of collaboration, for example in:

- indicative forestry strategies
- potential land cover change
- land quality assessment prior to development
- environmental risk assessment, in particular flooding and pollution risk
- habitat assessment, the impact resulting from land use change.

Services to private clients

The RCU offers its clients the benefits of expertise in environmental appraisal and land management. Services include:

- resource surveys, inventories and mapping
- interpreting resource data into land capability systems
- assessing peat or sand and gravel resources
- assessing land quality both prior to, and after, development, or on rent tribunal work
- land development, for example mineral/opencast coal extraction and recommendation for restoration.

A range of publicity material is available on application to the Head of the Resource Consultancy Unit, who will be pleased to answer specific queries or discuss potential projects.

Analytical Division

Central analytical facilities are available in support of the research programme and these encompass a wide range of procedures and instrumentation, routine chemical analyses and preparation of samples. The bulk of the materials submitted for analyses originates from soils, plants, waters and animals. The facilities have been heavily used and over the past year upwards of 100 000 estimations have been carried out.

Inorganic elemental analyses form a major component of the analytical facilities and these are achieved by inductively coupled plasma (ICP) atomic emission spectroscopy complemented by atomic absorption (AA) spectroscopy. The ICP instrument has the facility to allow the simultaneous analyses of up to 26 selected elements; by the use of the instrument in the scanning mode, the estimation of other elements can be effected. Long-term studies relating to the monitoring of water quality at various experimental sites make extensive use of ICP for the analysis of inorganic elements, included among which are sodium, potassium, magnesium, calcium, iron, manganese, aluminium, copper, zinc, silicon, sulphur and phosphorus. These analyses are complemented by those obtained from ion chromatography for the major anions, nitrate, sulphate and chloride. The technique of flow injection analysis is used to yield the orthophosphate content of water.

ICP and AA are also used to estimate major and trace inorganic elements in matrices such as acid digests (prepared by conventional or microwave digestion techniques) of plants, soils and material of animal origin, and soil and plant extracts. The technique of mass spectrometry is also available in support of the research programme and included in this facility is gas isotope ratio mass spectrometry (IRMS), thermal ionisation mass spectrometry (TIMS) and gas chromatography linked to mass spectrometry (GC-MS). Compounds labelled with stable isotopes, particularly ^{15}nitrogen, are used extensively to trace metabolic pathways and yield information on nutrient uptake, utilisation and cycling. Samples either in milled form or as acid digests are analysed for their ^{15}nitrogen content by IRMS. Isotope ratio data are used to assess the extent of atmospheric deposition of heavy metals and give information on the origin of such pollutants. In this connection, use is made of TIMS to estimate isotope ratios of lead. Organic pollutants, such as polychlorinated biphenyls, in soil and herbage and other intact organic molecules are identified and quantified by means of GC-MS.

Flow injection and rapid flow analysis techniques are utilised in the estimation of various chemical entities derived from soil, plant and animal material. In addition, fibre analysis and organic matter digestibilities estimations *in vitro* are carried out on a manual basis. Various biochemical intermediates are assayed utilising automated techniques.

Other techniques which are used extensively include gas chromatography for the estimation of long-chain alkanes derived from herbage and radioactivity counting (beta and gamma radiations) for a wide range of radio isotopes.

A service is provided also for the chemical characterisation of soils. Included are the estimations for total and extractable metals, total phosphorus and pH. Analytical data from such investigations are used to construct a comprehensive database for the soils of Scotland. Electron microscopy is available on a central basis and during the past year transmission electron microscopy has been used for studies relating to clay mineral morphology and diffraction and the internal morphology of animal fibres. The scanning microscope facility has been utilised to augment studies of root mycorrhizal interactions and fine particulate matter deposited from the atmosphere.

Central facilities are provided for sample preparation such as milling, oven-drying, freeze-drying etc.

All the facilities are available for undertaking work from commercial organisations on a contract basis.

A system of quality control is in place ensuring the authenticity of data and relating analytical results, as far as possible, to certified reference materials.

Technical Services have continued to provide a range of services included among which are the design and construction of scientific instrumentation and monitoring equipment, software development for microcontrollers and maintenance of the fabric of the main buildings and Research Stations.

Determination of anions by flow injection analysis.

Research Stations

The Institute has three research stations in Scotland and a joint share of one in Wales. Together they represent a range of soil and vegetation types typical of the hills and uplands and provide facilities for carrying out many of the Institute's field-based research projects. Each of the three Scottish stations also has an environmental monitoring site. During 1992 the station at House O'Muir near Edinburgh and the deer farm at Rahoy in Argyll were closed down.

GLENSAUGH RESEARCH STATION

Glensaugh Research Station is situated in Kincardineshire at the eastern end of the Grampians. It extends to 1016 ha, most of which comprises rough grazings of *Agrostis-Festuca* grasslands on the lower slopes and heather moors on the higher ground. There is also some enclosed grassland and reseeded land.

There are approximately 420 Scottish Blackface ewes, 300 Greyface ewes and 400 crossbred ewes and a herd of Blue Grey suckler cows. The Red Deer Unit at the station has a herd of breeding red deer hinds and stags and some South American camelids.

Research is conducted on agroforestry, the grazing ecology of semi-natural vegetation and sown swards undergoing extensification, welfare of farmed deer, fibre biology of South American camelids and cashmere goats, and aspects of the pollution and acidification research programmes.

SOURHOPE RESEARCH STATION

Sourhope Research Station is near Kelso in the Borders. Most of its 1100 ha consists of rough grazings, with *Agrostis-Festuca* grasslands on the lower ground and *Molinia* or *Nardus* grasslands on the higher ground. There is also some reseeded land and some enclosed grassland.

The station has over 1000 Blackface ewes, almost 1000 North and South Country Cheviot sheep, and about 50 suckler cows, mainly Blue Grey and Aberdeen Angus-Friesian. In addition there are some 340 goats for cashmere fibre production.

Research work includes the foraging strategy of sheep grazing hill vegetation, fibre biology and genetics of cashmere goats, cattle and goats, extensification of sown swards grazed by sheep, and complementarity of sheep and cattle grazing *Nardus*-dominated swards.

HARTWOOD RESEARCH STATION

Hartwood Research Station is located near Shotts in Lanarkshire in an area of upland livestock-rearing farms. The land is characterised by heavy textured, poorly drained soils. Its 360 ha are mostly in sown grassland, with some permanent pasture, indigenous hill vegetation, forage crops, and strips of woodland.

Livestock at Hartwood comprises approximately 900 Greyface ewes, 130 Blackface ewes, 80 Cheviot ewes, and 200 Hereford-Friesian and Blue Grey suckler cows.

Research is carried out on grazing ecology of sown swards, extensification of sown swards grazed by sheep, sheep grazing systems on upland sown swards, short-term tree rotation evaluation, effects of shelter on sheep foraging behaviour, aspects of the ruminant resource use research programme including complementarity of sheep, cattle and goats grazing, and some externally funded work for feed companies.

BRONYDD MAWR RESEARCH CENTRE

Bronydd Mawr Research Centre, which is jointly managed by MLURI and the Institute of Grassland and Environmental Research (IGER) is situated in Powys, Wales. Most of the 230 ha is reseeded grassland, which provides a range of permanent pastures, and there is also some rough grazings adjoining the station.

Livestock comprises Brecon Cheviot, Beulah Speckleface and Welsh Mule ewes, together with a herd of Welsh Black and Hereford x Friesian suckler cows and some goats.

MLURI carries out research on the control of rushes by goats, and detailed studies of the effect of grazing by cattle and sheep on clover development and sequential lamb performance. Sheep production evaluation of new grass and clover varieties and the effect of lower fertiliser inputs and stocking rates is conducted by IGER together with studies of nitrogen cycling in grass/clover swards, agroforestry and farm forestry. Research on low input sheep systems based on white clover is conducted jointly by both institutes.

Beef cattle at Hartwood Research Station.

Scottish Agricultural Statistics Service

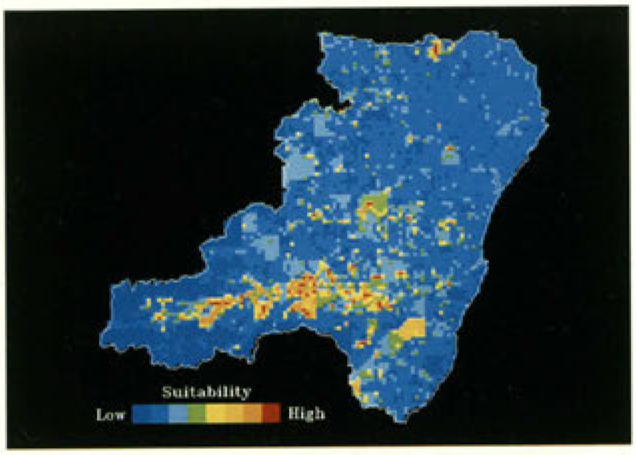
Staff in the Environmental Modelling Unit of SASS. Left to right: Karen Cattanach, Steve Beaney, Steve Buckland (head), David Borchers, Betty Duff, David Elston, Susan Ahmadi (student).

The Scottish Agricultural Statistics Service (SASS) is a group of 30 statisticians and mathematicians, with headquarters at the University of Edinburgh. It is responsible for statistical consultancy and training at the Scottish Agricultural Research Institutes and the Scottish Agricultural College. Training is provided through short courses in statistics, most of which utilise either GENSTAT or Minitab. In addition, SASS has commissions for a number of statistical and mathematical modelling research initiatives, and about 20% of its funding is through external contract. SASS has particular expertise in the fields of chemometrics, environmental studies, image analysis, systems modelling, food science, molecular biology, epidemiology and variety and crop system trials, and major projects in any of these fields can call on the expertise of the relevant SASS specialist. The areas of environmental studies, image analysis and systems modelling have particular relevance to MLURI.

