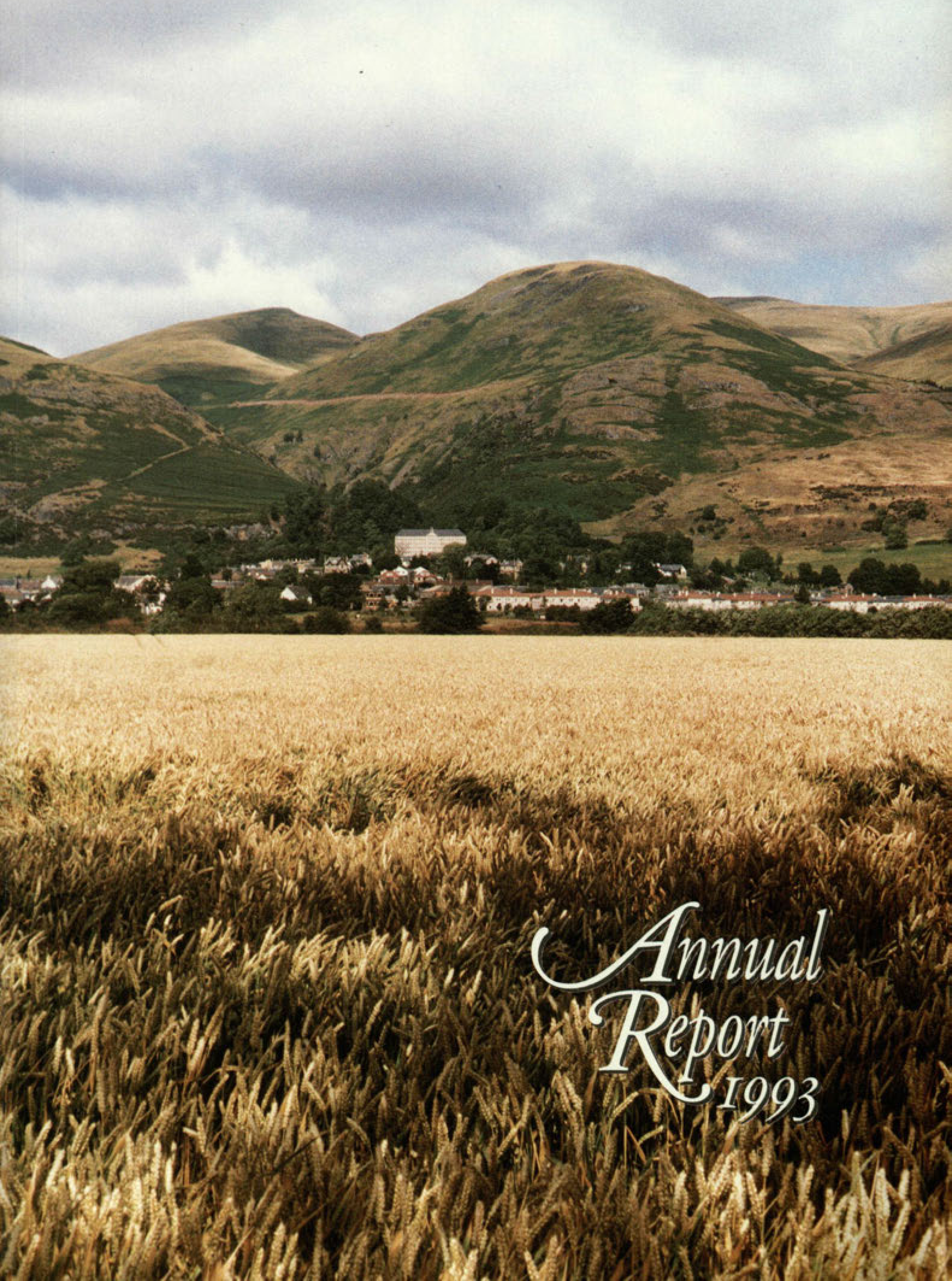
MACAULAY LAND USE RESEARCH INSTITUTE



Annual Report 1993

MLURI
The Macaulay Land Use Research Institute Craigiebuckler Aberdeen AB9 2QJ

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Annual Report 1993

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Director's Introduction

This year we have presented our work within the context of an integrated approach to Land Use Science. We believe that much of what we do is critical to meeting the future needs of rural communities in Europe and elsewhere: our research contributes to the knowledge which leads to wealth creation in such communities, but importantly, aims also to maintain and enhance the quality of life of the people who live in these communities, and of society as a whole. Our research is concerned with developing increasingly sustainable systems of land use.

This is the sixth Annual Report which the Institute has produced and one which is published at a time when the organisation and funding of British Science is undergoing a systematic multidepartmental scrutiny by the Efficiency Unit of the Office of Public Service and Science. The aim is to ascertain whether research institutes, and organisations like them, should be privatised or rationalised into large agencies in which, to a greater or lesser extent, decision making is centralised. The underlying purpose appears to be to reduce and prioritise research funding and introduce a much greater degree of competition for the research funds available.

To have effective competition there have to be enough competitors: in some areas of science, for example soil science, to name but one, there is a risk that inadequate or ill-balanced funding will reduce capability to dangerously low levels, as may already have occurred. There must also be concern that funding is maintained, if not enhanced for strategic science since it is from this area of research that the basis of technology for wealth creation and the enhancement of quality of life is derived. Strategic research requires continuity and long-term commitment. We believe that shorter term, competitive funding for applied-specific, experimental development and monitoring is appropriate. It is important, however, that the potential users of the output from such research are, in the case of Government Departments, funded adequately to do so, and in the case of industry, encouraged through fiscal incentives to participate in, and fund, the development of relevant wealth-creating research programmes.

Not surprisingly, the scrutiny has further encouraged the polarisation of opinion as to the relative merit of undertaking research in institutes as compared to universities. The debate appears to ignore the fact that each has a different purpose and a different job to do. University and Institute research programmes and activities can effectively complement each other, as is being done in Aberdeen within the Aberdeen Research Consortium. Central to the debate is the question of who should be in receipt of the greater amounts of the limited funds available for research. That should be determined by the quality and relevance of the science and whether it is fulfilling society's needs cost effectively; it should not be based on the unjustified generalised prejudices that are expressed in favour of one organisation compared to the other. Much has been achieved by both Universities and Institutes. It is important to identify the characteristics of funding, management, leadership and research programme formulation, implementation and development which has led to these achievements, rather than assume wrongly that Institute or University status automatically confers certainty of success.

The Scottish Office Agriculture and Fisheries Department's recent *Policy for Science and Technology* is a constructive approach to ensure that those life sciences which are most relevant to Scotland's needs are subject to the same degree of competition as elsewhere, but at the same time, is designed to ensure that the institutes and agencies which it funds are developed into a self-determining research consortium of international standing. The success of such an initiative will not only depend on the quality of the individual institutions but also upon the degree of co-operation between them, and on their links with the Scottish Universities. It is essential that Scotland's professional research skills and facilities in the life sciences are harnessed effectively so that Scotland can maintain and enhance its competitive position internationally.

Furthermore, it is important that the success of the research undertaken leads unequivocally to technology transfer, wealth creation and the enhancement of our quality of life. The Scottish Agricultural College, the Scottish Agricultural Research Institutes, and their private companies and research and consultancy units, have led the way, and have an excellent record of effective and efficient technology transfer. Recently they have established an international research and consultancy contracting agency, CAROS, based at Mylnefield, Invergowrie, Dundee.

The Macaulay Land Use Research Institute intends to play its full part in the evolution of world-class research in the life sciences in Scotland and, as an Institute created to integrate a range of disciplines in the pursuit of land use science, believes that it can contribute uniquely in doing so.

T J Maxwell
Director

Glencoe from Clachaig

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Picture: *NRSC Ltd, Science Photo Library*

Land use science

AN INTEGRATED APPROACH TO LAND USE RESEARCH AND DECISION MAKING

by T J Maxwell

This article aims to provide a rationale for land use research and describes some of the issues with which it deals. It also explores a definition of land use science as an integrative science within which land use research relevant to the needs of national and international communities is undertaken. It further describes a strategic research approach which aims to contribute to the science knowledge base and provide information to meet the needs of land managers, such as farmers, foresters and managers of our natural heritage, and those who formulate and implement the policies which determine the framework for both land management and use, such as national and local government departments, water boards and natural heritage and conservation agencies. It concludes with some ideas about the means by which the products of land use research might be transferred to these user communities.

A rationale for land use research

The prime reason why the Macaulay Land Use Research Institute was created was born out of a realisation in the Scottish Office in 1985 that the basis of research supporting the Agricultural Department and the agricultural industry in Scotland would need in the future to take account of interactions with other land uses. The consequences of the developing EC (now EU) and UK Government policies on the CAP and the environment would not only affect agriculture but rural land use and rural communities in general. There was a need to create a multidisciplinary-based organisation in which strategic and applied research on land use, in a holistic sense, could be undertaken. There was a need to utilise existing strengths in the soil, plant and animal sciences in a different way and in particular to bring together skills in systems research and geography as a means of fostering integrative programmes which would include environmental and socio-economic research.

Though at the time primarily aimed at meeting the needs of Scotland this research strategy was one which also had international relevance. Though yet to be published, the thinking that was taking place with respect to the Report of the World Commission on the Environment and Development, Our Common Future (WCED, 1987), had within it the fundamental idea that a more holistic approach with respect to the use of our natural resources would need to be taken. The concept of sustainability was promulgated as the means whereby this could be achieved. The joint publication by IUCN, UNEP and WWF (1991), Caring for the World, outlines a strategy for sustainable living in which the practical issues relevant to achieving such an objective are highlighted: they also provide a global rationale for land use research.

Land use and economic growth

The use of land is fundamental to man's existence: man's reliance on the land for the production of food, fibre, medicines and construction materials is no less now than it was 100,000 years ago when Homo sapiens emerged as part of the Earth's evolutionary development. Two hundred years ago the term 'land' was used by the classical and later by the neoclassical economists to encompass all natural resources; so central was it to their thinking about the extent to which continuing economic growth, or wealth creation, could be sustained (Tisdell, 1991). On a global basis, today's major concern is the extent to which the land will be able to support a population which it is estimated will double by the year 2050. There can be no doubt that unless ways are found by which this most fundamental resource can be used effectively and in a sustainable manner, there will be little hope of achieving long-term international political stability or peace throughout the world.

The reasons for this view are founded on economic and social principles which were first enunciated by Malthus in 1798. Malthus, living in an essentially agrarian society, developed a thesis which stated that economic production, (i.e. wealth creation), expands only in arithmetic progression whereas human population tends to increase in geometric progression leading to the conclusion that unless individuals consciously control their reproductive rate their incomes per head will not be sustainable. Ricardo somewhat later, in 1817, developed this thesis more explicitly and extended it to take account of the law of diminishing marginal productivity.

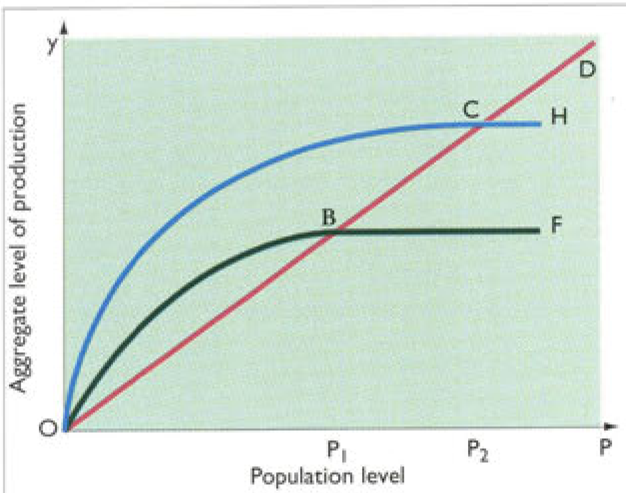

Figure 1. Ricardian model of limits to economic growth, emphasising importance of population levels and of technological change.

In Figure 1 (after Tisdell, 1991), the line OD represents the level of production necessary to sustain each level of population at subsistence level. The curve OF represents a production function based on a particular level of technological development. Up to the point where the curve OF intersects OD at B it can be assumed that population will increase to P1, the population at which income per head reaches subsistence levels. Populations which continue to grow beyond this point will suffer deprivation and famine. The solution is found in either controlling population growth or by achieving a greater production capacity through technological development as represented by the curve OH. Historically, in the developed world, a balance has been achieved by increasing production capacity by discovering, utilising and exploiting natural resources elsewhere and also by transferring people to the countries where these resources have been found: at the same time aggregate production has increased by virtue of scientific and technical 'know-how'.

This analysis, based on the Ricardian model, highlights first, the role of human population growth as an element of the sustainability of per capita incomes and second, the fundamental importance of a growing body of scientific and technological knowledge as a means of increasing production potential and of wealth creation. However, the model omits some important considerations.

While solutions undoubtedly can be, and have been found to sustain per capita incomes against a background of continued population growth using scientific and technical knowledge, this has not been, and cannot be, without its 'costs'. These 'costs' include the end products of economic production such as wastes and pollution which build up in the environment and threaten human health and welfare, and further production from the land. Wealth creation is also achieved by drawing on the stock of non-renewable resources, such as oil, a finite resource for which an acceptable alternative will have ultimately to be found. Urbanisation, intensification and the use of 'marginal' lands for crop production has led to the soil and an ever increasing range of living resources being subjected to extreme conditions and rendering them non-renewable.

The search, therefore, for ways in which economic growth can be sustained has not only the potential to reduce environmental quality but also the prospects of depressing the quality of human existence. Furthermore, a loss of genetic diversity may seriously hamper future production and wealth creation and render current levels of production unsustainable. **The challenge that confronts science, and land use science in particular, is to find successful ways of using land and other natural resources in creating wealth, without compromising environmental quality and the quality of human life, and by increasing the efficiency, and minimising the use of non-renewable resources.** The emphasis as to how, and the rate at which this objective might be achieved, is likely to be different in the 'developed', as opposed to the 'developing' world.

Land use research in the developed world

The context for land use research in the developed world in the late part of the twentieth century, and in particular within the EU, must be influenced by the fact that there has been, since 1985, a continuing surplus of many food products. It is also apparent that intensive systems of agriculture, increasingly introduced since the Second World War, have brought about environmental damage to the countryside. Already, ways to take land out of agriculture have been set in place and some agricultural land has been afforested. Also, the demands of the relatively wealthy and sophisticated societies of developed countries, with their substantial amount of leisure time and discretionary income, are having an increasing impact on rural resources in a variety of ways. For example, attitudes towards conservation in the countryside have been changing dramatically over the last decade because in the 'western' world, agricultural commodities derived from these resources are perceived as being of less value. Some parts of these societies, therefore, are concerned to protect the landscapes, habitats, wildlife and solitude that can be found there, and in the remoter areas would wish to constrain any further development within these ecosystems; others also wish to gain ready access to these remoter areas for recreation, sport and hunting and in some cases believe that this requires the exclusion of domesticated stock. During the same period, these same societies have become increasingly aware that the impact of urban industrialisation has created huge pollution problems which not only affect human health but also the future environmental quality and productive capacity of the land; they are also affecting our climate. Inevitably the demand for pollution controls and constraints on both urban and rural industries are seen as major environmental objectives.

For the most part, however, the countryside of the developed world is a managed ecosystem and one which supports a rural population, a part of which is dependent upon the use of the land for its economic well-being: it is recognised that the management of the land depends on maintaining its economic viability to retain that part of the population which makes the management of such ecosystems possible.

Looking beyond the end of the twentieth century, however, the 'western' world requires to consider the extent to which current objectives will have to change to take account of what is going on in the rest of the world. We are told, (IUCN, UNEP and WWF, 1991), that 15% of the Earth's total land surface is affected by human-induced processes of soil degradation. At least 66 m ha of irrigated land, that is 30% of the total, are affected by secondary salinisation. An estimated 6-7 m ha of agricultural land is made unproductive each year because of erosion and this is estimated to be more than twice the rate of the past three centuries. Overgrazing is widespread; in Africa for example, it is estimated that 49% of the land is degraded and in Australasia the figure is an astonishing 80%. Some of these rangelands are degraded beyond recovery. Land degradation is widespread in the world's drylands, affecting almost 5.5 m ha or 70% of their area. All of these factors and others combined with the relentless increase in population over the next three decades is likely to reduce the potentially cultivatable land in the developing parts of the world to very much less than a hectare per person.

Against this background, international aid, the provision of emergency food supplies in famine-affected parts of the world, the reforming of CAP and progressing the GATT negotiations are important and necessary but they will not in themselves provide long-term, global and sustainable solutions for land use and food supply. These will need to continue to be found from technological innovations appropriately developed and applied with, and by, the people who will ultimately use them.

Even so, it cannot be assumed that developing countries will be able, themselves, to provide for their future long-term food requirements. Indeed, it has even been suggested, (Carruthers, 1993) that developing countries, with their cheaper labour force, could become the centres of the manufacturing industries while the 'western', northern temperate areas of the world will become the major centres of food production. In the longer term, this scenario could be reinforced by the present predictions about the impact that climate change could have on equatorial countries. These scenarios have implications for the development of both short-term and long-term strategies of land use and rural economic development in Europe and America. The need to 'build-in' an element of flexibility and adaptability, as well as applying the most sophisticated, sustainable crop and animal husbandry techniques to improve efficiency, as well as competitiveness, would appear to be prudent objectives for land use and land use research in the developed world. These objectives are no less relevant to the Macaulay, operating within a more narrowly defined land resource base within Europe.

Research approach

At a time when the support for science funding and the organisation of science is being widely debated and decided it is relevant to consider briefly the place of science in society and how that influences the specific approaches to research and in particular the approach to land use research. In his book *The Philosophies of Science*, Harré (1992) draws a distinction between science as an activity justified by the value of its applications, and science as an activity justified by its intrinsic worth. Looking at science as an activity justified by its applications can be seen as valuable because it is instrumental to the achievement of further goals which in themselves have some intrinsic value. Harré refers to Francis Bacon who thought that scientific research should be supported because it would improve the health, wealth and general welfare of the nation. The moral and political issues concerning the value of scientific research are thus shifted away from the research itself to its associated technology, since it is in its applications that science shows its human worth. This is a particularly important point when considering the research which is undertaken with respect to the land.

The disciplines of land use research

In the past, such research has predominantly been carried out within agricultural and forestry science, disaggregated into the soil, plant and animal sciences but with the primary aim of increasing both production and productivity. Up until the mid-1970s, even within the 'disaggregated sciences', much of the research was undertaken by studying the function of whole plants and animals and a relatively narrow range of soils. It is only relatively recently through the development of cellular and molecular biology and molecular genetics that the science supporting agriculture, and its associated industries, has become increasingly fundamental and basic in its approach relying heavily on a reductionist philosophy. Notwithstanding its crucial importance for future wealth creation it has nevertheless a relatively narrow focus. It is primarily concerned with understanding processes which can be modified within the plant or animal in ways which elicit the production of different kinds of products for consumption, medicinal or other uses, or which increases their yield potential and gives them greater protection against a whole range of disease vectors. Such research is the basis of the hoped for biotechnological revolution of the first decade of the next century. It is a biotechnology which it is anticipated will reduce the use of agrochemicals and their deleterious impact on the environment, and reduce the use of medicines on animals and thereby improve the overall quality and safety of food produced. It is a biotechnology which it is expected will contribute significantly to a more sustainable agriculture but it will only do so if it is appropriately developed within management systems which take account of the nature and variation of the land resources, and the economic and social context in which it is to be applied.

The other major contributions to research concerning the land have come from animal and plant ecology, geology, hydrology and geography. Significant contributions from animal and plant ecology have been made with respect to the foraging behaviour of animals and the processes determining vegetation change. Descriptive ecology has provided the basis of our knowledge of species and genetic diversity and the extent to which we need to conserve and protect. Geology is concerned with the study of rocks involving the principles and techniques of physics and chemistry which includes mineralogy. It is important to an understanding of the formation and composition of soils as well as to the landforms and the processes of their development. The properties and behaviour of many soils, particularly their inherent fertility and factors involved in their sustainable use, often relate closely to their mineralogical composition. Geology is closely associated with hydrology which is concerned with the occurrence, distribution and composition of water at or near the Earth's surface. Of particular relevance to land use is soil moisture and groundwater, the factors that influence them, and the quality of the water, (its chemical and biological composition), which flows from land into stream waters.

Geography is a more pervasive and all-embracing science. It provides much of the inter-disciplinary framework within which the other sciences contributing to land use research can be logically pursued: it is the science which describes and analyses spatial variation in human and physical phenomena. Patterns and variations in distribution are studied together rather than in isolation. Statistical analysis, mathematical modelling, and computer based comparison of information gathered by satellites, electronic sensors, censuses, social surveys, and field and archival research lie at the heart of modern geographical research (Anon, 1988). Geographers are well equipped to contribute to research of a practical nature such as the management of natural resources, the implementation of land-use planning and techniques of environmental impact assessment. Recent new developments within the discipline have focused on the relationships between natural and cultural phenomena. Researchers on water-resource management, for example, employ their knowledge of hydrology, climatology, meteorology and geomorphology to address issues stemming from the human demand for water. Medical geography relates spatial variation in the occurrence of disease to complex social, dietary and environmental factors.

Thus, in a similar way, the need to create a paradigm in which land can be studied in relation to the use to which it is put to meet a range of objectives determined by man forms the basis of **land use science.** However, the rationale for land use research demands that the link between use and consequence goes beyond that of just natural phenomena; the social and economic consequences must also be addressed. Thus, the suggested definition of land use science within which appropriate theories can be developed is the **integrative study of the physical, environmental, economic and social consequences of land use.** Land use science therefore encompasses soil, plant and animal science, ecology, geography, economics and sociology, and is strongly associated with geology and hydrology. It consequently operates at various levels of physical and biological organisation and its outcome is invariably expressed with reference to location, spatial pattern and distribution.

Programmes and priorities for research are determined in a variety of ways. Within fundamental and strategic science, programmes and priorities have in the past invariably been 'science' led. Land use science is a science which is justified primarily by the value of its applications: it is mission-oriented and deals with phenomena at scales which are relevant to application. It is not surprising that the issues with which it deals and for which it is funded are the issues which land managers and those responsible for formulating and influencing policy believe to be important. But like all sciences, land use science has a need to develop appropriate research methodologies and scientific principles at a strategic level and in a research environment in which all the relevant disciplines are represented and where there is a common set of objectives.

Land use science in the Macaulay Institute

The context and focus of the land use research undertaken by the Institute arises primarily in relation to the land use issues relevant to Scotland within the UK and within the European Union; it takes account of, and is dependent upon the Institute's skills and its locus in relation to the other institutes and organisations sponsored and funded by the Scottish Office Agriculture and Fisheries Department (SOAFD), and it is significantly influenced by the Department's Policy for Science and Technology (SOAFD 1993) and Programme of Commissioned Research and

Strathspey: the Insh marshes, Creag Bheag and Creag an Mor. An example of an area of integrated land use, agriculture, forestry, conservation and recreation.
Photo: Words & Pictures, Aberdeen

Development (SOAFD 1992). The Institute's remit states that it **undertakes research, in the context of rural land use and resource management, to assess the environmental, economic and social impacts of agriculture and related land uses, and the consequences of change resulting from factors and influences such as policy, management, effects of climate and pollution.**

Though this remit provides for a wide range of issues to be tackled, within Europe the Institute has a set of skills which are particularly relevant to undertaking strategic research on land resources of marginal quality, predominantly used in extensive forms of agriculture, such as sheep, cattle, deer and goats, and farm woodlands and forestry, and which encompass important areas of conservation and recreational value. It is also well placed to update, evaluate and classify the physical, chemical and biological characteristics of soils and vegetation in general, as well as to undertake research to study the impact of anthropogenic pollutants. The programme of research is predominantly strategic and has an international relevance beyond that important to the application of its findings within a European context.

There are several ways in which mission-oriented research programmes on land use can be organised. In the Institute we recognise that we are involved in a programme of research which is ultimately aimed at meeting the needs of land managers and those formulating and implementing land use policy. Thus, anything we do has that as a prime objective. The logic of the approach is to gain knowledge and understanding about processes and mechanisms, to use such knowledge in systems synthesis, to investigate technical options for land use and its management, and study their impact on natural resources, people and the economy. Thus, within and across each of the programme or project areas we have a combination of skills and research approaches which supports systems synthesis as well as reductive and inductive science.

The programme of Land Use Science undertaken by the Institute is organised within this framework and is presented in a two-way classification (Figure 2). The programme is presented as two major themes with several sub-themes, and projects are classified with respect to the 'level of biological organisation and physical scale' of the research, and the 'scientific method' and 'research and experimental approach' used. The programme is managed as a series of Programme Units, as indicated in the figure, which contain the research projects listed on pages 83 - 87 of this report.

The first major theme, Anthropogenic Pollution of Soils and Waters, recognises that land use in Scotland is affected by acid deposition from the air arising from sulphurous and nitrous emissions from urban industry, heavy metal and organic pollution from sewage sludge and industrial waste, as well as from the atmosphere, and radionuclides from the nuclear industry. In using land, agriculture and forestry also contribute pollutants, particularly nitrogen and phosphorus, to river catchments. The research projects within this theme depend predominantly on soil, hydrological, hydrochemical and microbiological research which apart from contributing fundamentally to soil science, produce information in the form of critical load maps, water resource catchment models and rule-based risk assessment models. These models are subsequently used to carry out economic assessment of the effects of pollution. More generally the research contributes to characterising the impact of pollution on land and water resources and to the formulation and implementation of policies to control it. Detailed understanding of soil science is being coupled with spatial data analysis to determine the impact of land use, for example, on the potential for river eutrophication. Such an integrated approach allows an evaluation of the impact of management, such as fertiliser inputs or changes from winter to spring cropping to be made. Work in this area of the Institute's research is described in the article 'Soil processes and pollution chemistry'.

The second major theme, Land Use Options and Impacts, deals predominantly, but not exclusively, with the major uses of land characterised by soils of low pH, high organic matter and low fertility. This includes sub-themes on Trees and Other Crops, the vegetation dynamics of Semi-Natural and Natural Vegetation and Permanent Pastures, the foraging behaviour and resource use of Large Domesticated and Wildlife Herbivore, and the management systems that arise from the strategic research undertaken within these sub-themes.

The sub-theme on trees encompasses forests, farm woodlands and agroforestry: it includes other crops only in so far as it is necessary at the farm scale and above to include them in farm, regional and national land use models, policy analysis, and decision-support systems research. The main output from this sub-theme is in terms of refining the management protocols for the establishment, growth and development of trees in a wide range of soil types. In the study of the impact of whole-tree harvesting on long-term site productivity for second-rotation forestry, for example, there is a research emphasis on plant/soil interactions since the majority of the nutrients taken up by trees come from the decomposition of the soil organic matter and leaf litter by soil microbes, whose activity is in turn largely determined by exudation of carbon from roots. The study of assimilate partitioning in trees quantifies carbon partitioning in relation to rhizosphere carbon flow and the consequent effects on soil microbial activity, particularly the balance between the immobilisation and mineralisation of nitrogen in soils of low pH and high organic matter. The processes of internal cycling are being studied to enable us to quantify the contribution they make to tree growth under a variety of management inputs. This work is described in the article 'Soil-plant-microbe interactions and internal cycling'.

The other sub-theme is concerned with research dealing with topics most relevant to the utilisation of semi-natural and natural vegetation and permanent pastures by large domesticated and wild herbivore. The impact of animals grazing such vegetation in interaction with soil and climatic factors on plant community dynamics forms the basis of the research on vegetation dynamics. It is strongly linked to research on herbivore foraging and ruminant resource use which are concerned with the factors influencing and controlling grazing location, dietary intake and animal performance at the meso- and macro-scales: this includes intra- and inter-species social behaviour, the influence of secondary compounds and the impact of host/parasite interactions. This research contributes to theories and concepts on plant competition and foraging theory and provides quantitative information which is used in a series of models which form the basis of a set of decision-support tools which are being developed as aids to the management of both domestic and wild herbivore in these environments. The options in terms of agricultural use, beyond traditional sheep and cattle in these environments, are few. Agricultural and environmental policies have sought to encourage extensification and diversification: research therefore, contributes to the development of management protocols for production efficiency and the welfare of novel species of animals deemed to have the potential to provide economic alternative agricultural enterprises to sheep and cattle. The articles 'Foraging behaviour and vegetation dynamics' and 'Animals in agriculture' give further details of this work.