The Aberdeen Group of SASS comprises 10.5 posts. Four of these (one vacant) are based at the Rowett Research Institute. The remaining 6.5 comprise the Environmental Modelling Unit of SASS, based at MLURI, which is responsible for co-ordinating SASS statistical research in environmental studies. The primary duties of the four permanent posts in the unit are to provide a consultancy service to MLURI scientists and to develop a land use modelling programme. The latter arises from a recent SASS Visiting Group recommendation, and the subsequent funding of a new permanent post by SOAFD. The programme will develop empirical models for spatial data to allow: current land use distribution to be modelled; future changes in land use to be predicted; and the effects of land use change on the distribution of fauna and flora to be estimated.

Our consultancy service has led to strong collaborative links and joint research with many MLURI scientists. Areas of collaboration include: use of glass tubes (minirhizotrons) to estimate root density in the soil; monitoring changes in land cover in Environmentally Sensitive Areas; ground-truthing of air photo interpretation of land cover in Scotland; selection of food by grazing animals; observational studies of animal behaviour; vegetation dynamics and succession of plant communities,

Around one third of the income to the Environmental Modelling Unit comes from external funding, mostly in the field of wildlife resource management. Much of this involves modelling of spatial data, and thus links closely with the methods being developed under the SOAFD-funded land use modelling initiative. One project is to model the spatial distribution of dolphins in the Pacific, using oceanographic variables, to estimate trends in abundance with greater precision. Another is to model the past and present distribution of adders in Scotland, and to predict future distribution, in collaboration with the Institute of Terrestrial Ecology. The unit has a strong international reputation in the area of estimating animal abundance, with particular expertise in marine mammal, fisheries and ornithological applications. It has carried our work for many international and US agencies, and was recently sponsored by SOAFD to carry out a review of deer count methods in Scotland.



The unit is currently developing spatial modelling methodology, for use in modelling changes in distribution of land use and wildlife. Shown here is a map of habitat suitability for green woodpeckers in north-east Scotland, estimated from empirical modelling of land cover, climate and physical data.

INSTITUTE STAFF

Staff list at 1 January 1993

DIRECTOR'S GROUP

Director, Professor T Jeff Maxwell, B.Sc., Ph.D.

Deputy Director, John A Milne, BA, B.Sc., Ph.D.

Director's Scientific Administrator, Donald W Futty, B.Sc.

Public Relations Officer, Susan P Bird, B.Sc., Ph.D.

Director's Group secretaries, Catherine M Smollet
Karen J Scott

LAND USE DIVISION

Head of Division,
Richard V Birnie, B.Sc., Ph.D., PGCE

Divisional secretary,
Christian T Garden

Carol A Smith (Environmental & Socio-Economics and Computing and Information Services)

Nicola G Paterson (Resource Consultancy Unit)

1. Land management systems

Project leader,

Alan R Sibbald

Research objective leaders,

Gordon Hudson, B.Sc.

Nick J Hutchings, B.Sc., Ph.D.

Allan Lilly, B.Sc., M.Sc.

William Towers, B.Sc.

Other staff,

Robert D M Agnew, L.I. Biol. (H)

Andrew J I Dalziel, B.Sc. (H)

Staff undertaking doctorates,

Allan Lilly, B.Sc., M.Sc.

2. Remote sensing and Geographic Information Systems

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Research objective leaders,

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Staff undertaking doctorates,

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Research objective leaders,

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Anna L Tyler, B.Sc.

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Helen L McHenry, B.Agr.Sc.

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Project leader,
Christopher H Osman, B.Sc., M.Sc., Ph.D.

Geoffrey A Reaves, B.Sc., MBCS (computer manager)

Lindsay Robertson, B.Sc. (database manager)

Alexander D Moir (cartographic manager)

Tony H Sunman

Matthew G Wells, B.Sc., M.Sc.

Jane D Haughey

Ann Malcolm, B.Sc

Susan MacLeay, B.Sc.

Ruth A Morrison

Daniel W Rogers

Ann M Teale

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Head of Unit,
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John S Bell, B.Sc.

Alex W Blyth, B.Sc., BA, M.I. Biol.

Frank T Dry, B.Sc. (H)

Andrew G Richman, B.Sc., M.Sc.

Margaret J Still, B.Sc.

Sarah Madden, B.Sc., M.Sc.

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Cathy S Butcher, B.Sc., M.Sc., M.Phil.

Elizabeth V Deans

Ian G Finlayson

Patricia J Emslie

Helen Beattie

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M. Jeffrey Wilson, B.Sc., Ph.D., D.Sc., FRSE

Divisional secretary,
Aileen Stewart

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M Jeffrey Wilson, B.Sc., Ph.D., D.Sc., FRSE

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Moira Stewart, HNC

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Ann Kelly, HNC

Angela Norrie

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Frank W Milne

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Farai Chimeura, Dept of Soil Science, University of Zimbabwe, Zimbabwe

Miss Zheng, Commission for Integrated Survey of Natural Resources, Beijing, China

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Alessandro Gimona, University of Aberdeen

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Postgraduate students, Ph.D.,

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Project leader,

M Jeffrey Wilson, B.Sc., Ph.D., D.Sc., FRSE

Research objective leaders,

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Lynn M Clark, HNC

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B Bezvodova, Geological Survey of Prague, Prague, Czechoslovakia

Miguel Angel Castro, CSIC, University of Seville, Spain

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Anna Chlopecka, Institute of Soil Science and Plant Cultivation, Pulawy, Poland

Nikola Kostic, Faculty of Agriculture, University of Belgrade, Yugoslavia

Dr Mirodrag Jakovljvic, Faculty of Agriculture, University of Belgrade, Yugoslavia

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Adine Hird, Dept of Agriculture and Environmental Science, University of Newcastle (Ph.D.)

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Jason Owen, B.Sc., University of Aberdeen

Rory Maguire, University of Aberdeen

Graeme Paton, University of Aberdeen

Diane Mitchell, University of Aberdeen

3. Climate change project

Project leader,
Edward Paterson, B.Sc.

Research objective leader,
Stephen J Chapman, B.Sc., Ph.D.

Other Staff,
Raymond Swaffield, LRSC

Mitchell S Davidson, HNC

Angela Norrie

Madeline Thurlow, B.Sc.

Staff who have left Soils and Soil Microbiology Division since the last Annual Report

Michael L Berrow, B.Sc., Ph.D., C.Chem., FRSC (deceased December 1991)

John F Darbyshire, B.Sc., M.Sc., Ph.D.

James D Russell, B.Sc., C.Chem., FRIC, D.Sc.

Carole A Martin

Shona Ritchie

David Allen

Alexander M MacDonald, B.Sc.

PLANTS DIVISION

Head of Division,
Peter Millard, B.Sc., Ph.D.(acting head)

Divisional secretary,
Iona M Shand

1. Nutrient assimilation and cycling

Research objective leaders,

David Jones, B.Sc., M.Sc., Ph.D., MI.Biol., FRMS

Alan E S Macklon, B.Sc., Ph.D.

Peter Millard, B.Sc., Ph.D.

Derek Vaughan, B.Sc., Ph.D.

Carol A Marriott, B.Sc.

Lorna A Dawson, B.Sc., Ph.D.

Mike F Proe, B.Sc., Ph.D.

Barry Thornton, B.Sc., Ph.D.

Other staff,

Stuart M Allison, B.Sc., Ph.D.

Alastair S Lings, B.Sc.

Alex MacDonald, B.Sc. (NE River Purification Board)

Geoff R Bolton, B.Sc.,(H)

Julia M Fisher, HNC

Jess H Griffiths, B.Sc., M.Phil. (H)

Brian G Ord, HNC

Allan Sim, LRSC

Renate E Wendler, Dipl. Biol., Ph.D.

Shona M Pratt, B.Sc

Eileen J Reid, HNC

Sandra Galloway, HNC

Mary R Tyler

Mandy Whyte

Ruth MacDougall

2. Nutrient availability

Research objective leaders,

Alan E S Macklon, B.Sc., Ph.D.

Derek Vaughan, B.Sc., Ph.D.

Charles A Shand, B.Sc., Ph.D.

Berwyn L Williams, B.Sc., Ph.D.

Tony C Edwards, B.Sc., Ph.D.

Mike F Proe, B.Sc., Ph.D.

Other staff,

Jess H Griffiths, B.Sc., M.Phil. (H)

Brian G Ord, HNC

James A.M. Ross, NDA, SDA, SDDH

Allan Sim, LRSC

Grace Coutts, HNC

Denise R Donald, LRSC

Shona Smith, HNC

Yvonne E M Cook, HNC

Julie Sutherland

Miriam E Young, HNC

David W Nelson

Postgraduate students, Ph.D.,

Peter Anderson, SERC

Anura Dissanayke, Rubber Research Institute, Sri Lanka - completed July, 1992

James Green, NERC

Loutfy Ibrahim, University of Aberdeen

Zakia Parveen, University of Aberdeen

Lola Ron Vaz, Spanish Government

Staff undertaking M.Phil. degree,

Denise R Donald, MLURI/Aberdeen University

Staff who have left Plants Division since last Annual Report

Wendy Davidson

Margaret A B Birley, B.Sc.

Deirdre Craddock, B.Sc., M.Sc. (Temp)

John A M Anderson

Colin D Campbell, B.Sc., Ph.D. (transferred to Soils and Soil Microbiology Division)

Sheila Gibbs (transferred to Soils and Soil Microbiology Division)

Heather Brunton

Nicola Turner, B.Sc.

Doris Jones

Morag A Smith, B.Sc.

ANIMALS AND GRAZING ECOLOGY DIVISION

Head of Division,
John A Milne, B.A., B.Sc., Ph.D.

Divisional secretary,
Margaret W Forsyth

PU14 Manager,
John A Milne, B.A, B.Sc. Ph.D.

1. Vegetation dynamics

Project leader,

Sheila A Grant, B.Sc., M.Sc. (H)

Research objective leaders,

Peter D Hulme, B.Sc., Ph.D., M.I.Biol.

David J Henderson, B.Sc.

Carol A Marriott, B.Sc.

Andrew J Nolan, B.Sc.

Helen Armstrong, B.Sc., Ph.D.

Alison J Hester, B.Sc., M.Sc., Ph.D.