The use of semi-natural and natural vegetation by domesticated and wild herbivore, the planting of trees in farm woodlands, afforestation, and the provision of access for recreation all have an impact on landscape and wildlife distribution: these are the subject of research projects which cross the boundaries of the sub-themes in terms of land use and rely on information derived from them and from elsewhere. Other research projects cross the boundaries of the sub-themes such as those concerning decision-support models for assessing land use options at the farm level, the extent and significance of pluriactivity and the uptake of rural development and environmental initiatives. These projects deal with land use issues at a large scale and provide a context for research within the relevant sub-themes, draw appropriate information from them, but depend also on other kinds of information, (socio-economic, environmental, geographic), from elsewhere. These projects also depend, for example, on the development and availability of modelling

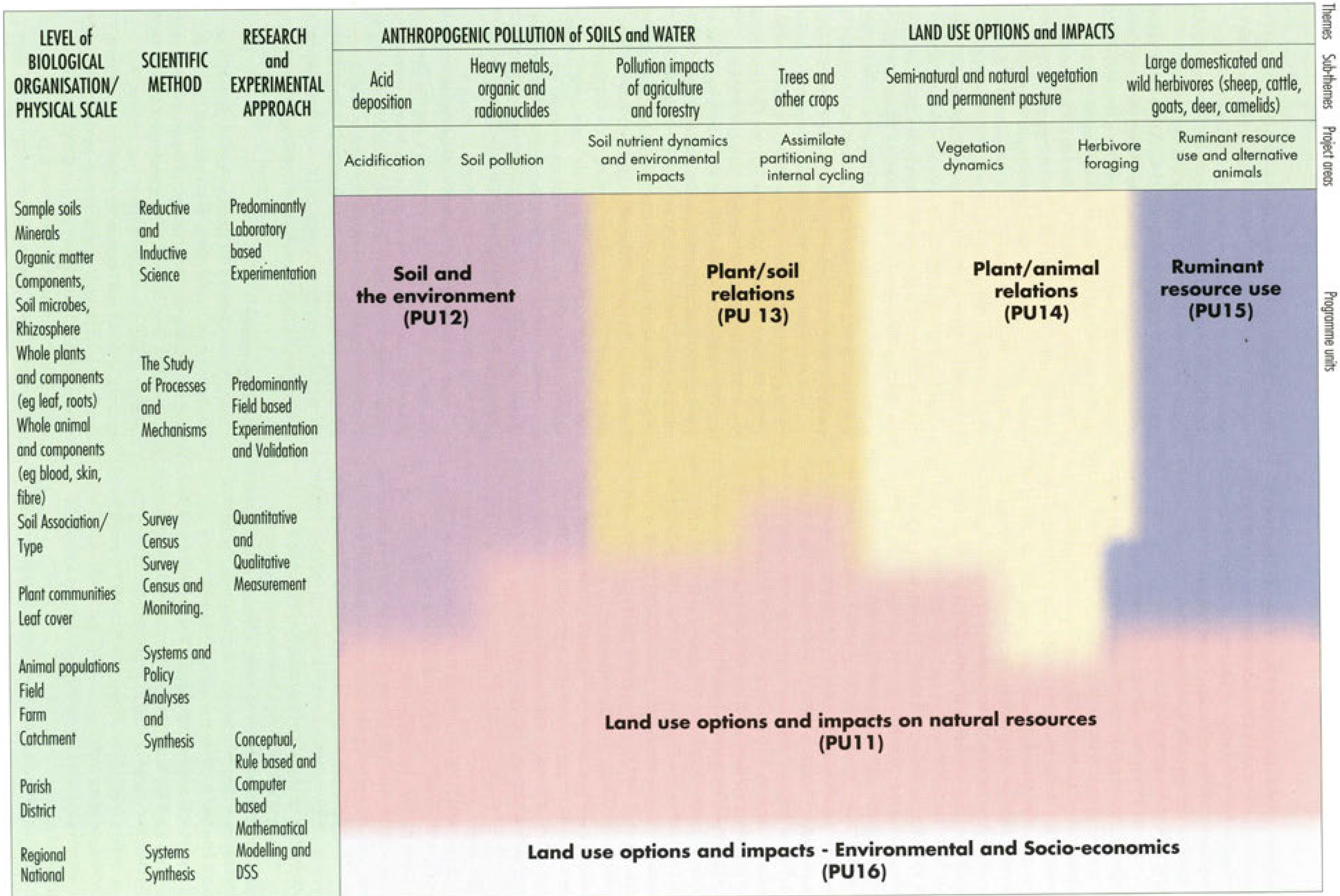

Figure 2. The MLURI land use science research programme showing physical, environmental, economic and social consequences of land use.

software, knowledge-based systems and geostatistics which form the basis of research topics in their own right in relation to research in the context of systems analysis, synthesis, and the creation of decision-support models. Some of this work is described in the articles 'Environmental and socio-economics' and 'Information technology'.

Central to the programme as a whole is the collection of relevant data by survey, census and monitoring. It is obvious that to undertake research on land use change, and the consequences of change, it is necessary to have baseline information, (soils, climate, land cover, agricultural and wildlife survey and census data), updated on a regular basis and monitored to measure change. Because such data have a spatial dimension which is important to its use, it is essential to have computer software and hardware systems designed to store, collate and manipulate such data, (see the article on 'Information technology'). Research in these areas serves all the sub-themes identified in the programme.

No classification of research of the kind that has been undertaken in Figure 2 can ever be perfect; the position of a research area or project with respect to the two-way table, particularly in relation to its position vertically within the table, should be regarded as indicative rather than absolute. This must be especially so with regard to 'scientific method'. Some of the large scale land use and environmental research undertaken in Programme Unit 11 (PU 11) and some of the socio-economic research in Programme Unit 16 (PU 16) dealing with regional and national issues involves inductive reasoning despite the fact that these projects appear at the lower end of the figure. The vertical position of the research projects in the table is largely determined by the 'level of biological organisation and physical scale' of the research and by the 'research and experimental approach' used. The framework of the table represents essentially a systems approach to land use science.

The systems approach

It can be seen in Figure 2 that as the physical scale of the research increases so the need to become involved in systems synthesis becomes apparent. This is particularly the case with regard to projects undertaken within environmental and socio-economics, geographic analysis and synthesis, and the development of decision-support systems. These are the projects which ultimately serve the needs of the users of the information resulting from the outcome of our research.

Dent and Blackie (1979), have defined a system as a 'complex set of related components within an autonomous framework' – the term defines, in a general way, the limits of autonomy and it implies that within these limits there is an unprescribed complex organisation'. The implications of the systems approach is that an understanding of the relationships between the components is so important, that studying the components exclusively in isolation precludes the possibility of understanding the system as a whole: 'the whole system is more complex, more comprehensive than the sum of the individual parts'.

Undertaking research within a systems context involves first, an analysis of the components and their relationships with each other; this phase requires the use of reductionist and inductive methods, the testing of hypotheses and the formulation of new hypotheses. Second, it involves a synthesis phase which depends on conceptual and mathematical modelling, and systems testing and validation where appropriate and possible. Analysis and synthesis are rarely distinct in time; rather a cycling between the two develops. It is by this means that an approach to understanding the whole is realised.

In land use science we are required to consider social and economic as well as physical and biological systems. Dillon (1976) recognised the shortcomings in attempting to understand the world, especially in science, wholly in terms of reductionism and mechanism. Concepts of a purposeful (teleological) nature, such as goals, choices and free will have no place in such research. The teleological view, that effects may be due to the purpose they serve, is an inadequate basis for science in its attempt to understand the world so as to achieve purposeful manipulation and control: there has to be a recognition that an understanding of the parts of a system is gained also from an understanding of the functioning of the whole.

In this context the systems approach or systems way of thinking provides a means of gaining a holistic understanding of the phenomena which determine land use. Consequently it has to be expected that physical and biological scientists working within land use research will increasingly have their terms of reference set by social, economic and political considerations. The aim of land use science, therefore, is to provide both improved explanations for phenomena and a framework within which informed judgements may be made about various land management options. Such judgements might be in terms of a range of goals, such as economic viability, sustainability, complementarity, animal welfare, environmental impact and cultural acceptability. The objective of land use science is to provide the knowledge whereby the judgements that have to be made, are made with an increasing certainty about their outcome.

Much of the Institute's research is concerned with the management of resources, decision making and the consequences that flow from those decisions; indeed, parts of our research programme could be classed as operations research. Recent thinking within the Institute has been in relation to developing systems whereby the information derived from our research programme is organised in ways which enable it to be most effectively used in decision-making processes.

Technology transfer

In business management the development of computer-based information systems that affect, or are intended to affect the way people make decisions has been going on for many years (Silver, 1991). Since the 1970s there has been a confluence of computer-based information systems, (e.g. information reporting systems), with operations research/management science, (e.g. optimisation and simulation models), to produce management decision-support systems (DSS). It is only relatively recently that DSS have come to be used in land use management. These have mainly been in the form of expert systems that solve problems by using knowledge bases, symbolic processing and inference techniques. Some researchers in the field would argue that in terms of strict definition, expert systems are different from DSS in that they are built to generate solutions without human intervention; there can be little doubt, however, that both, in a general sense, aim to provide a logical and explicit problem-solving environment with which decision-makers can interact.

As yet, in terms of land use science, there is no strong evidence that there is a user demand for such computerised systems, even though, in speaking to those who are involved in land management, and policy formulation and implementation, it is very apparent that complex decision-making issues abound. Take for example, the formulation of a policy and management strategy to reduce nitrogen loads to a river catchment to control eutrophication: there are not only complex technical issues but also a range of economic and social issues which require to be addressed. Similarly, the range of options for the management of semi-natural and natural vegetation extends from those related to agricultural production to those concerned with sport, conservation and habitat enhancement. Questions are legion in relation to the numbers of sheep, cattle and red deer that graze such vegetation, and how decisions which determine stocking rates affect plant species composition, grouse, other wildlife, the economic viability of holdings, and not least, the impact on rural populations. With present developments in computing and modelling technology, coupled with appropriate graphical user interfaces and visualisation, the possibility of building DSS to address issues of this kind now exist.

In the Institute a start has been made towards achieving such an objective but much needs yet to be done. Of one thing we can be certain, the exercise will identify further gaps in our knowledge base and will have an immediate impact in determining the strategic research that needs to be undertaken to provide relevant data and mathematical models: the building of DSS provides a further way of determining research priorities relevant to the needs of users. Experience elsewhere suggests that the participation of users in the building of DSS is important in influencing the structure of the DSS and in generating output which is most relevant to their needs. Such an approach, perhaps, provides the most appropriate environment in which technology foresight and technology transfer could be most effectively fostered.

Conclusion

In concluding this article it is important to emphasise that land use science is a developing, integrative science. The methods and tools which it employs are evolving rapidly, and there is evidence that in the future there will be a considerable potential to tackle complex land use issues in an explicit and structured way. It is a science which offers us the possibility of using our scientific ingenuity to design management systems for land use which are sustainable. It seems inevitable that the priorities in land use science will be on research which produces and draws together management information in ways which makes its application easy and the outcome of its use predictable in meeting this objective.

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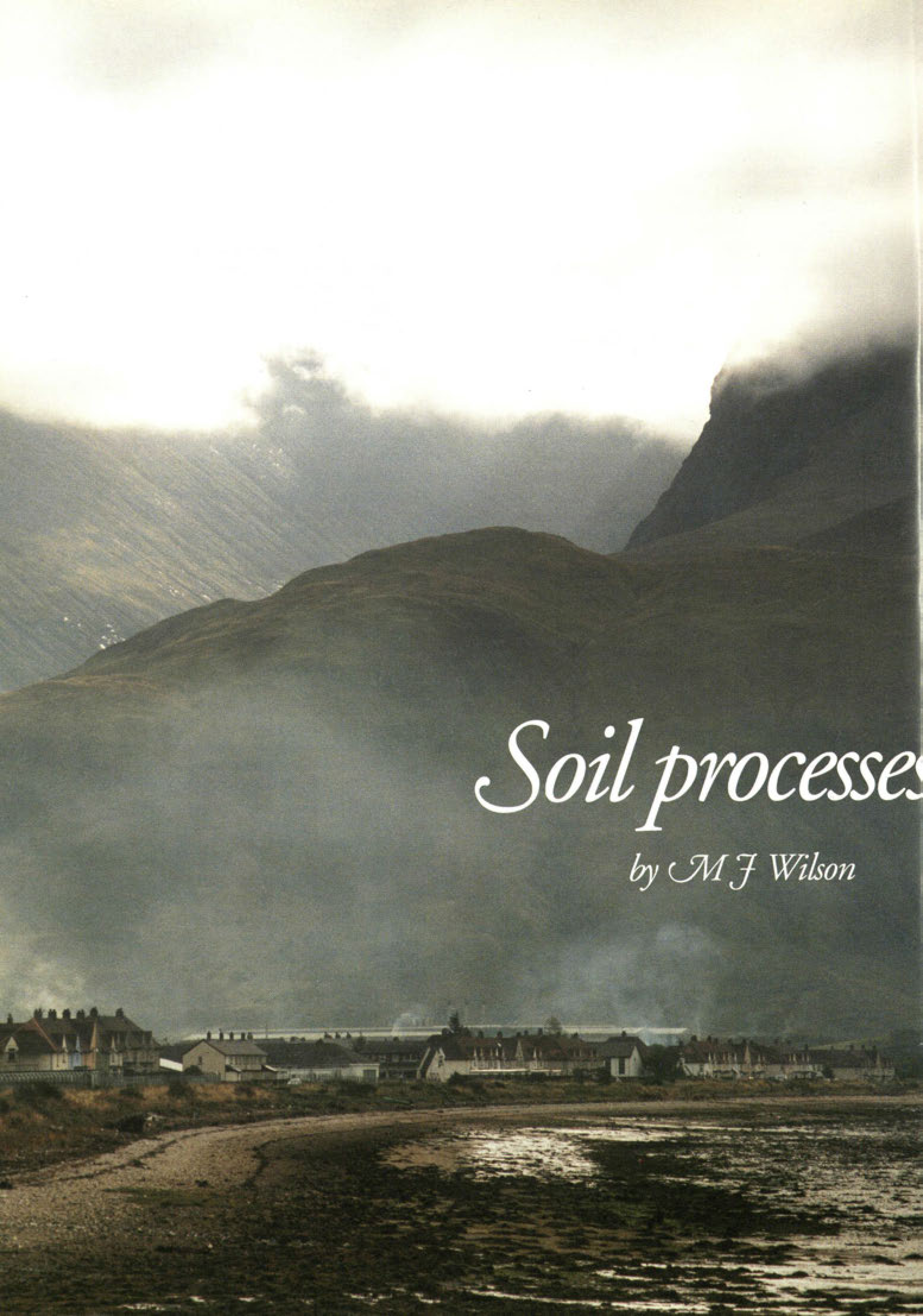

Soil processes

by M J Wilson

It has long been recognised that soil is a vital component of food-producing agro-ecosystems which it is essential to conserve. It is not so widely realised, however, that non-agricultural soils are also important in that they protect the aquatic environment by buffering the impact of pollutants, contribute to the landscape and provide suitable habitats, including forests, for wild life. In short, the way in which these soils function enhances our quality of life.

The soil is a finite and fragile resource. It requires to be protected from man's polluting activities but in order to do this effectively it is necessary to define and assess the risks associated with soil pollution and to understand what the consequences of pollution might be for thequality of the soil and that of the wider environment. Once this is done, appropriate remedial actions and policies can be formulated and brought to bear.It is to be expected that a major factor involved in such policies is their impact on land use and the socio-economic consequences which follow from this impact.