Other Staff,

G Titus Barthram, B.Sc. (H)

David E Suckling, HNC, C.Biol., M.Biol. (H)

Lynne Torvell, B.Sc.

Postgraduate students, Ph.D.,

Amanda Cook, B.Sc., University of Aberdeen

Fiona Stewart, B.Sc., University of Aberdeen

Visiting worker,

Teresa Cristina Magro, MS, Universidade de São Paulo, Brazil

2. Foraging strategies

Project leader,

Iain J Gordon, B.Sc., Ph.D.

Research objective leaders,

Richard H Armstrong, B.Sc. (Agric.) (H)

Keith D Farnsworth, B.Sc., M.Sc.

Other Staff,

T Gordon Common, HNC (S)

Alison J Smith, HNC (H)

Gordon J Baillie, HNC

Iain L Thomson

James L Small (S)

Postgraduate students,

Mariecia D Fraser, B.Sc. University of Edinburgh

Iain Stevenson, B.Sc. University of Cambridge

3. Physiology and nutritional ecology

Project leader,

Glenn R Iason, B.Sc., Ph.D.

Research objective leaders,

Alan J Duncan, B.Sc., M.Sc., Ph.D.

Angela M Sibbald, BA

Other staff,

David A Sim, HNC

Grant C Davidson, B.Sc.

Elaine Foreman

Postgraduate students,

Iain Hulbert, B.Sc. University of Aberdeen

Anna Murray, B.Sc. University of Aberdeen

PU15 Manager,
Iain A Wright, B.Sc., Ph.D

1. Energetics and seasonal biology

Project leader,

Robert W Mayes, B.Sc., M.Sc., Ph.D.

Research objective leaders,

Stewart M Rhind, B.Sc., Ph.D.

Donald B McPhail, B.Sc.

Pamela Dicks, B.Sc.

Alison J Hanlon, B.Sc. (G)

Other Staff,

C. Stuart Lamb, B.Sc. (Agric.)

Stuart R McMillen, HNC

Postgraduate students, Ph.D.,

Luis Pinto de Andrade, Lic. M.Sc. University of Edinburgh

José Alfonso Abecia Martinez, B.Vet.Med., Ph.D. Universidad de Zaragoza, Spain

2. Ruminant resource use

Project leader,
Iain A Wright, B.Sc., Ph.D.

Research objective leader,
Claire Howard, B.Sc., Ph.D.

Other Staff,

Thomas K Whyte, HNC, SDA

Patricia M Colgrove, HND (H)

Postgraduate student,

Manuel del Pozo Ramos, B.Sc. University of Edinburgh

3. Alternative animals

Project leader,

Angus J F Russel, B.Sc., M.Sc., Ph.D. (H)

Research objective leaders,

Peter J Goddard, B.Vet.Med., Ph.D., MRCVS

William J Hamilton, BA, NDA, NDD, C.Biol., M.Biol. (G)

Margaret Merchant, B.Sc., Ph.D.

Other Staff,

A Robson Fawcett, AIMLS (G)

Alastair J Macdonald, SDA, NDA

Carol A Soanes, HND (G)

Hilary L Redden, B.Sc.

David J Riach

Brenda Copland

Audrey R Stephen

Visiting worker,

Silvana Mattiello, B.Sc., University of Milan, Italy

INSTITUTE STAFF

Staff who have left Animals and Grazing Ecology Division since last Annual Report

Peter D Fenn, B.Sc., Ph.D.

Evelyn Sim

Hazel Eayres, B.Sc.

Inge Bristow, B.Sc.

Murray M Beattie, HNC, C.Biol., M.Biol.

ANALYTICAL DIVISION

Head of Division,
Alistair Smith, B.Sc., Ph.D., C.Chem., FRSC

Divisional secretary,
Lynda M Keddie

1. Inorganic element analysis

Albert C Birnie, M.Sc., C.Chem., MRSC

Yvonne F Riach

Alison M Stewart

Thelma Robertson

Doris M McCombie

2. Mass spectrometry

Andrew J Midwood, B.Sc., Ph.D.

Jennifer J Harthill, HNC

Kathleen H Davidson

3. Soil analyses

Basil F L Smith, B.Sc., M.Sc., C.Chem., MRSC

Keely P Taylor

Martin S Davidson

June B McAdam

4. Electron microscopy

Bill J McHardy, B.Sc., Ph.D.

Evelyn M McMurray, HNC

5. Radiochemistry

Harry Shepherd, LRSC

6. Colourimetric analyses and chromatography

Pat E Moberly, B.Sc.

Susan M McIntyre, HNC

Alistair G Inglis, B.Sc.,

Gillian L Sim, B.Sc.

Arlene M Taylor, HNC

Anna Hendry

Sheila A Young

Gillian Martin

Donna MacDonald

7. Technical services

Bert W Stuart, HNC

Graham J Gaskin, HNC

James S Anderson

Gordon J Ewen, HNC

Allan I A Wilson, HNC

David W Clark, HNC

Jim A Steinson

Staff who have left Analytical Division since last Annual Report

Carrie Batty

Gwen Hoad, HNC

Michelle G Hutchison

John MacKenzie, HNC

Tony H Phillips, B.Sc.

Shirley S Stout, HNC

Janette R Strachan, HNC

Jeffrey R Bacon, B.Sc., Ph.D (transferred to Soils and Soil Microbiology Division)

INSTITUTE STAFF

RESEARCH STATIONS DIVISION

Head of Division,
Professor T Jeff Maxwell, B.Sc., Ph.D.

GLENSAUGH

Head,
John A Milne, BA, B.Sc., Ph.D.

1. Farm resources

Officer-in-charge,
David L Nelson, B.Sc. (Agric.)

Administrative assistant,
Grace B Welch, HND

Staff,

John W Black (Snr.) (grieve)

Norman G McEwan (head shepherd)

Pamela Tapson (shepherd)

John W. Black (Jnr.) (tractorman)

John B Ferguson (tractorman/stockworker)

Jessie P Black (cleaner)

2. Red deer

Officer-in-charge,

William J Hamilton, BA, NDA, NDD, C.Biol., M.Biol.

Staff,

Craig A MacEachern

Duncan Murray

3. Animal house

Officer-in-charge,

A Robson Fawcett, AIMLS

Staff,

Andrew G Brown

Irene J Black

HARTWOOD

Officer-in-charge,

George K D Corsar, B.Sc., MS

Administrative assistant,

Sandra A Denham

Catherine Walsh (Typist)

Staff,

Robbie A Hetherington, B.Sc. (Agr.) (Deputy OIC/cattle manager)

Ian Boustead (grieve)

Robert Graham (head stockman-cattle)

Harry Habblett (head shepherd)

W Paul Leonard (stockworker-cattle)

Jim C MacDonald, B.Sc. (stockworker-sheep records)

Betty Farley (cleaner)

Judith M A Leonard (cleaner)

SOURHOPE

Officer-in-charge,
Harry M Sangster, B.Sc., Dip. FBOM

Staff,

Geoffrey D Gittus NDA (deputy officer-in-charge)

John L Wallace (head shepherd)

Charles M Grant (shepherd)

T Gavin Rogerson, Dip.FBOM (goats)

John A R McGlen (shepherd)

James C Pringle

Patricia Gentry (recording officer)

Dorothy H Wallace (cleaner)

Staff who have left Research Stations Division since the last Annual Report

A John Senior (G)

David Fleming (H)

Lilian Thomson (H)

David A Henderson (H)

Colin Blackie

INSTITUTE STAFF

ADMINISTRATION DIVISION

Institute Secretary,
Robert B Devine, DPA, MIM

Institute Deputy Secretary/Finance Officer,
David T Wilkinson, MA

Secretary's secretary,
Eileen J Cockburn

Financial and general administration,
Christina M R Burness
Murray G C Mainland
Catherine B Adams
Elaine T Watson
Janice M Laing
Jacqueline S Wales

Secretaries/typists,
Margaret W Forsyth
Christian T Garden
Iona M Shand
Carol A Smith
Aileen Stewart
Susan King
Joyce H Pirie
Heather Cunningham
Nicola G Paterson

Telephonist,
Roberta M Simpson

Stores,
Lynne Thomson

Library,
Anne H W Dickie, ALA, M.I.Inf.Sc.
Lorraine E Wilson, BA, Dip.Ed.

Publications and Graphics,
William S Shirreffs
Patricia R Carnegie
Caroline C Milne
David J Riley

Dining Room,
Sheila W M Angus
Kathleen I Dow
Hazel A Mutch
Elizabeth M Strachan

Cleaners,
Elsie M Gardiner
Margaret Kindness
Joyce McAllan
Vilma Main
Agnes M Rennie
Patricia Robertson
Margaret A Walker

Outdoor staff,
Brian N Kemp (head groundsman)
Graham A S Davie (groundsman)
John S West (groundsman)

Security staff,
Fred Brand
John R Ewen
William L W Ross
Allan E J Rhynas
Wilfred F Wallace

Others,
James Robertson

Staff who have left Administration Division since last Annual Report
Fiona Cormack
Dorothy Gall
Peter Newbould
Alexander Stewart
Doris McCombie (transferred to Analytical Division)

INSTITUTE STAFF

SASS STAFF BASED AT MLURI

Head,

Steve T Buckland, B.Sc., M.Sc., Ph.D.

Other staff,

Steve J Beaney, B.Sc.

David L Borchers, BA., B.Sc.

Karen L Cattanach, B.Sc., M.Sc.

Betty I Duff, B.Sc.

David A Elston, BA, M.Sc.

HONORARY FELLOWS

G Anderson, B.Sc., Ph.D.

J F Darbyshire, B.Sc., MSc., Ph.D.

Miss E J Dey, MBE

J Eadie, B.Sc.

Miss E A Piggott, OBE

Mrs A F Stewart, MA

T S West, CBE, FRS

E G Williams, B.Sc., Ph.D.

HONORARY ASSOCIATES

P C DeKock, M.Sc., D.Phil.

V C Farmer, B.Sc., Ph.D., C.Chem., FRSC, FRSE

R Glentworth, BSA (Manitoba), Ph.D.

R Grant, MA, B.Sc.

R H E Inkson, B.Sc., FSS, FIS

R C Mackenzie, D.Sc., Ph.D., FGS, FRSE

J W S Reith, B.Sc., C.Chem, FRSC

R A Robertson, OBE, B.Sc.

A M Ure, B.Sc., Ph.D., C.Chem., FRSC

HONORARY RESEARCH ASSOCIATE

Professor H G Miller, B.Sc., Ph.D., D.Sc., FI (For.)

Early winter snow, Aberdeenshire

VISITING WORKERS

April 1991 to December 1992

LAND USE DIVISION

Dr Jan Feranec, Institute of Geography. Bratislavia, Czechoslovakia

Dong Hong Lin, Ningxia Academy of Agroforestry Sciences, Yinchuan, Ningxia Autonomous Region, People's Republic of China

Frantisek Zemek, Institute for Landscape Ecology, Czechoslovakia

Glynis Read, Department of Geography, Royal Holloway and Bedford New College, Egham, Surrey, UK

Dr V Sucha, Institute of Geology, Bratislava, Czechoslovakia

Miquel Vidal, Department of Analytical Chemistry, University of Barcelona, Spain

SOILS AND SOIL MICROBIOLOGY DIVISION

Maria Alba, Department of Inorganic Chemistry, University of Seville, Spain

Isabel Alonso, University of Leon, Spain

Carla Andrade, Instituto Politecnico de Castelo Branco, Portugal

Kiran Angadi, Department of Geology, University of Birmingham, UK

Dr Irena Atanassova, Nikolai Pushkarov Institute for Soil Science and Agrochemistry, Sofia, Bulgaria

Dr B Bezvodova, Geological Survey of Prague, Czechoslovakia

Enrico Casati, Instituto di Agronomia, Universita degli Studi, Milan, Italy

Miguel Angel Castro, CSIC, University of Seville, Spain

Farai Chimeura, Department of Soil Science, University of Zimbabwe, Zimbabwe

Dr Anna Chlopecka, Institute of Soil Science and Plant Cultivation, Pulawy, Poland

Guiseppe Corti, Department of Soil Science and Plant Nutrition, University of Florence, Italy

Dr Cui Zhen Dong, Chinese Academy of Sciences, Beijing, China

Dr Thomas Forge, University of Minnesota, USA

Stephanie Glendinning, Department of Civil Engineering, University of Loughborough, UK

Adine Hird, Department of Agriculture and Environmental Science, University of Newcastle,UK

Dr Miodrag Jakovljevic, Faculty of Agriculture, University of Belgrade, Yugoslavia

Dr Nikola Kostic, Faculty of Agriculture, University of Belgrade, Yugoslavia

PLANTS DIVISION

Isabel Alonso, University of Leon, Spain

Pedro Alpendre, Department of Fitotecnia, University of Evora, Portugal

Professor Alfonso Escudero, University of Salamanca, Spain

Dr Robert Habib, INRA Agronomy Station, Avignon, France

Professor S Haque, Bangladesh Agricultural University

Dr Peter Kemp, Massey University, New Zealand

Pedro Ochoa, Institute of Agronomy, Lisbon, Portugal

Miquel Vidal, University of Barcelona, Spain

ANIMALS AND GRAZING ECOLOGY DIVISION

Dr Snejana Alexieva, Institute of Animal Science, Rostinbrod, Bulgaria

Roberto Ruiz de Azua, SIA, Vittoria, Spain

Dr F Bermudez, CSIC, Leon, Spain

Mr Christian Bretagne, Ecole Superieure d'Agriculture, Angers, France

Phillipe Cherdel, Ecole Superieure d'Agriculture, Angers, France

Dr Paloma Cuartas, Institute Piremaico de Ecologia, Jaca, Spain

Mr Daniel Delaunay, Ecole Superieure d'Agriculture, Angers, France

Ms Silvana Divierio, Veterinary Faculty, University of Perugia, Italy

Dr Joe Folse, Texas A & M University, USA

Dr Torstein Garmo, Agricultural University, As, Norway

Dr Jesus Gonzalez, University of Leon, Spain

VISITING WORKERS

Frederic Leonard, Ecole Superieure Agricole, Lempdes, France

Dr Clare Macarthur, Monash University, Melbourne, Australia

Teresa C Magro, Universidade de São Paulo, Brazil

Dr Angel Mantecon, University of Leon, Spain

Ignacio Marco-Sanchez, Veterinary Faculty, University of Barcelona, Spain

J Alfonso Abecia Martinez, University of Zaragoza, Spain

Silvana Mattiello, Instituto di Zootecnia, University of Milan, Italy

John D Milne, IERM, University of Edinburgh, UK

Carmen Olivan Garcia, Centro de Experimentacion Agraria, Asturias, Spain

Dr Juan Plaza, SIA, Extremadura, Spain

Professor Maciej T Rogalski, Agricultural University of Pozman, Poland

Victor Jamerz Rojas, Servicio de Investigacion Agraria de Extremadura, Badajoz, Spain

Bernard Roncin, Ecole Superieure d'Agriculture, Angers, France

Dr Gete da Rosa, Universidade Federal de Mato Grosso do Sul, Camp Grande, Brazil

Dr Roberto Rubino, ISZ, Potenza, Italy

Dr Maria Sitzia, Instituto di Agronomia dell'Universita, Sassari, Italy

Dr Jane C Wheeler, University of Colorado, USA

Visiting workers at MLURI.

POSTGRADUATE RESEARCH STUDENTS

April 1991 to December 1992

(with University and Funding source)

* current workers, December 1992

LAND USE DIVISION

PhD

Tom R Anderson, University of Edinburgh, SOAFD

Steve Green, University of Edinburgh, SOAFD

* Rob Macfarlane, University of Aberdeen, SOAFD
* Charles Muchoki, University of Aberdeen, Rockefeller Foundation

MSc

Jacob Aidoo, University of Aberdeen, British Council

Etienne Bresch, University of Aberdeen, EEC Social Fund

Merial Brown, University of Dundee, SEC

Rhona Dennis, University of Aberdeen, Huntings Survey

Pilar Flores, University of Aberdeen, EEC Social Fund

Anna Gonzalez, University of Aberdeen, EEC Social Fund

Alan M Hampson, University of Stirling, self-funded

Ioannis Sotiropoulos, University of Aberdeen, Private

John Kwabena Tufour, University of Aberdeen, funded by University of Aberdeen

* Anna Tyler, University of Aberdeen, Scottish Forestry Trust

Diploma in Agriculture

Christelle Martin, Ecole D' Agriculture, French Government

SOILS AND SOIL MICROBIOLOGY

PhD

* Peter Anderson, University of Strathclyde, SERC, CASE (jointly with Plants Division)

Manas Ranjan Banerjee, University of Aberdeen, Rotary International

G Campbell, University of Aberdeen

Jonathan Fulford, University of Dundee

* Saman Hettiarachchi, University of Aberdeen, Sri Lankan Government
* Kirsty MacPhee, University of Aberdeen, DOE
* Rory Maguire, University of Aberdeen, EC (jointly with Plants Division)
* Diane Mitchell, University of Aberdeen, EC (jointly with Plants Division)
* Jason Owen, University of Aberdeen, Thomas Tait Studentship
* Graeme Paton, University of Aberdeen, Joint Research Studentship
* Simon Peacock, University of Aberdeen, EEC/SOAFD

Hazel Tapp, Department of Chemistry, University of Birmingham

* Maureen Young, Robert Gordon University

MSc

Paola Adamo, University of Aberdeen, CRN, Italy

Alessandro Gimono, self-funded

Morgan M Wairiu, University of Aberdeen, ODA/ Solomon Island Government

* Shen Zhongyue, University of Aberdeen, Watts, Blake & Bearne plc.

PLANTS DIVISION

PhD

* Peter Anderson, University of Strathclyde, SERC, CASE (jointly with Soils and Soil Microbiology Division)
* Amanda Cook, University of Aberdeen

John Dicks, University of Aberdeen, Pentlands Scotch Whisky Research Ltd

Anura Dissanayake, University of Aberdeen, World Bank

* James Green, University of Stirling, NERC
* Loutfy Ibrahim, University of Aberdeen, self-financed

Elizabeth Lavender, University of Aberdeen, AFRC

* Rory Maguire, University of Aberdeen, EC (jointly with Soils and Soil Microbiology Division)
* Diane Mitchell, University of Aberdeen, EC (jointly with Soils and Soil Microbiology Division)
* Zakia Parveen, University of Aberdeen
* Lola Ron Vaz, University of Aberdeen, Spanish Government

Loku Somasiri, University of Aberdeen, World Bank

MSc

V P Caraballo, University of Aberdeen, EEC Social Fund

Dolores Falcon di Pineda, University of Aberdeen, EEC Social Fund

A M Farran, University of Aberdeen, EEC

E Fisher, University of Aberdeen

POSTGRADUATE RESEARCH STUDENTS

Marion G Hill, University of Aberdeen

P Mandalazi, University of Aberdeen, FAO

W Morrison, University of Aberdeen

Chris O'Hara, University of Aberdeen

* Hari K Pant, University of Aberdeen, ODA

ANIMALS AND GRAZING ECOLOGY DIVISION

PhD

* Luis Pinto de Andrade, University of Edinburgh, Portugese Government/British Council
* Susan Borwick, University of Aberdeen, SERC CASE Studentship
* Mariecia D Fraser, University of Edinburgh, SOAFD
* John Hadjigeorgiou, University of Aberdeen, Greek Government
* Ian Hulbert, University of Aberdeen, NERC

I Mainland, University of Sheffield

* Anna Murray, University of Aberdeen, SOAFD
* Manuel del Pozo Ramos, University of Aberdeen, NERC CASE Studentship

Katherine Pritchard, University of Nottingham, AFRC

* Fiona Stewart, University of Aberdeen, NERC CASE Studentship
* Iain Stevenson, University of Cambridge, SERC

MSc

H Hermann, Institute of Ecology and Resource Management, University of Edinburgh

P Tobin, Institute of Ecology and Resource Management, University of Edinburgh

Mohammed Zailani, University of Edinburgh, British Council

Postgraduate research students at MLURI.