Among the major threats to the soil, and to the terrestrial and aquatic environments related to the soil, are acidifying inputs from the atmosphere, heavy metal pollution from contaminated sewage sludges and excessive fertilisation in agricultural areas (Brown, 1992). The objective of this article is to illustrate how research into soil processes is essential for gaining a better understanding of the environmental risks posed by pollution and for enabling policies to be planned in a more objective and cost-effective way.

and pollution chemistry

ENVIRONMENTAL RISK ASSESSMENT AND IMPACT ON LAND USE

Soil acidification

Natural soil acidification is particularly prevalent in areas of high rainfall and base-deficient parent materials, but it is now widely accepted that increased acid inputs deriving from the release of oxides of sulphur and nitrogen from fossil fuel combustion are also involved. In general terms, for sensitive soils acid deposition would be expected to deplete base cations from the exchange complex of the soil at a rate greater than can be compensated for by inputs from other sources. The effects of acid deposition can be exacerbated by land use, in particular forestry, because trees are capable of scavenging acidic pollutants from the atmosphere, both in dry and wet deposited forms, and these inputs are eventually added to the soil. In this connection we have found that Sitka spruce has an enhanced ability to intercept sulphur from the atmosphere compared with Norway spruce and lodgepole pine (Miller *et al.*, 1991). Sulphur may act as a mobile acidic anion in many soils and, where it is leached to surface waters, is still strongly implicated in their acidification. However, many other processes are also involved in soil and surface water acidification and in this article attention is focused on aluminium release, soil organic matter decomposition and mineral weathering.

Acidification of the soil exchange complex inevitably involves production of protonated aluminium ions, mainly through the structural decomposition of minerals, with concomitant increases in soluble aluminium in soil solutions and eventually surface waters. Soluble aluminium can exist as a number of different complexes associated with various ligands and the relative distribution of these complexes (speciation) has a direct influence upon the toxicity of aluminium to aquatic life. For example, where the simple aquo-ion Al^{3+} or hydrolysed species such as $AlOH^{2+}$ or $Al(OH)_2^+$ exceed a critical level then harmful ecological effects may ensue. On the other hand, aluminium may be associated with silicate, to give complexes such as $AlH_3SiO_4^+$ or with organic acids or humic substances, and in such circumstances its toxicity is much reduced. We are determining the complexation chemistry of aluminium with dissolved humic substances by applying a thermodynamic modelling approach which will enable us to predict the likely aluminium speciation in surface waters and to assess potential toxicity risks.

Humic materials assume great significance in the soils and waters of the hills and uplands which are considered to be the areas most susceptible to increased acidification. Not only are humic substances responsible for most of the soil exchange acidity but also they are released to surface waters. An understanding of the structure and behaviour of soil organic matter is therefore relevant to acidification research. A significant part of soil organic matter acidity is related to the polysaccharide fraction. This contains uronic acid groups and also incorporates the so-called 'secondary polysaccharides' which are present in soluble fulvic acids, the most acidic of all humic substances. This secondary polysaccharide is quantitatively significant but its nature is problematic. The evidence suggests that it may originate through ring opening in the polysaccharide chain, thus retaining a high molecular weight and giving increased acidity, at the same time no longer giving an analysis for sugar by the usual hydrolytic methods (Cheshire *et al.*, 1992). Future work will emphasise the nature of aluminium humic complexes.

Mineral weathering is the major soil process capable of neutralising incoming acidity over the long term by the sustained release of base cations. The rate at which this process occurs is, therefore, crucial in determining whether or not a soil will acidify. In many areas of Scotland, chemical analysis of soil profiles indicates that overall mineral weathering rates since the initiation of soil development are much lower than the current rate of acid deposition (Bain *et al.*, 1990). For example, Table 1 shows that the long-term base cation release rates from soil developed on various parent materials can be much lower than current levels of acid inputs. The table indicates that weathering rates in the Kelty and Chon catchments in the south-west Highlands are not able to compensate acidic inputs from the atmosphere, and these catchments are known to be acidified. In contrast, weathering rates in the Mharcaidh catchment in the Cairngorms are able to neutralise acid inputs. This catchment becomes acidic only under high-flow conditions.

Work on current mineral weathering rates has been incorporated into, and indeed is at the heart of, the application of the critical load concept to acid inputs to soils. Critical load is '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 Grenfelt, 1988). Depending on the mineralogy of the soil, it is possible to construct critical load classes indicating the sensitivity of the soil to acid inputs and we have compiled a map showing the distribution of these classes across Scotland (Langan and Wilson, in press), and in collaboration with the Soil Survey and Land Research Centre and the Institute of Terrestrial Ecology, incorporated this into a critical load map of the UK as a whole. Taking into account the current levels of acid inputs from the atmosphere, it is possible to delineate the areas where critical load has been exceeded and where the risk of ecological damage has been enhanced. This approach has enabled us to assess on a national scale, in the context of the ecological stock at risk, the likely consequences of various levels of acid emission reductions. It also provides a rational basis for setting target loads and for policy formulation and has indeed been used to this effect by the Department of the Environment.

Catchment	Acid input[1]	Long-term weathering rate[2]	Current weathering rate[2]
Mharcaidh	21	45	49
Kelty	81	26	19
Chon	79	72	44

[1]Harriman R, Ferrier R C, Jenkins A and Miller J D, 1990.
[2]Bain D C, Mellor A, Wilson M J, and Duthie D M L, 1990.

Table 1. Acidic inputs to catchments and weathering rates in catchment soils (meq/m²/year).

A more detailed approach is required when attempting to determine the interactive effects of atmospheric inputs, land use and soil type on the hydrochemistry of surface waters on either a local or a regional scale. Here it is necessary to use mathematical models such as MAGIC or PROFILE, both of which require the input of soils data such as weathering rates, dissociation constants of organic matter and aluminium solubility. In collaboration with the Institute of Hydrology we have been able to show (Figure 1) that MAGIC can be used to predict the effect of land use change under different scenarios of acid deposition on soil and water chemistry (Ferrier *et al.*, 1993). The link between water chemistry and fish stocks also enables a modelling approach with respect to the evaluation of the economic impact of acid emission reductions in selected areas (see the article on Environmental and Socio-economics in this Report). Thus the economic benefits of a 60% abatement, such as is required of the UK by the Large Combustion Plant Directive of the European Community, has been calculated for the rod and line salmon fishery in Galloway. It is estimated that by the year 2038 the market value of this fishery will have increased by £2 million in real terms over the predicted market value under constant 1988 emissions (Macmillan and Ferrier, in press).

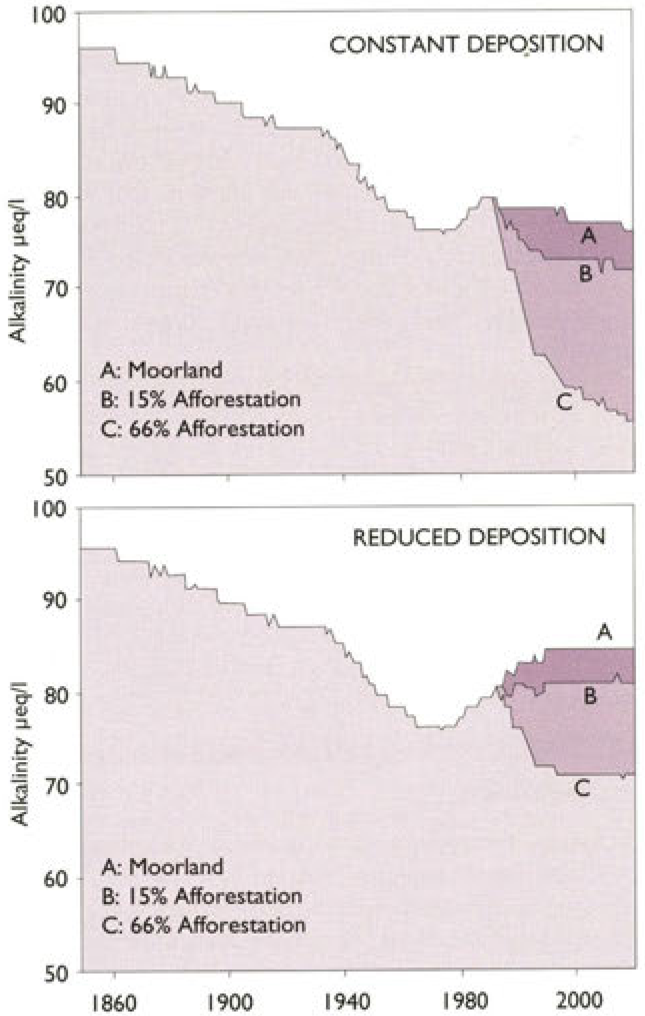

Figure 1. Alkalinity trends estimated using MAGIC for the Monachyle catchment under moorland and forest land use, and for constant and reduced deposition.

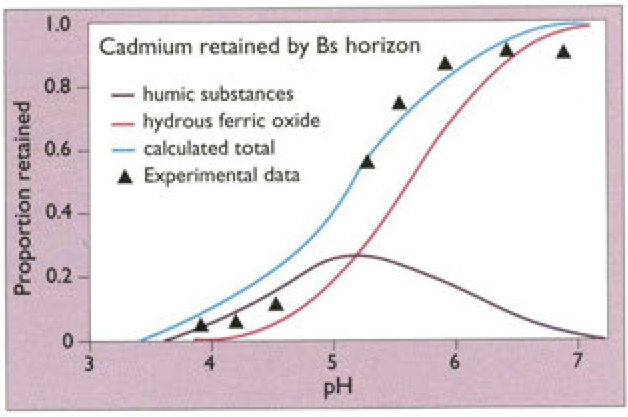

Figure 2. Calculated retention of cadmium by soil components (humic substance and hydrous ferric oxide) compared with experimental cadmium retention in the Bs horizon of a podzol derived from mica-schist parent material.

Heavy metal pollution

Heavy metals can accumulate in soils because of contributions from a number of sources. These include the geological parent material, deposition from the atmosphere following emissions from industrial and other sources, and additions from sewage sludge applications, farm wastes and fertilisers. What is the fate of these heavy metals when they are incorporated into soils? It is known that heavy metals associate strongly with various soil constituents and that at circum neutral soil pHs they will be effectively retained in the soil. However, under more acid conditions there is an increasing risk that the metals will be taken up by plants, where they may be ingested by animals, or even leached to surface and groundwaters. Furthermore, there is strong evidence that in some soils heavy metals may adversely affect the activity of important soil microorganisms like *Rhizobium*, thus impacting upon long-term soil fertility. These concerns are particularly relevant in Scotland where the soils are characteristically acid with a higher organic matter content and where the disposal of heavy metal contaminated sewage sludges to land will increase following prohibition of the dumping of such sludges at sea in 1998.

In order to predict the behaviour of heavy metals in soils, an understanding of the physico-chemical retention mechanisms on soil particles is essential. The major mechanisms include retention on the variable charged hydrous oxyhydroxide minerals of iron, manganese and aluminium, retention on permanently charged clay minerals as outer sphere complexes associated with exchangeable cations, or complexation of various functional groups associated with soil humic substances. We have applied theoretical models which enable the effects of varying solution composition and pH on metal retention to be explored. Thus we have compared the retention of cadmium by a hydrous ferric oxyhydroxide surface, by humic acid and by a specific soil, all as a function of pH (Figure 2). This approach is now allowing us to assess the relative importance of different retention mechanisms of heavy metals in selected soils.

The safe limits of heavy metals in agricultural soils are currently under review, partly as a consequence of reports that soil microbial activity can be reduced at or near the present limits. These microbial effects depend strongly on soil type, not only because of the effect of soil properties on the bioavailability of the metals, but also because the microbial populations in certain soil types may be more or less susceptible. Thus, in sandy loam soils there is usually a higher bioavailability of metals and a smaller microbial biomass than in heavier soils. The higher metabolic quotient found in light soils means that the biomass has to work harder and has a higher turnover rate than in heavier soils (Table 2, overleaf) and may therefore be more sensitive to stress caused by pollutants such as heavy metals. Such considerations are clearly relevant to risk assessment or site suitability studies.

The current or background heavy metal content of Scottish soils also needs to be taken into account in such studies. Heavy metals maps have now been prepared for the whole of Scotland showing distribution patterns based on the analysis of National Soil Inventory samples. The relationship

Soil type and locality	C_{mic} (ug/g)	Basal respiration (ug/g/hr)	Metabolic quotient
Sandy alluvium Garrionhaugh	264	1.40	74.1
Clay Watsonfoot	533	2.16	46.8
SED	71.6	0.23	10.87

df = 16

Table 2. Microbial biomass (C_{mic}) respiration and metabolic quotient in the top 7.5 cm of two contrasting soils under pasture in the Strathclyde region.

between the heavy metals arising from the geological parent material and anthropogenic deposition comes out clearly (Figure 3) but the dataset can also be used to indicate the effect of altering heavy metal limits on the distribution of soils which may be considered as suitable for sludge disposal. For example, if the upper limit for lead is reduced to the lower limit of the EC range, a limit currently already accepted in some countries, then the number of unsuitable soils for sludge disposal increases from only 7 to over 200 out of 800. Similar sensitivity exists for cadmium, whereas nickel is intermediate with an increase of 7 to 57 unsuitable soils on decreasing the upper limit from 75 to 30 ppm. Zinc, copper and chromium show little sensitivity with respect to the current EC ranges.

Research such as that described above enables a better understanding of the influence of purely edaphic factors in determining the suitability of land for the disposal and utilisation of sewage sludge both at site specific and strategic levels. In this connection we have recently classified the suitability of agricultural land for sewage sludge application and established a series of decision rules taking into account environmental characteristics, . including soil type (Towers, in press).

Eutrophication

Eutrophication can be defined as the enrichment of water by nutrients, especially compounds of N and/or P causing an accelerated growth of algae and higher plants to produce undesirable disturbance to the balance of organisms present in water and to the quality of the water concerned. It is becoming more common in the surface waters of Europe, although it is not clear to what extent agriculture contributes to this problem. However, the nutrient status of many agricultural soils, particularly their P status, has risen steadily to such an extent that nutrient losses from soils are a possible source of concern. Therefore, the transportation of N and P from soils to surface waters and the link between land use and nutrient losses needs to be assessed.

The great majority of the P lost from many soils is likely to be associated with eroded fine-grained particulates (Kronvang, 1990). However, soluble P can be important too because even though the amounts are relatively low (<2 kg P/ha) most is in a bioavailable form (Ron Vaz *et al*, 1993). Furthermore, we have concluded that most of the soluble P lost to aquatic systems in north-east Scotland is in an organic rather than the inorganic orthophosphate form. Nevertheless, further work on particulate P losses is advisable focusing particularly on the nature of the particles and on the way in which P is associated with them (He *et al*, in press). Thus, although particulate P may not be immediately bioavailable during erosion and deposition, it could become so if the chemical conditions change at the depositional site. For example, if the P is associated with fine-grained iron oxides then it could be released from this form following a change in redox conditions.