STAFF VISITS ABROAD
April 1991 to December 1992

(funded by SOAFD unless stated otherwise)

DIRECTOR'S GROUP

Professor T J Maxwell. IV International Rangelands Congress, Montpellier, France, April 1991.

Professor T J Maxwell. Australian Society of Animal Production Nineteenth Biennial Conference, Melbourne, Australia, 5-9 July 1992; ASAP Branch Meeting, CSIRO Division of Plant Industry, Canberra; visit to University of Adelaide and Department of Agricultural Technology and Environmental Science and Rangeland Management, Adelaide; visit to the Pastoral and Veterinary Research Institute, Victoria Department of Food and Agriculture, Victoria; seminar on Animals in Agroforestry, School of Agriculture, University of Western Australia, Australia, July 1992.

P Newbould. Marianski Lazue, Czech Republic, to visit a possible site for the headquarters of a proposed Czech/ Scottish Institute; Prague, Czech Republic, for discussions with ministry officials and architects on the feasibility of designing and constructing a new HQ/laboratory building in Czechoslovakia, 12-16 August 1991.

P Newbould. Workshop in Brno, Czech Republic, on the proposed establishment by the Czech Republic of a Czech/ Scottish Institute for Ecology and Use of Hill Regions; visit to Institute of Animal Production, Prague, Czech Republic; visit to Institute of Soil Fertility, Bratislava, Slovakia to draw proposals for joint work on aspects of environmental pollution, 5 - 9 October 1992.

LAND USE DIVISION

R J Aspinall. 1st International Conference/Workshop on Integrating GIS and Environmental Modelling, Boulder, Colorado, USA, 15 - 19 September 1991.

R J Aspinall. GIS/LIS '91 Conference, Atlanta, Georgia, USA, 28 October - 1 November 1991 (self funded).

R J Aspinall. Ottawa, Ontario, Canada. Energy Mines and Resources, Canada Centre for Remote Sensing, Environment Canada, Tomlinson Associates, August 1991 (self funded).

R J Aspinall. European Research Conference on Tools for 3D Spatial Analysis, Castelveccio Pascoli, Italy, 31 May - 4 June 1992.

R J Aspinall. 5th International Symposium on Spatial Data Handling, Charleston, South Carolina, USA, 3 - 7 August 1992.

R J Aspinall. Centre for Biosystems Modelling, Forestry, Fisheries and Wildlife, Geography, Entomology and Agricultural Engineering, Texas A & M University, USA, 9 - 15 August 1992.

R J Aspinall. The Noble Foundation, Ardmore, Oklahoma, USA, 15 - 17 August 1992.

R J Aspinall. IUFRO meeting, Berlin, Germany, 28 August - 5 September 1992.

R J Aspinall. GIS/LIS '92 Conference, San Jose, California, USA, 9 - 13 November 1992.

R J Aspinall. National Centre for Geographic Information and Analysis, and Remote Sensing and Biogeography Centre, University of California, Santa Barbara, USA, 16 - 20 November 1992 (self funded).

R J Aspinall. NASA Ames Research Centre, USA, 21 - 22 November 1992 (self funded).

R V Birnie. Seminar on the Application of Remote Sensing for Forestry, Copenhagen, Denmark, 13 - 15 November 1991 (EC funded).

R V Birnie. European Collaborative Programme Workshop on Grassland Classification and Mapping, Paris, France, 28 - 29 April 1992 (EC funded).

R V Birnie. National Centre for Geographical Information and Analysis, Santa Barbara, USA, 8 December 1992.

J R Crabtree, to discuss an EC submission, Brussels, Belgium, 11 - 15 November 1991.

J R Crabtree. 30th Seminar of the European Association of Agricultural Economists, Chateaux D'Oex, Switzerland, 11 November 1992.

J R Crabtree. 28th Seminar of the European Association of Agriculture Economics, Lisbon, Portugal, 10 September 1992.

G Hudson. Centre de Geostatistique, Fontainebleau, France, 1 April - 30 June 1991.

G Hudson. GIS and Geostatistics in Soil Science Workshop, Montpellier, France, 29 - 30 April 1991 (self funded).

G Hudson. Pedometrics - 92: Developments in Spatial Statistics for Soil Science, International Agricultural Centre, Wageningen, The Netherlands, 1 - 3 September 1992.

G Hudson. Fuzzy Classification Workshop, Agricultural University, Wageningen, The Netherlands, 4 September 1992.

G Hudson. Centre de Geostatistique, Fontainebleau, France, 7 - 8 September 1992.

G Hudson. 4th International Geostatistics Congress, Troia, Lisbon, Portugal, 13 - 18 September 1992.

STAFF VISITS ABROAD

N J Hutchings. INRA-Systemes Agraires et Developpement Department, France.

N J Hutchings. Plant Ecology Group Workshop, Lusignan, France, 1 - 2 October 1991.

N J Hutchings. Danish Institute of Plant and Soil Science, Research Centre, Foulum, Denmark. Sabbatical from August 1992.

N J Hutchings. 2nd European Livestock Systems Symposium, Zaragoza, Spain, 11 - 12 September 1992.

N J Hutchings. Visit to Professor A. Korner, University of Kiel, Germany, November 1992.

A Lilly. Pedometrics - 92: Developments in Spatial Statistics for Soil Science. 1st Conference of the Working Group on Pedometrics of the International Soil Science Society, Wageningen, Netherlands, 1 - 3 September 1992.

Dong Hong Lin. Poplar Research Centre, Belgium, 17 - 20 September 1991.

D C Macmillan. European Association of Environmental and Resource Economists, Stockholm, Sweden, 12 - 15 June 1991.

D C Macmillan. European Association of Environmental and Resource Economists, Krakow, Poland, 16 - 19 June 1992.

D C Macmillan. European Association of Environmental and Resource Economists, Autumn Seminar, Venice, Italy, 1992.

K B Matthews. Global Climate Change Conference, Bad Durkheim, Germany, 14 - 18 June 1992.

D R Miller. Institute of Photogrammetry, University of Stuttgart; Department of Ecology, University of Bayreuth; and Department of Land Use, Technical University, Munich, Germany, 9 - 15 August 1991 (self funded).

D R Miller. 1st International Conference/Workshop on Integrating GIS and Environmental Modelling, Boulder, Colorado, USA, 15 - 19 September 1991.

D R Miller. GIS/LIS `91 Conference, Atlanta, Georgia, USA, 28 October - 1 November 1991.

D R Miller. 5th International Symposium on Spatial Data Handling, Charleston, South Carolina, USA, 3 - 7 August 1992.

D R Miller. Centre of Biosystems Modelling, Forestry, Fisheries and Wildlife, Geography, Entomology and Agricultural Engineering, Texas A & M University, USA 9 - 15 August 1992.

D R Miller. The Noble Foundation, Ardmore, Oklahoma, USA, 15 - 17 August 1992.

D R Miller. Photogrammetric Week, Institute for Photogrammetry, University of Stuttgart, Stuttgart, Germany, 2 - 6 September 1992 (self funded).

D R Miller. GIS/LIS '92 Conference, San Jose, California, USA, 9 - 13 November 1992.

D R Miller. National Centre for Geographic Information and Analysis, and Remote Sensing and Biogeography Centre, University of California, Santa Barbara, USA, 16 - 20 November 1992 (self funded).

D R Miller. NASA Ames Research Centre, USA, 21 - 22 November 1992 (self funded).

D R Miller. National Centre for Geographic Information, Lisbon, Portugal, 4 - 9 December 1992 (self funded).

A R Sibbald. INRA-Systemes Agraires et Developpement Department, France.

A R Sibbald. 2nd International Livestock Systems Research Conference, Zaragoza, Spain, 11 - 12 September 1992.

A R Sibbald. Poplar Research Centre, Belgium, 17 - 20 September 1991.

W Towers. Soil Pollution and Protection, an International postgraduate course, Belgium, 11 -16 May 1992.

SOILS AND SOIL MICROBIOLOGY DIVISION

H A Anderson. Gordon Conference, Plymouth, New Jersey, USA, 29 June - 3 July 1991.

J R Bacon. 12th International Mass Spectrometry Conference, Amsterdam, Holland, 26 - 30 August 1991.

J R Bacon. Workshop on Sequential Extraction in Sediments and Soils, Sitges, Spain, 29 March - 1 April 1992 (EC funded).

D C Bain. 2nd International Symposium on Environmental Geochemistry, Uppsala, Sweden, 16 - 19 September 1991.

D C Bain. 7th Euroclay Conference, Dresden, Germany, 26 - 30 August 1991 (supported by the Mineralogical Society).

C N Bedrock. 6th International meeting of the International Humic Substances Society, Bari, Italy, 20 - 25 September 1992.

C D Campbell. Eurosoil: European Conference on Integrated Research for Soil and Sediment Protection and Remediation, Maastricht, Netherlands, 6 - 12 September 1992.

M V Cheshire. 6th International meeting of the International Humic Substances Society, Bari, Italy, 20 - 25 September 1992.

R C Ferrier. MAGIC Working Group, Captiva, Florida, USA, 3 - 11 January (part funded by the Norwegian Institute Water Research).

R C Ferrier, Lake Gardjon, Sweden, 30 June - 7 July 1992 (EC funded).

R C Ferrier. Ecosystems Manipulation Conference, Copenhagen, Denmark, 18 - 24 May 1992.

D Jones. INRA, Lusignan, France, 9 - 11 October 1991 (part INRA funded).

D Jones. SEM International Conference, Chicago, Illinois, 11 - 15 May 1992 (part funded by SEM International, part self-funded).

S J Langan. University of Lund, Sweden, to discuss critical load work across Europe, 21 - 28 September 1991 (supported by the Department of the Environment).

A MacDonald. Global Climate Change Conference, Bad Durkheim, Germany, 14 - 18 June 1992.

M Thurlow. Global Climate Change Conference, Bad Durkheim, Germany, 14 - 18 June 1992.

M J Wilson, to promote collaborative work on mineral weathering and heavy metal pollution with Institute of Materials Sciences, Seville, Spain, 11 - 15 November 1991 (British Council funded).

M J Wilson. EUROLAT Conference, Berlin, Germany and 7th Euroclay Conference, Dresden, Germany, 23 - 30 August 1991.

M J Wilson. ENCORE Project Meeting, Strasbourg, France, 24 - 27 September 1991 (EC funded).

M J Wilson. Faculty of Agriculture, Belgrade, Yugoslavia and Tuzla, Bosnia, to promote collaborative work on heavy metals and to attend Yugoslav Soil Science Society Meeting, 10 - 15 June 1991 (British Council funded).

M J Wilson. 2nd International Association of Lichenologists Symposium, Bastad, Sweden, 30 August - 4 September 1992 (part IAL funded).

M J Wilson. Workshop in Brno on the proposed establishment by the Czech Republic of a Czech/Scottish Institute for Ecology and Use of Hill Regions; and visit to Institute of Soil Fertility, Bratislava to discuss proposals for joint work on aspects of environmental pollution; and International Potash Institute, Prague, 5 - 18 October 1992 (part IPI funded).

M J Wilson. Joint meeting of the Clay Minerals Society/ Soil Science Society of America, Minneapolis, USA, 2 - 6 November 1992 (part CMS funded).

PLANTS DIVISION

S Allison. Global Climate Change Conference, Bad Durkheim, Germany, 14 - 18 June 1992.

A C Edwards. Department of Agricultural Science, University of Naples, Italy, 5 - 19 June 1992 (British Council funded).

A C Edwards. 4th International IMPHOS Conference, Belgium, 8 - 11 September 1992.

A E S Macklon. University of Florence, Italy and University of Athens, Greece, 14 - 21 November 1991 (part-funded by British Council).

C A Marriott. Centro di studio sul miglionamento della produttivira dei pascoli, Sassari, Sardinia, 25 March - 1 April 1992 (British Council funded).

C A Marriott. Plant Ecology Group Workshop, Lusignan, France, 1 - 2 October 1991.
P Millard. Universities of Madrid and Salamanca, Spain, 26 July - 1 August 1991 (British Council funded).

P Millard. INRA Agronomy Station, Avignon, France, 23 - 27 September 1991 (British Council funded).

P Millard. STEP project co-ordination meeting, Bayreuth, Germany, 5 - 11 November 1991 (EC funded).

P Millard. Conference on the effects of elevated C02 levels, air pollutants and climate change on natural plant ecosystems - impact on tree physiology, Aghia Pelaghia, Crete, 3 - 7 April 1992.

P Millard. 5th International Colloquium on Plant Nutrition, Lisbon, Portugal, 31 August - 8 September 1992 (EC funded).

P Millard. EC collaborators meeting, Spain, 12 - 17 November 1992.

M F Proe. IEA/BE T6/A6 Workshop, Vaxjo, Sweden (part-funded by ETSU).

B Thornton. Walz, Effeltrich, Germany, 12 - 15 December 1991 (part funded by Walz).

D Vaughan. Teagasc and Trinity and University Colleges, Dublin, Cork and Galway, Eire, 16 September - 2 October. (EC funded).

D Vaughan. 3rd International Nordic Symposium on Humic Substances, Turku, Finland, 19 -23 August 1991 (Nordic Humus Society funded).

D Vaughan. Agricultural Research Institutes in Prague and Bratislava, Czechoslovakia, 16 -27 March 1992 (British Council funded).

D Vaughan. Institute of Crop Production, Prague, Czechoslovakia, October 1992, as a member of an International Science Group reviewing that Institute's research programme.

R Wendler. STEP project co-ordination meeting, University of Bayreuth, Germany, 5 - 11 November 1991 (EC funded).

R Wendler. Instituto Superior de Agronomia, Lisbon, November 1991 - March 1992 (EC funded).

B L Williams. Evora, Portugal, 13 - 18 January 1992 (British Council funded).

B L Williams. 1st Symposium on Terrestrial Ecosystems: Forests and Woodlands, Florence, Italy, 20 - 24 May 1991.

B L Williams. 9th International Peat Congress, Uppsala, Sweden, 22 - 27 June 1992.

ANIMALS AND GRAZING ECOLOGY DIVISION

H Armstrong. IV International Rangelands Congress, Montpellier, France, April 1991.

H Armstrong. Texas A&M University, USA, October 1991.

G T Barthram. 6-month study period, October 1991 - March 1992, at Massey University, New Zealand (British Council funded).

A J Duncan. INRA, Jony en Josas, 9 October 1992, and CNR, Potenza, Italy, 12 - 16 October 1992 (British Council funded).

K D Farnsworth. Texas A&M University, USA, to develop spatial models of animal/environment interactions, 5 October - 8 November 1992.

I J Gordon. IV International Rangelands Congress, Montpellier, France, April 1991.

I J Gordon. EEC Workshop on Grazing Herbivores, Bella, Naples, Italy, 10 - 14 November 1991 (EC funded).

I J Gordon. Texas A&M University, USA, 3 - 9 November 1991.

I J Gordon. University of Tromso and Nature Conservancy Council, Trondheim, Norway, 17 - 22 October 1991 (funded by University of Tromso).

S A Grant. Plant Ecology Group Workshop, Lusignan, France, 1 - 2 October 1991.

W J Hamilton. EC project co-ordination meeting, National Institute of Animal Science, Folum, Denmark, 5 - 9 August (EC funded).

A J Hester. International Association for Vegetation Science Symposium, Eger, Hungary, 26 - 30 August.

A J Hester. Conference on disturbance related dynamics of birch and birch-dominated ecosystems, Illugastadir, Iceland, 18 - 22 September 1992.

C Howard. EC project co-ordination meeting, Teagasc, Galway, Eire, May (EC funded).

C Howard. EC project co-ordination meeting, Asturia, Spain, 6 - 10 July 1992 (EC funded).

G R Iason. University of Leon, Spain, July - August (British Council funded).

G R Iason. Browse/Browsers Forum and Workshop, University of Witwatersrand, South Africa, 19 - 26 October 1992.

C S Lamb. EC project co-ordination meeting, Teagasc, Eire, 5 - 9 August (EC funded).

P Lynch. European Hair Research Society, Berlin, Germany, 3 - 4 October 1992.

R W Mayes. Agricultural Research Institute, Iceland, 12 - 19 October 1991 (NATO funded).

R W Mayes. EC project co-ordination meeting, Teagasc, Eire, 5 - 9 August (EC funded).

R W Mayes. European Association of Animal Production, Berlin, 8 - 9 September 1991.

R W Mayes. International Union of Radiologists, Uppsala, Sweden, 11 - 12 September 1991 (EC funded).

R W Mayes. CEC Workshop on age-dependent factors on radiation dosimetry, Garmisch, Germany (EC funded).

J A Milne. IV International Rangelands Congress, Montpellier, France, April 1991.

J A Milne. European Conference on Wild Livestock Management, Grado, Italy, 10 - 12 October 1991 (funded by Italian Government).

J A Milne. INRA, Clermond-Ferrand, France, 24 March 1992 (INRA funded).

J A Milne. 7th Research Meeting on Nutrition of Herbivores, Paris, France, 25 March 1992 (INRA funded).

J A Milne. EC Consultancy, SIA Extremadura, Spain, May 1991 (EC funded).

STAFF VISITS ABROAD

J A Milne. Assessor for the EC Agriculture and Agro-Industry Research Programme, Brussels, Belgium, October 1991 and February 1992 (EC funded).

J A Milne. SNICEF International Symposium, Bordeaux, France, 29 - 30 September 1992.

S M Rhind. 12th International Congress in Animal Reproduction, The Hague, Netherlands, August 1992.

A J F Russel. Cashmere study visit to Australasia (part funded by Cashmere Breeders Ltd).

A J F Russel. IAEA Co-ordinated Research Programme on Camelids, Morocco, July (IAEA funded).

A J F Russel. University of Santiago, Chile, August 1991 (British Council funded).

A J F Russel. EC Seminar on New Development in Goat Husbandry for Quality Fibre Production, Lisbon, Portugal, 27 - 29 October 1992.

D A Sim. University of Leon, Spain, July - August 1991 (British Council funded).

I A Wright. EC project co-ordination meeting, Teagasc, Galway, Eire, May (EC funded).

I A Wright. University of Leon, Spain, January 1992.

I A Wright. EC project co-ordination meeting, Asturia, Spain, 6 - 10 July 1992.

ANALYTICAL DIVISION

A C Birnie. Third Seminar on Soil Analysis, Blois, France, 13 - 14 November 1991.

A Smith. Meeting on Selective Chemistry Analysis, Helsinki, Finland, 6 - 8 November 1991.

A group of the participants at a Soil Pollution and Soil Protection course in Gent, Belgium which was attended by Willie Towers, Land Use Division (back row second from right).

Dr Richard Birnie, head of Land Use Division, with Mr Andy Wightman (left), development officer for Reforesting Scotland, participating in a study tour to western Norway.

Maddie Thurlow, MLURI, Soils Division with Dr Ken-ichi Kanda and Dr. Katsu Minami, from the National Institute of Agro-Environmental Sciences, Tsukuba, Japan. The equipment is for monitoring methane emissions from paddy fields at Ryugasaki Field Station.