Given that nutrient losses from agricultural land could be involved in the eutrophication of rivers, it is clearly important to be able to model the effects of future land use changes on water quality. We have done this on a catchment scale for the River Don using the water quality model QUASAR as applied to N losses (Ferrier *et al*, in press). Figure 4 shows the effect of increasing nitrate inputs from land projected as being used for more intensive agriculture about 25 km upstream from a sampling point some 8 km from the coast. Future work will attempt to link this and other models into the economic effects, whereby the costs of the environmental consequences of land use change can be balanced against the profits to the agricultural community.

A future look

The major threats to the soil and to the ecosystems associated with it which have been outlined above will probably continue to be matters of future concern. Acidic and heavy metal inputs, from diffuse or point sources, are unlikely to be reduced to levels where they can be safely ignored and farmers will still require to add phosphates to their fields in order to optimise crop yields. However, other potential soil pollutants could also assume a higher profile depending upon

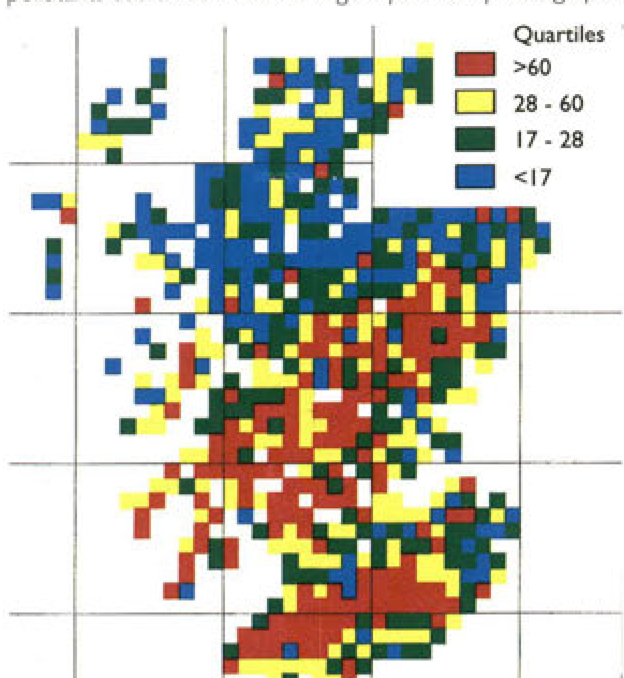

Figure 3. Aqua-regia extractable Pb, mg/kg.

accidental releases to the environment. For example, the recent incident off Shetland, when the oil tanker MV Braer ran aground and subsequently broke up, highlighted the fact that it was not possible to predict what the consequences would be for soils and vegetation following extensive hydro-carbon contamination. In fact, organic pollution of the environment is more pervasive than is often realised and we have recently illustrated this by showing that stable pollutants such as PCBs are readily detectable even in remote areas of Scotland (Bracewell *et al.,* 1993). Again, predictions concerning the fate of the radiocaesium deposited on British soils after the Chernobyl incident of 1986 were found to be inaccurate because they were based on the behaviour of mineral soils, whereas most of the fallout occurred on organic soils. Our work has shown, however, that even highly organic soils vary greatly in their capacity to immobilise radiocaesium and that small amounts of included mineral matter may exert a disproportionate effect in this respect (Shand *et al.,* in press).

These examples serve to illustrate the general point that predicting the effects of soil pollution requires continuing efforts at a fundamental level aimed at understanding the nature of the interactions of pollutants with both organic and inorganic soil

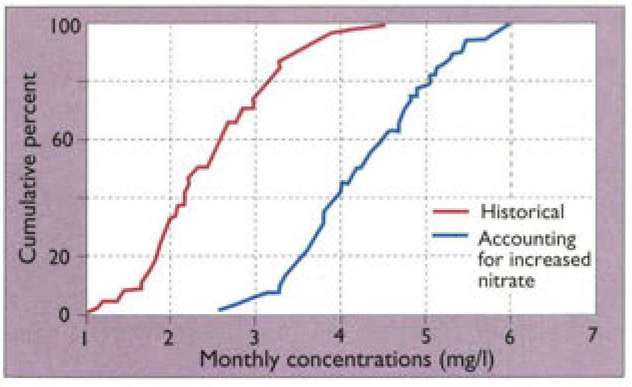

Figure 4. Observed (—) and modelled (—) monthly nitrate concentrations in the River Don at Parkhill given increased mineralisation in arable sub-catchments further upstream.

constituents, the conditions under which pollutants may be degraded, fixed or mobilised, the extent to which pollutants are transported either in solution or adsorbed onto fine colloidal particles, the degree to which pollutants become bioavailable, and the consequences of this bioavailability both on-and off-site. Such research carried forward on a broad front and involving participation of, and collaboration between, soil chemists, physicists and biologists provides an essential foundation for the development of predictive models aimed at determining the effects of pollutants on soils, particularly their vulnerability and their rates of recovery

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Soil, plant &

Nutrients used by plants can come from several sources. In intensive agricultural systems, fertilisers provide most of the nutrients, with smaller inputs from biological nitrogen fixation or atmospheric inputs (which can provide up to 22 kg N/ha/year in Europe; Skeffington, 1990). However, in low input and extensively-managed agricultural and forestry systems the majority of nutrients taken up by plants comes from the mineralisation of soil organic matter, due to the activity of soil microbes. Perennial plants can also store nutrients from one growing season to the next, remobilising them to augment nutrients taken up by the roots. Such internal cycling allows plants to make the most efficient use of the nutrient sources available to them and so is particularly important for plant growth on infertile soils (Millard 1993).

The objective of the research on soil, plant and microbial interactions and internal cycling is to understand the processes governing the supply of nutrients for plant growth in low input agricultural and forestry systems. Such an understanding is important for determining the sustainability of such systems in terms of both the capacity for nutrient uptake and use by plants and the potential for nutrient losses from soils, causing pollution problems (Edwards *et al.,* 1990; Wright *et al.,* 1991) as described in the article on Soil Processes and Pollution in this Report. While contributing to our strategic understanding of plant-soil interactions in low input systems, the knowledge gained will also allow the development of management strategies to ensure the sustainability of such systems. To provide information for agriculture and forestry managers, process-based models will be developed to produce an output suitable for use in decision support systems. The research, therefore, underpins studies of land use science elsewhere in the Institute.

microbial interactions and internal cycling

THEIR IMPORTANCE IN LOW INPUT AGRICULTURAL AND FORESTRY SYSTEMS

by P Millard

Plant roots lose carbon into the soil and so can have a major impact on soil microbial activity. In particular, exudation of small organic molecules from roots is the cause of the intense microbial activity in the rhizosphere compared with the bulk soil (Kraffczyk *et al.,* 1984). Understanding the interactions between plants and soil microbes, and ultimately how rhizosphere processes can be manipulated, is important for optimising plant growth in sustainable organic or low input systems. This review discusses recent MLURI work studying the exudation of carbon from tree roots and the consequent effects on soil microbial activity and nutrient availability.

The balance between soil organic matter and internal cycling in providing nutrients for plant growth is affected by the stage of plant development and the level of soil fertility. For example, it is well established that tree crops deplete soil nutrients more rapidly before canopy closure than after, when internal cycling provides more nutrients (Miller and Miller, 1987). Another example of the balance between root uptake and internal cycling providing nutrients for growth is the response of grasses to defoliation by grazing animals. Remobilisation of nitrogen from stubble and roots has been shown to provide nitrogen for laminae regrowth in defoliated grasses (Millard *et al.,* 1990). The relative ability of species to reutilise nitrogen by such internal cycling may be a factor governing vegetation dynamics in low input, grazed systems (Thornton *et al.,* 1993). Study of the processes of nutrient storage and remobilisation is important if we are to understand and ultimately model the ability of perennial plants to sustain their growth through internal cycling. This review also describes work at MLURI studying the impact of nutrient supply on the internal cycling of nitrogen in trees and grasses.

Exudation of carbon and nutrient availability

In low input systems the majority of nutrients taken up by plants is derived from soil organic matter, through the action of soil microbes. The activity of soil microbes is often limited by the availability of carbon substrates. Therefore, for a system of land use to be sustainable, it is necessary that there is sufficient cycling of carbon, firstly to ensure that soil organic matter levels are not depleted, and secondly to provide adequate substrates for microbes to mineralise the organic matter. Plant inputs to the soil through leaf litter and root turnover and death provide carbon for soil organic matter, most of which is relatively unavailable to the soil microbes (Vaughan and Ord, 1985). In contrast, the low molecular weight root exudates are more readily biodegradable and so have a far greater impact on soil microbial activity than other forms of carbon inputs from plants.

Exudates can affect soil fertility both directly and indirectly. Direct effects include the chelation of metal ions, thereby enhancing their uptake (e.g. Marschner, 1986, 1991; Vaughan and Ord, 1991a, b; Vaughan, Lumsdon and Linehan, 1993) or reducing rhizosphere pH by releasing protons (Marschner, 1991). However, the most significant effects are indirect, by acting as carbon substrates for soil microbes. The interactions between plant roots and soil microbes are extremely complex. In order to determine if exudation can be manipulated by management inputs, it is first necessary to understand the qualitative and quantitative interaction between exudates, soil microbes and other soil components. Research at MLURI is studying the influence of carbon partitioning in trees on root exudation and soil microbial activities.

Little is known about exudate losses of carbon from tree roots (Leyval and Berthelin, 1993). By growing young sycamore trees axenically in a $^{14}CO_2$ atmosphere we have shown that 32%, 40% and 24% of the carbon assimilated during a two-week period was partitioned to the leaves, stems and roots, respectively. Only 3% of the radioactivity was recovered in the culture solution. Gel filtration of the culture solution recovered 40% of this radioactivity as low molecular weight (<1000) exudates. In a similar experiment with Scots pine, 4% of the total radioactivity was released into the growth medium after 56 days of which one quarter was in exudates.

In addition to their utilisation as carbon sources by soil microbes there are several possible fates for carbon exuded from roots. Firstly, exudates can be adsorbed on to the soil components. We found that 22% of exudates added to sterile soil were adsorbed after 1 hour, increasing to 32% after 5 hours. These absorbed substances were not subsequently released. Secondly, enzymes are secreted from roots which can degrade exudates. For example, we have found that exudates from grass roots contain peroxidases (Vaughan, Cheshire and Ord, 1994) which can utilise phenolic acids which are found in exudates (Vaughan and Ord, 1991a; Marschner, 1991). Other enzymes reported in exudates have been phosphatases (Chhonkar and Tarafdar 1981) and invertase and nucleases (Chang and Bandurski, 1964).

Exudates can also be re-adsorbed by roots (Jones and Darrah, 1992). We have shown that some 10-15% of exudates from pine roots were taken up by sycamore roots after 6 hours of incubation.

The mineralisation of soil organic matter is facilitated by microbial enzymes. A wide range of enzymes occur in soil and, although it is probable that enzyme activities are greater in the rhizosphere than in bulk soil, few datasets can confirm this. Before we started soil enzyme studies, we developed a non-destructive technique for sampling rhizosphere soil under trees (Vaughan, Ord, Buckland and Duff, submitted). Soil was sampled in the late summer along transects running from the base of the stem of Sitka spruce trees, at 45° to its neighbour. The samples were analysed for a range of enzyme activities, which were then matched to the distribution of the root systems of the tree which was carefully excavated. Figure 1 shows the relationship between the activity of invertase and distance from the stem. The activity is also compared with that found in rhizosphere soil.

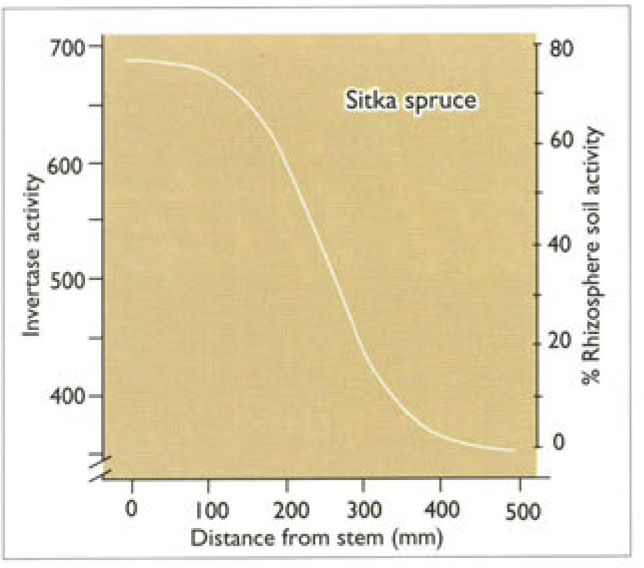

Figure 1. Fitted logistic curve for *Picea sitchensis*. Left hand axis shows invertase activity and the right hand axis shows the percentage of enzyme activity relative to that found in the rhizosphere.

Using this technique we have shown that rhizosphere soil from around sycamore roots has an invertase activity three times that of the bulk soil (Vaughan, Ord, Buckland and Duff, submitted). Similar values have been found for phosphatase activity in the rhizosphere of barley (Burns, 1985). Soil enzyme activities are indicative of microbial activity. We have studied the changes in a range of soil enzyme activities under several tree species including sycamore, Sitka spruce and hybrid larch growing in a farm forestry experiment. During the growing season there was an increase in the activities of all soil enzymes studied, from May until August, followed by a small decrease in September (Table 1). These changes reflected altered patterns of rhizodeposition, but no differences were found when soils from under different trees were compared.

Root exudates frequently contain phytotoxins which inhibit plant growth (Vaughan and Ord, 1991a). We have shown that free-living soil microbes, which can utilise these organic phytotoxins as substrates (Vaughan *et al.*, 1983,1988) can ameliorate their effect on plant growth (Vaughan, Jones and Ord, 1993). In addition to free-living soil microbes, exudates can affect mycorrhizal fungi, which greatly enhance the uptake of nutrients by plants, particularly phosphorus (Reid, 1990). From studies of mainly herbaceous arbuscular mycorrhizae, infection of plants has been shown to alter the nutritional status of the plant and increase photosynthetic rates (Linderman, 1991). The biomass of vesicular arbuscular mycorrhizae may be directly related to the amount of sugars exuded by the host root (Azcon and Ocampo, 1981). The fungi in turn can influence the amount of material released, with infected plants exuding more (Schwab *et al.*, 1984). Exudation from roots infected with ectomycorrhizal fungi has been less studied. We have shown that Scots pine infected with *Laccaria lacata* exuded more protein (5.2 ± 0.4 mg/g fresh weight root) than uninfected plants (3.1 ± 0.4 mg/g fresh root) after 3 months.

Enzyme	May	June	July	Aug.	Sept.
		% increase from March			
Invertase	24	72	107	155	132
Amylase	36	95	162	210	185
Cellulase	13	31	71	92	85
Phosphatase	21	59	87	110	93
Dehydrogenase	15	39	61	76	70

Table 1. Seasonal increases in enzyme activities in soil samples under sycamore at Lower Affleck farm in 1991.

Our work has demonstrated that, although the amount of carbon lost by tree roots as exudates is small compared to that assimilated by the plant, the exudates are quickly used by soil microbes and are very important for stimulating soil enzyme activities. In order to be able to manipulate the interactions between trees and soil microbes it is important to have a detailed understanding of the impact of root exudation on soil microbial diversity and activity.

Future work will utilise new techniques which have been developed to allow *in situ* studies of plant microbes. One such technique is the use of RNA/DNA probes, which will allow us to detect the presence of specific organisms *in situ* (Ogram and Sayler, 1988). This approach will be used to determine the validity of standard microbiological techniques such as plate-count culturing systems to assess the presence of microbial populations in soil. Another recent technique that has been developed, that we wish to use to follow the distribution and activity of microbes *in situ*, is the lux system. The lux gene, isolated from marine bacteria, has been inserted (either chromosomally or plasmid-borne) into host cells, which are then luminescent (Rattray *et al.*, 1990). Detection systems for fungi have lagged behind those for bacteria. However, both antibiotics raised against cell surface proteins and DNA probes are possibilities (Bazin *et al.*, 1990) which we can use in the future. Models are being developed to simulate carbon dynamics in the rhizosphere in relation to microbial biomass (Darrah, 1991). In the future we shall develop such models to predict changes in management inputs on root exudation, microbial activity and nutrient cycling in low input agricultural and forestry systems.

Internal cycling of nitrogen

Internal cycling is a major source of nutrients for the seasonal growth of both trees (Millard, 1993) and deciduous grasses (Thornton and Millard, 1993). In low input forestry systems internal cycling is a key mechanism governing sustainability. The greatest demand for soil nutrients occurs early in the life of a tree, often when they receive their only fertiliser inputs. As trees grow and their capacity for storage increases, internal cycling becomes increasingly important to the overall nitrogen economy of the plants. For example, Miller and Miller (1987) showed that for a 10-year-old Corsican pine crop, less than 20% of the annual requirement of N for growth was supplied by internal cycling; after 40 years of growth this figure had risen to over 50% for both N and K.

Internal cycling is also important in providing nutrients for tree growth on more fertile soils. It has been shown in fruit orchards that internal cycling supplies some 45% of N used for growth in 5-year-old pear trees (Sanchez *et al.*, 1991), 50% in mature almond trees (Weinbaum *et al.*, 1987) and 84% in mature citrus trees (Feigenbaum *et al.*, 1987). Understanding and predicting the impact of fertiliser inputs to trees in a range of systems, from conventional and farm forestry to agroforestry systems requires a knowledge of the seasonality of both the processes of internal cycling and root uptake of nutrients for growth. It is also necessary to know if enhanced soil fertility reduces the efficiency of the internal cycling, as has been shown to occur for annual plants cycling nutrients between vegetative and reproductive growth (Millard, 1988).

The processes of internal cycling comprise nutrient storage during winter and remobilisation of nutrients from store for spring growth, in both evergreen and deciduous trees (Figure 2 overleaf). Deciduous trees complete their annual cycle by withdrawing a proportion of the nutrients from their senescing leaves, while root uptake can contribute directly to storage in the autumn in both evergreen and deciduous trees. In order to understand how trees will respond to changes in soil fertility or management inputs, it is necessary to be able to quantify the remobilisation of N in the spring (Millard, 1993). Nitrogen budget studies have been used to quantify internal cycling in relation to site fertility (e.g. Miller *et al.*, 1979; Aronsson and Elowson, 1980; Nambiar and Fife, 1991) and stand age (e.g. Miller, 1981; Helmisaari, 1992). A limitation of such studies is that they are relatively imprecise (Nambiar and Fife, 1991) and have seldom allowed the processes of internal cycling to be measured directly. Instead, remobilisation has either been assumed to be equal to the amount of N withdrawn from senescing leaves (e.g. Helmisaari, 1992) or calculated by net losses

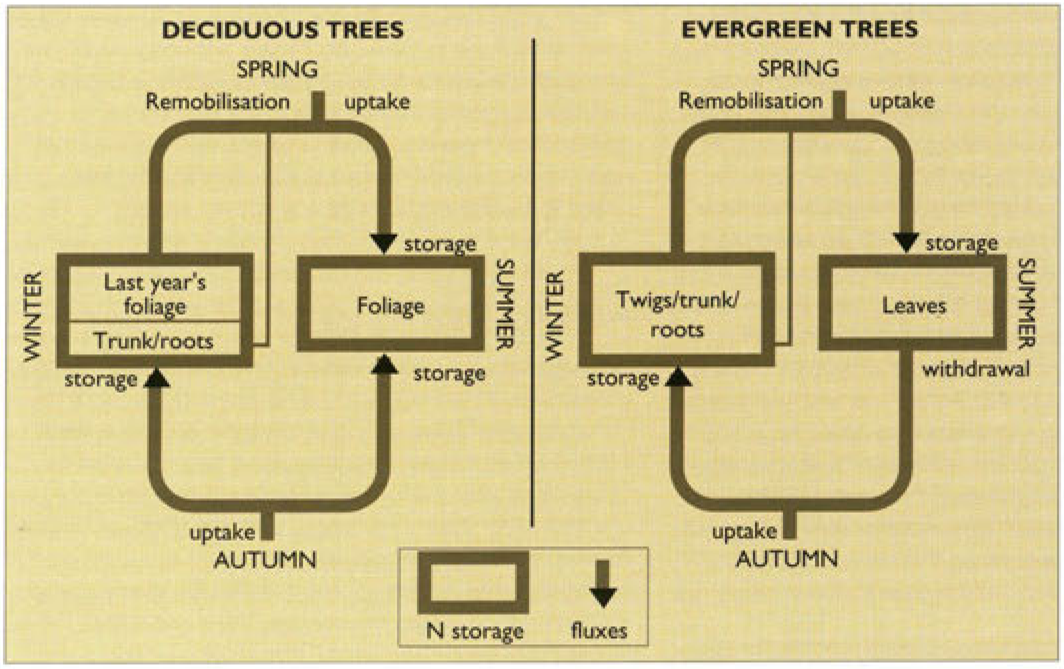

Figure 2. The seasonal pattern of internal cycling of N in deciduous and evergreen trees.

of N from older tissues (e.g. Miller *et al.*, 1979; Nambiar and Fife, 1987), often excluding roots. Such approaches make it difficult to assess the impact of soil fertility on the efficiency of N remobilisation in the spring. The first method probably underestimates N remobilisation, since it does not allow for the withdrawal of N from leaves prior to senescence (Nambiar and Fife, 1991) or N uptake in the autumn augmenting N storage pools directly (Millard and Thomson, 1989; Millard and Proe, 1991). The second method is imprecise, because of the nature of the measure- ments made and, in some cases, a failure to complete budgets for whole plants. A further danger of budget studies to quantify internal cycling is that they estimate only the net transfer of nutrients within plants. Differential partitioning of uptake and remobilised nutrients can occur (Proe and Millard, a, b, in press), leading to possible errors in interpretation of data.

An alternative approach has been to use isotopes to quantify internal cycling (e.g. Hill-Cottingham and Lloyd-Jones, 1975; Weinbaum *et al.*, 1987). We have used sand culture techniques to allow the nutrient supply of trees to be controlled precisely, and both nutrient uptake by roots and remobilisation to be accurately measured using isotopes (Carvalho *et al.*, in press; Millard and Neilsen, 1989; Millard and Proe, 1991, 1992, 1993; Millard and Thomson, 1989; Proe and Millard, a,b, in press). Table 2 shows the results from such experiments, using ^{15}N to quantify the remobilisation of N for spring leaf growth in a range of species. Young trees, typically three or four years old, were grown for one year and provided with ^{15}N throughout. Internal cycling of N was quantified by the recovery of unlabelled N in the leaves over successive destructive harvests (e.g. Millard and Neilsen, 1989). Alternatively, trees were preconditioned with either a generous or poor ^{15}N supply for a whole year and supplied unlabelled N in the second year. Recovery of ^{15}N in the leaves grown in the second year quantified the remobilisation of N in the spring (e.g. Millard and Proe, 1991).

The use of ^{15}N in these experiments allowed us to determine several characteristics of remobilisation that would not have been possible from N budget studies. Firstly, in each species the amount of N remobilised for the spring growth of leaves was not affected by the current N supply (Table 2). In contrast, leaf growth was influenced by the generous N supply, in each experiment producing a significantly greater leaf mass per tree than for those provided with a poor N supply in that year. When sycamore or Sitka spruce had their growth preconditioned, their capacity for remobilisation of N in the spring of the second year was dependent only on the N supply the previous year (Table 2). In a similar study of the grass *Molinia caerulea*, we found that the proportion of the N in the basal internodes and roots remobilised for spring leaf growth was unaffected by the amount of N supplied to the plants (Thornton and Millard, 1993).

Secondly, remobilisation of N tended to occur before the majority of root uptake occurred. The data in Table 2 show that in the spring (once remobilisation of N had finished), internal cycling had provided a large proportion of the total leaf N content. However, root uptake subsequently continued, so that later on in the summer the maximum total leaf N content was often greater than the amount of N supplied by internal cycling. A similar pattern of N remobilisation for spring leaf growth was found for *Molinia* as well.

These findings demonstrate that fertilising plants will increase their growth and the capacity for storage, but has little or no effect upon the efficiency of remobilisation of N for spring growth (Millard, 1993). They explain the common observation that fruit trees benefit more from fertiliser applications immediately pre- or post-harvest, than in the spring (Taylor, 1967; Sanchez *et al.*, 1992).

Measurements of the processes of internal cycling using ^{15}N have determined that: (1) N remobilisation in the spring is dependent on the size of the store and is unaffected by current N supply (Table 1) and (2) internal cycling provides N for leaf growth in the spring before rapid root uptake. This knowledge has allowed us to measure the spring

Species	N supply: Pre-conditioning	N supply: Current	Max leaf N content in the summer	N remobilisation in spring	Max leaf mass of tree in summer
			mg N/tree	mg N/tree	g/tree
Fraxinus excelsior	-	Generous N	315±24.0	65± 9.5	10.3±0.9
		Poor N	118±21.9	48± 7.7	5.1±0.7
Betula pendula	-	Generous N	-	30± 3.3	10.6±0.6
		Poor N	-	23± 4.8	4.4±0.3
Malus domestica	-	Generous N	320± 7.8	58± 5.1	8.3±0.8
		Poor N	71± 4.4	62± 3.1	4.2±0.9
Acer pseudo-platanus	Generous N	Generous N	382±28.5	238±17.2	18.3±2.1
	Generous N	Poor N	283±20.0	232±20.0	9.4±2.7
	Poor N	Generous N	217±16.6	46± 6.8	18.9±1.3
	Poor N	Poor N	109±21.1	47±11.0	8.3±1.7
Picea[a] *sitchensis*	Generous N	Generous N	600±32.5	121±23.5	22.6±1.3
	Generous N	Poor N	162±10.7	104± 3.1	12.8±2.1
	Poor N	Generous N	673±30.7	29± 3.4	29.0±1.9
	Poor N	Poor N	78± 2.1	28± 2.9	6.1±1.0

[a]Data relate to current season's foliage only

Table 2. The effect of current N supply on the spring remobilisation of N for leaf growth by a range of species. Values for the remobilisation of N (as measured using ^{15}N), the maximum leaf N content and the maximum leaf mass per tree found in the growing season represent the mean and standard error of four replicates.

remobilisation of N in larger trees growing in the field for the first time. Soil pools of N were saturated with ^{15}N immediately prior to bud burst by sycamore and Sitka spruce trees and recovery of the isotope in leaf samples used to estimate when soil N uptake occurred. The leaf N content prior to any root uptake of N was used as a direct estimate of N remobilisation (Millard, in press). Some 4-5 mg N/leaf was recovered in sycamore before any fertiliser ^{15}N was detected (Figure 3). The total N content was some 15 mg/leaf, suggesting that about one third of leaf N was remobilised from storage.

Another method for measuring the remobilisation of N in the spring in field-grown trees is being developed. There is a marked seasonal fluctuation in the concentration of nitrogen recovered in the xylem sap of trees (Moreno and Garcia-Martinez, 1983; Glavac and Jochheim, 1993). Increases in the concentrations of glutamine in xylem sap from poplar in the spring have been linked to the breakdown of bark or wood storage proteins (Sauter and van Cleve, 1992), known to be a major storage site for N during the winter in a range of species (Wetzel *et al.*, 1989; Langheinnich, 1993). Ash and birch trees are having their N storage preconditioned with ^{15}N, before xylem sap measurements coupled with ^{15}N flux measurements quantify both the duration of N remobilisation and increased concentrations of N in the xylem saps.

In order to translate our understanding of the impact of soil fertility on the processes of internal cycling from young to older trees, a model has been developed to simulate nitrogen partitioning in relation to that of carbon. The original model predicted nitrogen partitioning within peach trees up to the onset of leaf senescence (Habib *et al.*, 1989). We subsequently developed the model to include the withdrawal of nitrogen from senescing leaves, using data from a study of sycamore trees, thereby enabling simulation over several years growth to be made (Habib and Millard, 1992). The model proved to be robust to variations in both tree size and nitrogen status, accurately predicting the nitrogen content of leaves and roots, while slightly underestimating the partitioning to twigs and overestimating the nitrogen in the trunk (Habib *et al.*, 1993).

Our work has demonstrated the importance of internal cycling in providing nitrogen for tree growth each year. Internal cycling is not a mechanism for adapting to infertile soils. Instead, nitrogen remobilisation is a method of augmenting the N supply to apical growing points, allowing bud burst in trees to occur before rapid uptake from the soil. Storage of nitrogen allows trees to make the most efficient use of the available nutrient resources. When given, fertiliser applications will influence tree performance by an effect on current growth and storage of nitrogen.

Response of grasses to defoliation

In addition to providing N for spring growth, internal cycling may be an important factor governing vegetation dynamics in low input systems that are grazed. Grasses have two possible sources of N for leaf growth after defoliation, current root uptake or remobilisation of stored material. The use of ^{15}N allows these two sources of N to be discriminated (Ourry *et al.*, 1988; Millard *et al.*, 1990). When the supply of N to the roots of a range of grass species was varied, decreases in

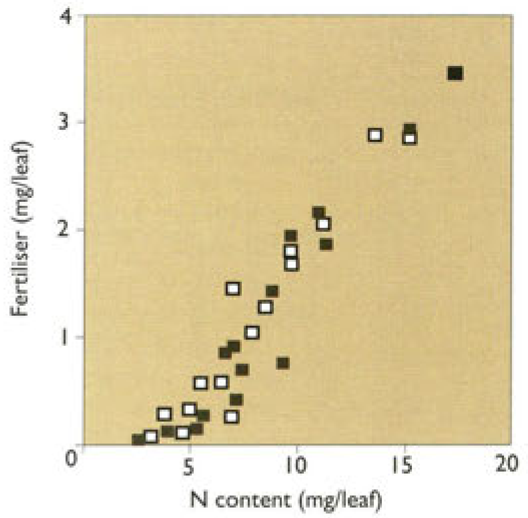

Figure 3. The relationship between N content and fertiliser ^{15}N content of individual leaves of *Acer pseudoplatanus* harvested during the spring and summer. Values are the mean of 20 replicates from the upper (□) or lower (■) canopy.