PROGRAMME of RESEARCH

April 1991 to December 1992

PROGRAMME UNIT 11

Land use options and impacts on natural and human resources

Current research

011148 Develop and test land use suitability models (G Hudson)

011150 Assessment procedures in wide area conservation evaluation (R J Aspinall)

011013 Field testing of low input upland sheep systems (A R Sibbald)

011803 Field testing of upland beef cow systems (I A Wright)

011151 Modelling and field testing of silvopastoral systems (A R Sibbald)

011152 Modelling upland sheep systems (N J Hutchings)

011153 Decision-support models for assessing land use options at the farm level (A R Sibbald)

011157 Use of GIS techniques with process-based environmental assessment procedures for water quality modelling (D R Miller)

011159 Land suitability/risk assessment in relation to the disposal of wastes rich in heavy metals (W Towers)

011847 Development of a GIS-based screening procedure for assessing the potential effects of climate change on Scottish agriculture (K B Matthews) [SOAFD Flexible Funding]

011160 To model effects of rainfall variability on soil water regimes (A Lilly)

011161 Relationships between changes in agricultural intensity and land use on the nitrate and phosphate loadings of Scottish river systems (G G Wright)

011162 Application of remote sensing to land use change and agricultural statistics: towards a strategic European Advanced Agricultural Information System (G G Wright)

011163 Development of the Macaulay Land Use Information and Modelling System [MLUIMS] (C H Osman)

011164 Use of knowledge-based systems and geostatistical techniques in land use modelling procedures (A N R Law)

011236 Integration of land cover and ecological information from MLURI and ITE surveys to provide an enhanced and co-ordinated land cover database for Scotland (N A Brooker) [SOAFD Flexible Funding]

011278 GIS Planning at MLURI (R J Aspinall) [SOAFD Flexible Funding]

011281 Assessment of tourist attitudes to landscape amenity value in Scotland (R V Birnie) [SOAFD Flexible Funding]

PROGRAMME UNIT 12

Soil and the environment

Research projects completed since April 1991

012258 Upgrading of long-term monitoring sites (M J Wilson) [SOAFD Flexible Funding]

012279 Determination and mapping of the heavy metal content of Scottish topsoils on a national basis (E Paterson) [SOAFD Flexible Funding]

Current research

012165 Determine environmental changes at a series of long-term monitoring sites (J D Miller)

012166 Quantify the principal hydrological and hydrochemical consequences of forestry, in relation to soil type, atmospheric inputs and management practices (J D Miller)

012167 Quantify sources and sinks of acidity under selected hill land uses, and their effects on water quality and quantity (H A Anderson)

012168 Retention and release of sulphur in upland soils by biological and other mechanisms (S J Chapman)

012169 Factors controlling the dynamics of organic matter decomposition in soil releasing organic acids and plant nutrients (M V Cheshire)

012170 Effects of acidification and metal complexant ligands on chemical speciation and mobilisation of aluminium and other toxic metals in soils and waters (D G Lumsdon)

012171 Mineral weathering in relation to the vulnerability of catchments to acidification in Southern Scotland (D C Bain)

012172 Assessment of acid sensitive waters in Scotland and of critical loads of acid deposition on Scottish soils (M J Wilson)

012173 Water resource modelling; the effect of land use change and atmospheric deposition (R C Ferrier)

012174 Assess the retention of heavy metals and major nutrients following sewage sludge application to acid soils (J R Bacon)

012175 Characterise amounts, sources and fate of heavy metals deposited from the atmosphere on Scottish soils and taken up in the food chain (J R Bacon)

012176 Determine the effects of heavy metal pollution on microbial activity, including mycorrhizas, in forest soils (C D Campbell)

012177 Investigate interactions between heavy metals and the fine-grained constituents of mineral soils (E Paterson)

012178 Effect of organic matter of soil on the cycling of radiocaesium and its availability to various upland plant species (M V Cheshire)

012179 Effect of diet quality, age and genotype on radiocaesium transfers in grazing sheep (R W Mayes)

012180 Investigate the nature and ion-exchange properties of hill and upland soils (E Paterson)

012139 Climate change (increasing temperature and altered precipitation) and CO_2/CH_4 release from the organic matter of soils and peats (S J Chapman) [SOAFD Flexible Funding]

012181 Soil response to climate change (E Paterson) [SOAFD Flexible Funding]

PROGRAMME UNIT 13

Plant-soil relations

Research projects completed since April 1991

013256 A study of leaf senescence using Nuclear Magnetic Resonance Spectroscopy (P Millard) [SOAFD Flexible Funding]

Current research

013182 Mineral nutrition and assimilate partitioning in trees, including consequences of coppicing (M F Proe) [Central Scotland Countryside Trust/ SOAFD]

013183 Effects of water and nutrient stress on root demography, architecture and turnover in deciduous trees (L A Dawson)

013185 Effect of root exudate components on the ecology of specific soil microbial populations (D Jones)

013186 Analysis of the effects of climate change on tree crops in Scotland using indicator species (S Allison) [SOAFD Flexible Funding]

013188 The effects of grazing animals on partitioning and internal cycling of nutrients and the consequences for vegetation dynamics (C A Marriott)

013189 Seasonal internal cycling of nitrogen in evergreen and deciduous trees and the consequences for nutrient use efficiency (P Millard)

013190 Leaf surface exchange of atmospheric inputs acting as pollutants or potential nutrients and their interactions with internal cycling and growth potential of trees (A E S Macklon)

013191 Seasonal nutrient storage in evergreen and deciduous trees in relation to nutrient supply, leaf and root demography (P Millard)

013192 Soil physical conditions and effects on activities of microbial populations (B L Williams)

013194 Organic matter turnover in upland soils and its relationship with N and P transformations and availability to plants (B L Williams)

013196 Dynamics of phosphorus depletion and repletion, and forms in soil solution in relation to plant growth (C A Shand)

013846 Dynamics of phosphorus forms in organic soils and utilisation by clover (C N Bedrock) [SOAFD IFS]

013197 Availability of nutrients, particularly phosphorus, in acid soils with a high organic matter content (A C Edwards)

013198 Influence of soil phosphorus dynamics and interactions with iron, manganese and aluminium on uptake, exchange and assimilation of phosphorus by *Agrostis tenuis* and *Lolium perenne* (A E S Macklon)

013199 Factors affecting nutrient source/sink relations on second-rotation forest sites (M F Proe) [Forestry Commission/SOAFD]

013289 Shade adaptation by indigenous grasses and the consequences for carbon assimilation, growth and vegetation dynamics (B Thornton)

013290 Influence of management practices on root exudates produced by contrasting tree species and their impact on microbial activity and cation availability in soils (D Vaughan)

PROGRAMME UNIT 14

Plant-animal relations

Research projects completed since April 1991

014201 The effect of grazing by species of ruminant on diet composition and proportion of *Nardus* in acid grassland (S A Grant)

014202 The effect of cattle grazing on the floristic composition and nutritive value of *Molinia* grassland (S A Grant)

014212 Grazing strategies with goats to reduce the vigour of weed species in sown swards (M Merchant)

014120 Modelling the agricultural and environmental consequences of sheep and red deer grazing heather moorland (H Armstrong) [IFS]

014211 Effect of sward composition and structure on sward growth rate and ingestive behaviour of herbivores in the autumn (R H Armstrong)

014257 Artificial intelligence modelling of foraging strategy (I J Gordon) [SOAFD Flexible Funding]

Current research

014203 The effect of grazing intensity by sheep on vegetation dynamics and diet selection in species-poor *Agrostis-Festuca* grassland (P D Hulme)

014204 Approaches to aiding rehabilitation of degraded heather stands (P D Hulme)

014205 Interactions between burning and grazing by sheep on floristic change in different variants of Atlantic heather moor (A J Nolan)

014206 Phenology and morphology of ryegrass and white clover in relation to climate and grazing strategies (S A Grant)

014207 The development of spatial heterogeneity and persistence of white clover in swards grazed by sheep (C A Marriott)

014208 Changes in floristic composition, diet selection and soil nutrients of grazed sown swards under nutrient stress (C A Marriott)

014209 Develop and test foraging strategy theories for herbivores grazing mixed hill vegetation (I J Gordon)

014142 The influence of vegetation pattern on the foraging strategy, plant dynamics and population ecology of sheep and deer (I J Gordon) [SOAFD Flexible Funding/JAEP]

014210 Assessment of diet composition and behaviour of ruminants grazing indigenous hill vegetation (R W Mayes)

014213 Factors influencing the intake, diet selection and foraging behaviour of goats (M Merchant)

014214 Diet selection by sheep grazing ryegrass/clover swards differing in the distribution of clover in the sward (R H Armstrong)

014215 The effect of the structure of herbage on foraging strategies of sheep (R H Armstrong)

014216 Diet selection and intake by camelids and goats grazing indigenous hill plant communities (I J Gordon)

014143 Factors influencing the selection of individual plants within species by herbivores (G R Iason) [SOAFD Flexible Funding/JAEP]

014217 Prediction of herbage intake by grazing ruminants from a study of physiological factors (A M Sibbald)

014218 Free radical stress induced by the ingestion of secondary plant compounds by ruminants (D B McPhail)

014219 The influence of physiological status on diet selection by ruminants (I J Gordon)

014220 The nature and extent of herbivore adaptation to ingestion of plant secondary compounds (G R Iason)

014221 Energetic constraints on ruminants: the role of sheltering behaviour, feeding ecology and seasonal energetic variation (G R Iason)

014284 Development of computer models to predict the effects of grazing by herbivores on plant community composition and dynamics (H Armstrong)

014285 Effect of grazing on the competitive ability of tussock and prostrate species (S A Grant)

014286 Modelling the foraging strategy of herbivores in heterogeneous ecosystems (K D Farnsworth)

014297 Influence of vegetation structure on faunal species diversity in indigenous ecosystems (I J Gordon) [SOAFD Flexible Funding]

014299 The development of spatial models of animal/environmental interactions (K D Farnsworth) [SOAFD Flexible Funding]

PROGRAMME UNIT 15

Ecology of grazing ruminants and resource utilisation

Research projects completed since April 1991

015098 Effect of body composition, nutrient intake on post-partum ovarian follicle activity and endocrine control in beef cows (S M Rhind)

015100 Effect of nutrient partitioning on the efficiency of resource use by beef cows of different genotypes (I A Wright)

015102 Assessment of the lifetime performance of red deer hinds (W J Hamilton)

015103 Development of hybrids between exotic deer and red deer and assessment of their potential for deer production (J A Milne)