N supply increased the proportion of the N used for regrowth that was derived from remobilisation (Millard et *al.*, 1990; Thornton, Millard and Duff,1993). The form of N supplied and the temperature also influenced the degree of remobilisation. We found that *Lolium perenne* supplied with ammonium sulphate remobilised more N for laminae regrowth than when grown with calcium nitrate (Thornton, Millard and Galloway, 1993). At lower temperatures growth was slower, but we found that remobilisation is relatively more important in supplying N for laminae regrowth than root uptake.

Decreases in fertiliser inputs to grasslands result in slower growth and changes in species composition (Olff and Bakker, 1991), particularly in systems that are mown or grazed. Sown swards of *L. perenne* managed with few inputs undergo changes in botanical composition with species of *Poa, Agrostis, Holcus* and *Festuca* invading the swards (Morrison, 1979). As soil fertility decreases, species relying predominantly on root uptake to supply N for regrowth may be progressively disadvantaged. We studied four species commonly found in low input grassland systems and found that the order for an increasing reliance on remobilisation of N in response to defoliation was *L. perenne* < *P. trivialis* < *A. castellana* < *F. rubra* (Thornton, Millard, Duff and Buckland, 1993). This species order was little affected by the level of N supplied (Thornton, *et al.*, submitted) and matched the succession of species ingress into *L. perenne* swards reported by Morrison (1979).

In order to determine the significance of the processes of internal cycling for vegetation dynamics in grazed communities, it will be necessary to develop techniques for measuring N and P remobilisation in the field. The isotope techniques that are used currently are only applicable to miniswards, growing under controlled conditions. The development of techniques to quantify remobilisation under field conditions will allow the response of grasses to defoliation to be studied, and so enable the impact of grazing intensity as an option for managing vegetation to be modelled mechanistically. Research will concentrate on identifying biochemical and physiological markers for nutrient remobilisation, such as protein turnover in roots (Ourry et *al.*, 1989) or patterns of amino acid translocation (Bigot et *al.*, 1991). These techniques will be validated using existing isotope techniques and used to quantify remobilisation of nutrients in relation to the frequency of defoliation and edaphic factors such as soil temperature, pH and fertility.

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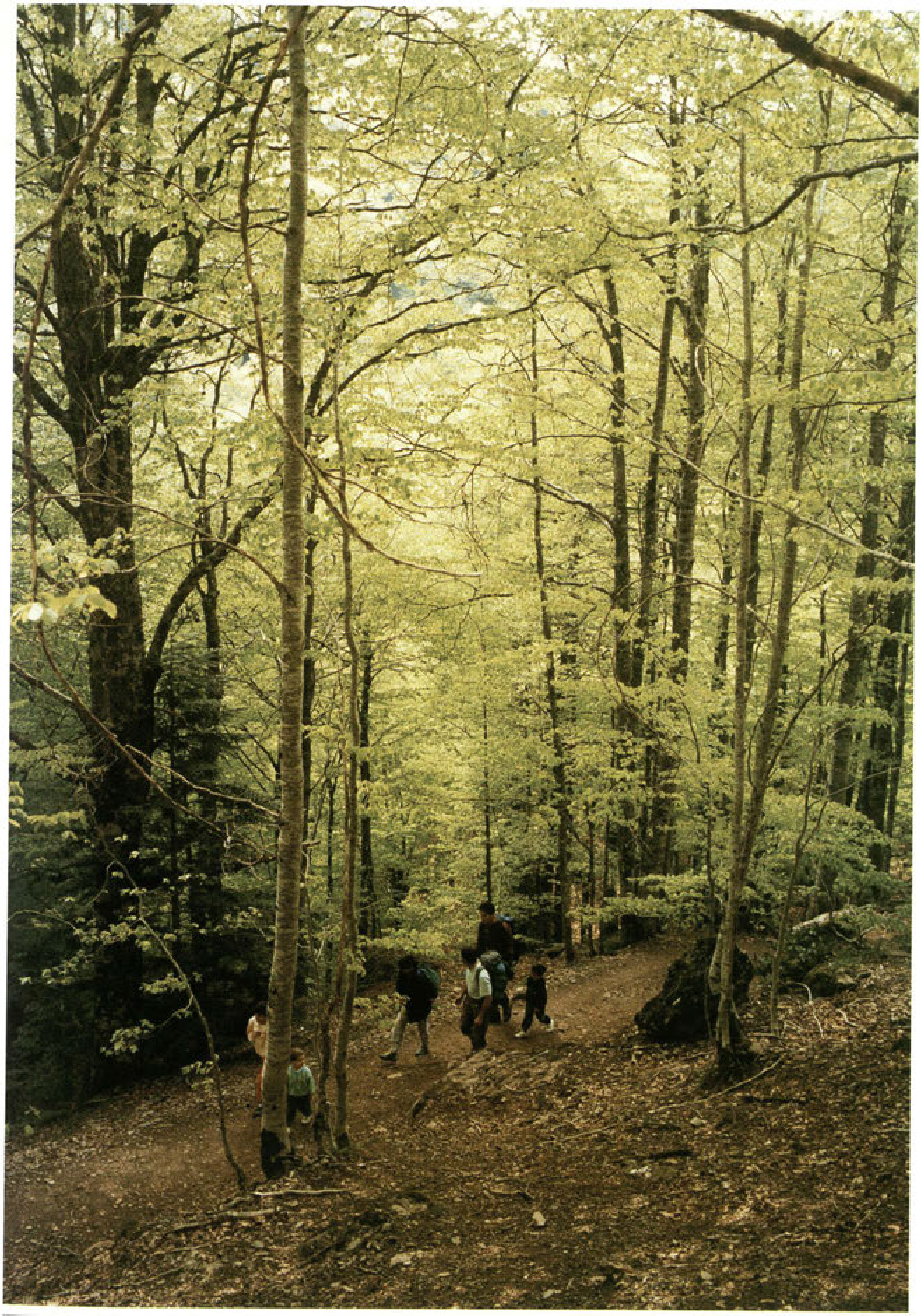

Woodlands and forests can contribute to our quality of life in many positive ways. Near Killin, Perthshire.

Foraging behaviour and vegetation dynam

by J A Milne

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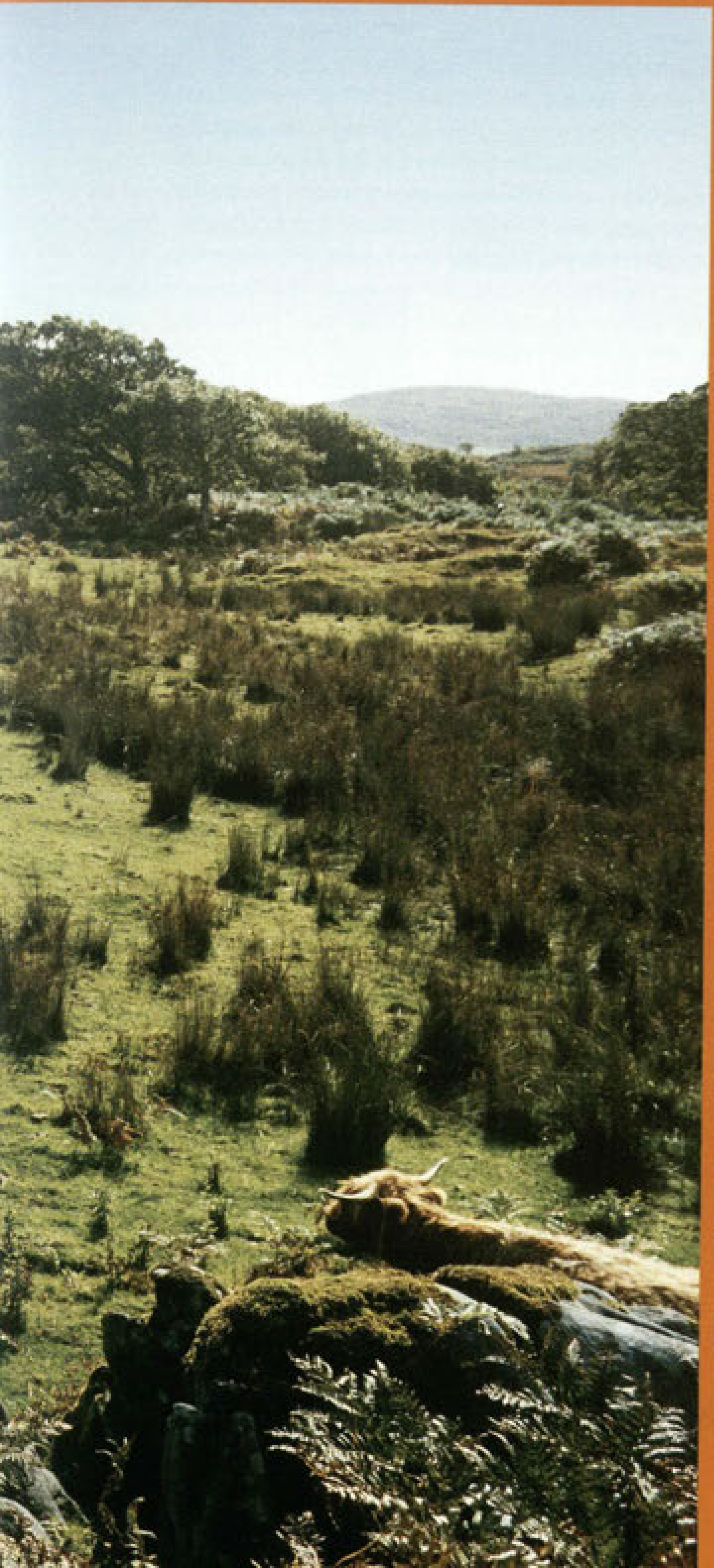
UNDERSTANDING THE IMPACTS OF LARGE HERBIVORES IN UPLAND BRITAIN



In Upland Britain there are 5.3 m ha of rough grazings, i.e. semi-natural vegetation, and 5.4 m ha of marginal agricultural land, mainly permanent pasture, which account for 47% of the land area of Britain (Ball, Radford and Williams, 1983). This vegetation was grazed by 12.2 m breeding ewes and 1.0 m suckler cows in 1991. The total output from these sheep and cattle amounted to £1.35 bn which was over 90% of the total agricultural output from the upland sector. It should be noted, however, that approximately half of the financial output was obtained through EC and UK government subsidies. Agriculture in Upland Britain employs 130,000 people and together with related industries, such as tourism, is thus a major employer and contributor to the total monetary output. From a wildlife conservation stand-point Upland Britain provides habitats which are considered to be important both nationally and internationally. They contain plant communities, such as blanket bog and Calluna heath, which have European and world significance and there is probably a greater mixture of boreal, arctic, temperate and continental bird species than in any other comparably sized part of Europe (Ratcliffe and Thompson, 1988). Nationally, the range of ecosystems is greatly extended by the presence of upland areas and these help to create Britain's distinctive landscapes.

An understanding of how domestic herbivores graze these land resources, where the degree of control of grazing is less than in lowland Britain, how vegetation is changed by grazing and how domestic herbivores interact with wildlife is central to achieving the aims of (1) developing efficient systems of agricultural production, (2) enhancing conservation value and (3) creating attractive landscapes. The appropriate use of domestic herbivores can help to achieve these multiple land use objectives and thereby minimise the cost to the Exchequer of sustaining rural populations whilst at the same time maximising those aspects of quality of life associated with amenity and environmental sustainability. Such an understanding is not only relevant to government and regional policy-makers but to all those who use these land resources whether to obtain their livelihood or to enjoy the wildlife populations and landscapes that are created.

There are a number of important scientific issues which require to be addressed in order to be able to predict the impacts of the grazing animal and the consequences for its productivity. Not only do these issues have relevance to grazing by domestic and wild herbivores in upland Britain but they are applicable to the rangelands of the world. They are concerned with how large herbivores forage in environments which are heterogeneous by virtue of topography, climate, vegetation and anthropogenic influences, how individual plants, plant species and communities are influenced by components of grazing, in particular defoliation, and how our knowledge of these numerous and interacting processes can be organised through computer modelling to provide decision-support systems for scientists working on the subject and land managers wishing to predict the consequences of changes to their systems.

This article addresses these scientific questions, the extent to which our understanding has developed in recent years and what issues remain to be resolved.

Foraging by large herbivores

How animals forage can be reduced to a number of related questions. These are: what do animals select as food, where do they select it from and how much do they ingest? These questions need to be addressed within the context of a herbivore meeting a need for specific nutrients and avoiding the ingestion of potentially toxic compounds. In relation to the UK the main limiting nutrients are those which influence the energy budget of the animal. This is because the energy/ protein ratio of most herbages in the UK is such that protein is not likely to be limiting in ruminants, the principal herbivores, and minerals are seldom the limiting nutrient except in specific circumstances. Hence, research concentrates on the potential digestible energy intake by herbivores and how it is modified by their morphology, physiology and their behavioural responses to the complex environment within which they forage.

How much can be ingested?

The potential digestible energy intake from the major plant communities of upland UK is now known for sheep and cattle (Hodgson *et al.*, 1991) and current work at MLURI is extending its database by obtaining data for other species such as goats, red deer and South American camelids (Gordon and Fraser, 1991). Although the functional response, i.e. the relationship between biomass and digestible energy intake, for sheep and its seasonal changes have been described at MLURI for some of the important semi-natural communities, such as heather *(Calluna vulgaris)*, (Milne *et al.*, 1979) and for sown grassland (Bircham and Hodgson, 1983), insufficient data exist for such an approach to be used as a means of predicting actual intake from biomass or a correlate such as sward height. Hence a different approach was adopted to predict the digestible energy intake of sheep in the construction of the foraging sub-model within the Hill Grazing Management Model developed by a group at MLURI (Armstrong and Sibbald, 1992). It was based on how the potential digestible energy intake of a plant community is modified by the manner in which the components of intake, namely bite mass, biting rate and grazing time, are influenced by biomass. This approach used a mixture of empirical data and theoretical considerations, derived from work carried out at MLURI (see Milne, 1991; Illius and Gordon, 1987, 1992). Since the functional response differs between species, such as sheep, cattle and goats (Bircham and Hodgson, 1983; Wright and Whyte, 1989; Merchant and Riach, in press, see Figure 1), and there is a moderately large number of important plant communities that are likely to be grazed in the UK uplands, it is unlikely that predictions of digestible energy intake from a range of vegetation types for other species can be made solely from empirical data. It is envisaged that future approaches to predicting the digestible energy intake from plant communities for species other than sheep and in other pastoral circumstances could adopt the same approach of combining empirical results with theoretical considerations and it is intended to develop a generalised approach to the computer modelling of such predictions at MLURI.