015233 Growth and carcase composition of dual-purpose goats used for cashmere and meat production (M Merchant)

015235 The characterisation of animal fibres according to their cellular structure (A J F Russel)

Current research

015222 Impact of exposure on energy expenditure of free grazing animals (R W Mayes)

015223 Measurement of energy expenditure in grazing sheep (R W Mayes)

015224 Seasonal variation in appetite in red deer (S M Rhind)

015225 Hormone control of seasonal coat growth in cashmere goats (S M Rhind)

015141 The role of the follicle in the control of the growth and shedding of animal fibres (P Dicks) [SOAFD Flexible Funding]

015226 Fibre growth and energy expenditure of cashmere goats following shearing (M Merchant)

015227 The complementarity of sheep and cattle grazing indigenous hill vegetation (I A Wright)

015228 The complementarity of sheep, cattle and goats through the sequential grazing of sown swards (I A Wright)

015229 Effects of grazing management strategies on cattle performance and floristic composition in *Nardus*-dominated swards (I A Wright)

015230 Effects of genetically derived increased prolificacy on efficiency of resource use and welfare of sheep in different nutritional environments (A J F Russel)

015231 Modelling the influence of animal attributes on efficiency of resource use by ruminants (I A Wright)

015232 Cashmere production from goats and its improvement by crossbreeding and selection (A J F Russel)

015234 Fibre production and characteristics of fibre from camelids in upland environments (A J F Russel)

015138 Welfare aspects of the catching of wild deer for use in deer farming (P J Goddard)

015101 Performance of red deer in extensive and large scale management systems (W J Hamilton)

015259 Behavioural stress and immuno-competence in farmed deer (J A Milne) [SOAFD Flexible Funding]

015287 Effect of social behaviour on the prediction of intake and diet selection by grazing sheep (I A Wright)

015288 Speciality fibres and their role in the future use of land resources (A J F Russel)

015298 Modelling helminth larval intake in grazing ruminants (I A Wright) [SOAFD Flexible Funding]

PROGRAMME UNIT 16

Land use options and impact: environmental and socio-economics

Current research

016155 Economic effects of land conversion to forestry from agriculture with special reference to environmental effects and development of multi-objective forestry policies at regional and national levels (D C Macmillan)

016146 The extent and significance of pluriactivity in Scottish agriculture (J R Crabtree) [JAEP]

016156 Economic models in land use planning and policy development (J R Crabtree)

016158 Identify economic effects of acid deposition on water catchments in Scotland with special reference to land use change to forestry (D C Macmillan)

016277 Uptake of rural development and environmental initiatives - socio-cultural attitudes and determinants (J R Crabtree)

PROGRAMME UNIT 09

External Contracts with source of funding

Land Use Division/Resource Consultancy Unit

Contracts completed since April 1991

090838 Soil properties and land use in relation to peat and mineral extraction (J H Gauld) [SOAFD-Lands, British Coal]

090145 The measurement and analysis of land cover changes in the Cairngorms and Central Scotland with respect to interactions between agriculture, forestry, conservation and the impact of development policy (J H Gauld) [SOEnD/SOAFD Flexible Fund]

090254 Evaluation of land capability for agriculture, forestry or other uses (J H Gauld)

090269 Commercial contracts - [Misc]

090266 Soil Surveys of ITE sample 1km grid squares (J H Gauld) [ITE]

090264 Greenbelt Company (C H Osman)

090260 Peat as fuel (R V Birnie) [ETSU EEC]

Current contracts

090111 Interpretation of air photographs and development of a database expressing land cover types in Scotland (R V Birnie) [SOEnD/SOAFD]

090255 To characterise the soils, vegetation and physical attributes of the Scottish Environmentally Sensitive Areas and monitor their response to management schemes (J H Gauld) [SOAFD]

090261 The extent and significance of pluriactivity in Scottish agriculture (J R Crabtree) [JAEP]

090291 An investigation of the effect of site quality on the productivity of Douglas fir, Scots pine, Japanese larch, oak and birch on better quality land in Scotland (D C Macmillan) [Forestry Commission]

090282 Carbon sequestration in soils in Scotland (J H Gauld) [ITE]

090293 Vegetation re-survey at Loch Fleet (J H Gauld) [Scottish Power]

090309 Production of a moorland map for Scotland based on the MLURI Land Cover Database (J H Gauld) [SOAFD]

090312 Land use and heritage (J R Crabtree) [University of Aberdeen]

Soils and Soil Microbiology Division

Contracts completed since April 1991

090265 Natural History Museum (T Forge)

090251 Certified Reference Materials: Trace and Heavy Metal Analysis - BCR Organisation (J R Bacon) [CEC]

090262 British Council, Spain (M J Wilson)

090275 Literary overview covering excavation, storage and restoration of soils and peat for open cast operation (M J Wilson) [British Coal]

Current contracts

090292 Sewage sludge applications to forest soils, effects of clearfelling (R C Ferrier) [Scotland & Northern Ireland Forum for Environmental Research (SNIFFER)]

090250 Critical loads of acid deposition on soils and assessment of the distribution of acid-sensitive waters in Scotland (M J Wilson) [SOEnD]

090252 Commercial contracts - [Misc] Clay mineral analysis of soils and rocks (D M L Duthie)

090253 Monitoring acidified catchments in Galloway (R C Ferrier) [SOEnD]

090147 Biological cycling of pollutant sulphur in organic soils (H A Anderson) [EEC/ENCORE/STEP]

090249 Mineral weathering in relation to the acid neutralizing capacity of acid-sensitive catchments (M J Wilson) [EEC/ENCORE/STEP]

090294 Certified Reference Materials: Extractable Trace Elements, Stability and Homogeneity testing - BCR Organisation (J R Bacon) [CEC]

090274 British Council, Yugoslavia (M J Wilson) [British Council]

090283 Mineralogy of the ball clay resources of north and north east China (M J Wilson) [Watts, Blake, Bearne & Co]

090280 Utilisation of paper waste for agricultural purposes (M V Cheshire) [Federal Paper Board]

090303 Immobilisation of soil nitrogen by decomposing plant residues and the potential of the forms of immobilised nitrogen for remineralisation (M V Cheshire) [EC]

090304 Phosphate release potential for overfertilised soils of important agricultural areas of the European Community: Implications for the sustainability of agricultural systems and for the environment (M J Wilson) [EC]

090311 Critical loads of acidity to soil and surface waters in selected Scottish catchments (S J Langan) [DOE/NERC]

090302 The effect of livestock farming (beef and dairy cattle) activities on catchment water quality (H A Anderson) [SOAFD Flexible Funding]

Plants Division

Contracts completed since April 1991

090840 Assess the effects of agroforestry on soil condition and nutrient losses (P Newbould [EEC]

090263 Soil physical measurements in Portugal (M Goss) [NATO]

090267 The leaf demography and internal cycling of nitrogen in forest trees (P Millard) [British Council, Spain]

Current contracts

090129 Factors affecting nutrient source/sink relations during the establishment of second-rotation tree plantations (M F Proe) [Forestry Commission]

090247 Internal cycling of nitrogen in deciduous and evergreen forest trees (P Millard) [EEC]

090248 Biogeochemical cycling in agroforestry systems (P Newbould) [EEC]

090268 Modelling the growth and internal cycling of nitrogen within deciduous trees (P Millard) [British Council, France]

090270 Commercial contracts [Misc]

Animals and Grazing Ecology Division

Contracts completed since April 1991

090130 The application of reproductive technology to the deer farming industry (P J Goddard) [MAFF/Institute of Zoology]

090132 Factors influencing the selection of individual plants within species by herbivores (G R Iason/A J Duncan) [JAEP cognate with RO 014143]

090134 The influence of vegetation pattern on the distribution and foraging strategies of hill sheep and red deer and consequential effects on vegetation community dynamics (I J Gordon/A J Hester) [JAEP cognate with RO 014142]

090135 Effect of body size and vegetation structure on functional responses and foraging choices in mammalian herbivores (I J Gordon) [NERC/University of Edinburgh]

090136 Fat cover in live animals - instrumentation (A J F Russel) [SDA]

090240 Factors affecting radiocaesium transfer to ruminants (R W Mayes) [EEC]

090242 Development of a method to rapidly predict the availability of radiocaesium in ruminants (R W Mayes) [ITE]

090244 Hill land use and lagomorph ecology (G R Iason) [Forestry Commission]

090245 Studies of the transfer of S35 to milk (R W Mayes) [ITE/Nuclear Electric]

090241 Finishing lambs at pasture using dried molassed sugar beet pulp supplements (J A Milne) [Trident Feeds]

090137 The feeding behaviour of wild vertebrates in relation to the glucosinolate and SMCO content of oilseed rape (A M Sibbald) [MAFF/SCRI/Game Conservancy]

090295 Double synchronization of beef cows (I A Wright) [Intervet UK Ltd]

090296 The investigation of possible heather decline on Fair Isle (J A Milne) [NTS]

Current contracts

090119 The effect of controlled grazing on vegetation and tree regeneration in broad-leaved woodland (continuation) (A J Hester) [NCC]

090133 Advisory and development support for HIDB deer farming (W J Hamilton) [HIDB]

090237 Fibre testing and analysis (A J F Russel) [Misc]

090238 Ultra-sonic scanning training (A J F Russel) [Misc]

090239 Deer farming consultancy (W J Hamilton) [SAC]

090243 N-alkane determinations (J A Milne) [SAC]

090246 Development of mixed grazing systems of animal production for the management of semi-natural vegetation to protect the rural environment in sparsely populated areas (I A Wright/C Howard) [EEC cognate with 015227]

090273 Diversification by deer farming through improving efficiency of production, welfare and the development of new marketing strategies (J A Milne) [EEC]

090271 Commercial contracts [Misc]

090276 Identification of 'hot spots' in restricted areas (R W Mayes) [ITE]

090301 Transfer of radionuclides in animal production systems (R W Mayes) [CEC]

090300 The welfare of sheep before, during and after transport (P J Goddard) [Edinburgh University]

090310 Development of rapid techniques to assess the availability to food animals of radionuclides in or on feed (R W Mayes) [ITE]

090306 Production of high quality cheese from extensive systems of sheep and goat production in less favoured areas (I A Wright) [EC]

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090272 Commercial contracts (A Smith) [Misc]

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