The potential digestible energy intake is not only determined by the biomass of the vegetation but also by its chemical composition. As well as the well-recognised relationships between digestible energy intake and the cell wall and nitrogen contents of forages, secondary plant compounds can have important effects by reducing the digestion of plant material, for example through the action of phenolic compounds in the rumen, or by altering the animal's metabolism. Duncan and Milne (1993) found that allyl cyanide, a ruminal breakdown product of glucosinolates, secondary plant compounds found in *Brassica* species, caused a reduction in intake which was probably associated with an effect on the animal's metabolism, but they also showed that ruminal adaptation to allyl cyanide occurred over a period of a week (Duncan and Milne, 1992). Similarly, ruminal adaptation to phenolic compounds, such as those found in heather, has also been observed. Whilst this has relevance to the digestible energy intake of herbages, the adaptation process may also be important in the extent to which adaptation and prior experience influence diet selection when a range of plant species with different chemical compositions is offered. Research in this area is being initiated at MLURI.

In addition to plant biomass and its chemical composition, digestible energy intake is also influenced by the intake potential of the herbivore. There is a large number of morphological and physiological functions of herbivores which can influence their intake potential. Animal size has been shown to be of major importance in ungulates (see Gordon and Iason (1989) for discussion). With temperate species of herbivore seasonal factors are of particular importance in determining intake potential. In red deer (Loudon *et al.*, 1989; Milne *et al.*, 1978) and some UK genotypes of sheep (Iason *et al.*, in press) there are natural patterns of intake and digestibility associated with daylength, which are closely linked to other seasonally related physiological processes (Milne *et al.*, 1990) but which interact also with biomass availability (Haydon *et al.*, 1993). High herbage availability was found to

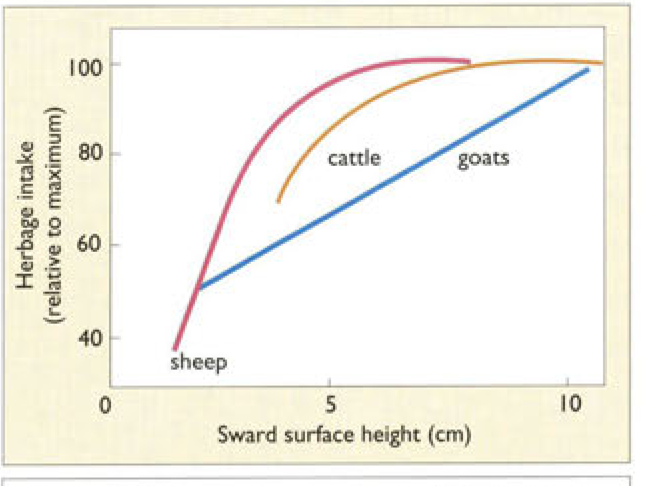


Figure 1. Relationship between sward height and herbage intake (expressed relative to maximum) for sheep, cattle and goats grazing sown swards.

be associated with the expression of a seasonally manipulated intake potential whilst low herbage availability resulted in no expression (see Figure 2). An important area for future research is to discover the mechanisms at the brain and gut level which determine the outcome of the interaction between seasonality of intake and digestibility and the functional response. Seasonality of nutrient supply also leads to seasonal patterns in fatness, which is negatively related to herbage intake in sheep (Gunn *et al.*, 1991). Herbage intake in the autumn, however, is not related to an immediately prior level of nutrition (Sibbald and Kerr, in press). This suggests that longer-term controls on intake potential are present and these are currently being explored through the study of early-life effects on intake.

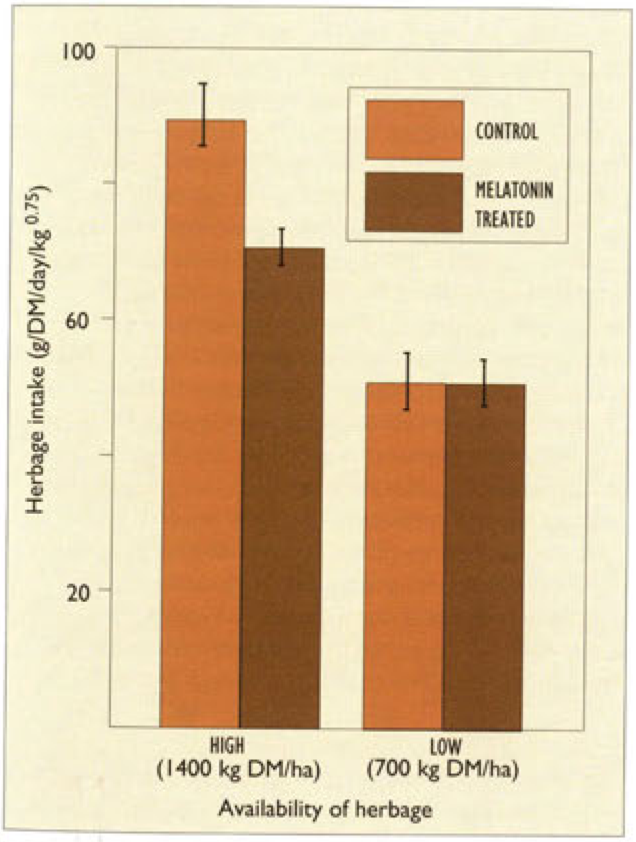


Figure 2. The effect of melatonin treatment (to manipulate seasonality of intake) and herbage availability on herbage intake of red deer hinds in the autumn. (Haydon *et al.*, 1993)

How do large herbivores forage?

The issues concerned with predicting what the potential digestible energy intake of any plant community by a large herbivore may be are a necessary prerequisite to understanding how animals forage. The questions about what diet is selected and where from will now be addressed. A widely accepted paradigm is that foraging animals attempt to optimise their energy intake in relation to the energetic costs involved. Applied to foragers whose feed is distributed as discrete and relatively large food items, it has been possible to develop a body of experimental evidence and to describe the processes involved in support of this paradigm (Stephens and Krebs, 1986). In the case of large herbivores, which may ingest up to 40,000 bites of herbage per day, these theoretical models of foraging are likely to require adaption. A recently published model (Spalinger and Hobbs, 1992), which identifies three limiting processes for intake by herbivores, namely encounter of food items, travel time between food items and handling time of food items, has been generalised at MLURI. This has resulted in the prediction that when a forager is limited by the rate of handling food items only the most profitable food item will be selected and when the forager is limited by the rate of encounter with food items it will be less selective. Such predictions require to be tested experimentally.

'Profitable' in the above paragraph can be defined in terms of the balance between the digestible energy gained during foraging and the energy costs involved in foraging. In most studies on the foraging of large herbivores the emphasis has been placed on the former because the energy costs associated with handling, ingestion and travel time are low. Hence considerable emphasis has been placed on digestible energy intake maximisation in the prediction of the selection of a diet from a range of plant communities. For example, the Hill Grazing Management Model, alluded to previously, uses habitat matching theory (Fagan, 1987) to predict the communities selected by sheep. This assumes that sheep select those communities with the highest potential intake of digestible energy and in relation to their area as a proportion of the total area. This model was found to be inadequate in predicting foraging behaviour of sheep grazing some upland areas and required reparameterisation to provide adequate predictions.

It is not surprising that such a simple model should prove inadequate. It does not take account of circumstances where nutrients other than energy, such as secondary plant compounds, or the structure of the plant influence diet selection. In addition it does not consider how the spatial distribution of plant communities and social behaviour alter diet selection and how climatic variables can affect the energy costs of foraging.

In relation to effects of chemical composition of plants on diet selection, Duncan *et al.* (in press) have shown that manipulation of the crude protein content of patches of heather using fertilisers causes sheep to select those plants in a heather monoculture. The structure of young trees was also found to be important in determining the choice of trees by red deer.

Considerable emphasis at MLURI in the last 4 years has been placed on determining experimentally the effect of spatial distribution of plant species and communities on diet selection. The ability to determine dietary composition has been greatly enhanced by the development of a technique for determining the species composition of the diet from the n-alkane composition of the faeces (Dove and Mayes, 1991). The technique, developed at MLURI, is particularly useful where a small number of species is present but it is planned to develop the technique further to extend the number of plant species that can be determined.

The spatial distribution of plant species influences the foraging behaviour of large herbivores in a number of ways. In grass pastures where white clover patches of different size and distance between one another were artificially introduced and grazed by sheep, the proportion of white clover in the sward affected the proportion in the diet but distance between patches and the size of the patch were unimportant (Armstrong *et al.*, in press). Size of patch and distance between patches at the same geographical scale were found, however, to be important in determining foraging behaviour by sheep when a greater nutritional contrast between two plant communities, namely heather and grass, exists (Clarke *et al.*, in press). It is not only the distribution of nutrients that can influence foraging behaviour. When plant structure was manipulated, without altering nutritive value, by using different brassica species and distributing the species spatially, sheep ingested more of the plant species with the less erect habit.

Further work has shown that there are differences between sheep and red deer in their grazing of large and small patches with sheep preferring smaller patches than red deer (see Figure 3). This is probably associated with differences in social behaviour between the species. The significance of social interactions in determining ingestive behaviour by large herbivores has been largely ignored in the past and research is planned to examine the importance of

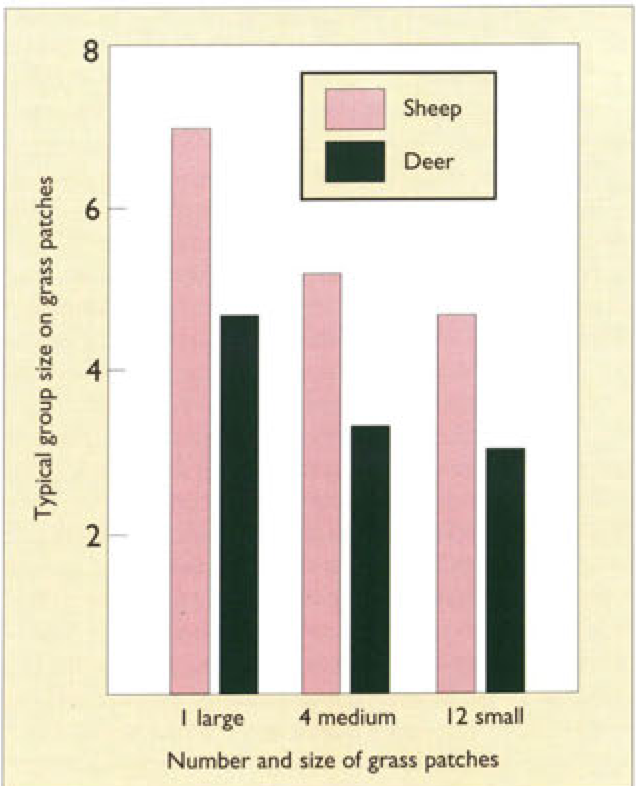


Figure 3. The group size of sheep and red deer on large, medium and small patches of grass in grass/heather mosaics. (Gordon *et al.*, in press)

social facilitation and competition in influencing diet selection and intake. The datasets from the experiments described above together with additional datasets from other research groups in the UK are being used to test hypotheses about how foraging occurs in heterogeneous ecosystems using a Geographical Information System approach. Included in such an approach is a description of microclimate so that the significance of climatic variables on energy costs can be assessed. This will aid the planning of experimentation to provide a quantification of the predicted effects.

Vegetation dynamics

Large herbivores influence change in plant species composition principally through the process of defoliation. Plant species have different responses to defoliation and these influence their ability to compete with one another. Depending upon the nutrient and moisture status of the soil, the outcome of such plant competition will be a change in the floristic composition, initially within a plant community but ultimately leading to changes in the plant communities present. In the uplands of the UK these processes occur relatively slowly but can lead over a period of 50 years to dramatic changes in the vegetation and in the landscape, for example reduction in the area of heather moorland. Scientifically the challenges are to (1) understand the effects of defoliation on the ecophysiology of the plant, (2) describe and understand the processes associated with plant competition in these communities and (3) predict the spatial and temporal changes in the important grassland, heath and woodland communities associated with changes in grazing pressure by large herbivores. At MLURI research has concentrated recently on the ecophysiology of grass species, competition between grasses and white clover in sown swards and the spatial and temporal and spatial changes associated with the grazing by large herbivores of the most important plant communities in the uplands of the UK.

Effects of defoliation on plant competition

The influence of defoliation on the plant's competitive ability may be mediated through responses in mobilising nutrients from above- or below-ground stores, root growth and uptake of nutrients and responses to light. In *Molinia*, a deciduous species intolerant of grazing, nitrogen remobilisation from roots and base internodes occurred in the spring, to support new leaf growth prior to uptake of nutrients by roots. Defoliation in the summer caused a higher proportion of remobilisation from roots while the extent of remobilisation from base internodes was unaffected (Thornton, 1991). From field experimentation it was found that levels of defoliation which removed either 30% or 60% of leaf through cattle grazing reduced the productivity of *Molinia*, with the greatest decline occurring at the 60% level (Torvell *et al.*, 1988). These findings together suggest that remobilisation from roots is an important process in the response to defoliation.

With four species of permanent grassland, *Lolium perenne*, *Agrostis castellana*, *Festuca rubra* and *Poa trivialis*, remobilisation of nitrogen relative to root uptake to supply nitrogen for lamina regrowth was species-dependent with increasing remobilisation occurring in the order, *Lolium*, *Poa*, *Agrostis* and *Festuca* (Thornton *et al.*, 1993). Interestingly the order relates to the order of ingress of species into a permanent grassland under continuous sheep grazing over a period of 20 years (Morrison, 1979). Increased severity of defoliation under regular defoliation reduced the extent of remobilisation, which was also altered by whether the nitrogen was in the form of ammonium or nitrate. Future work will investigate the effect of frequency of defoliation. The value of these observations would be greatly enhanced by the development of biochemical markers for nitrogen mobilisation after defoliation which could be used in field studies. Since phosphorus is the next most limiting nutrient to nitrogen in many grassland ecosystems, the reallocation of phosphorus within the plant also requires to be studied.

In addition to nutrient reallocation, it has also been argued above that root dynamics and competition for light following defoliation are important determinants of plant competitive balance. Within the context of extensification of sown swards with little or no inputs of fertilisers and low stocking rates of grazers, experimentation is being conducted to examine the relative importance of these factors and to allow the parameterisation of a model to explore their significance for plant competition. In a long-term study of extensification, commenced in 1990, there have been dramatic shifts in species composition in ungrazed treatments but much slower changes where sheep grazing has occurred. Figure 4 shows the effect of removal of grazing on the reduction in ryegrass and white clover content of the sward and the increase in proportion of other grass species. Current research is examining the extent to which relative growth rate, remobilisation of nutrients and lifespan of leaves of different species, the role of gaps and the timing of defoliation influence floristic change.

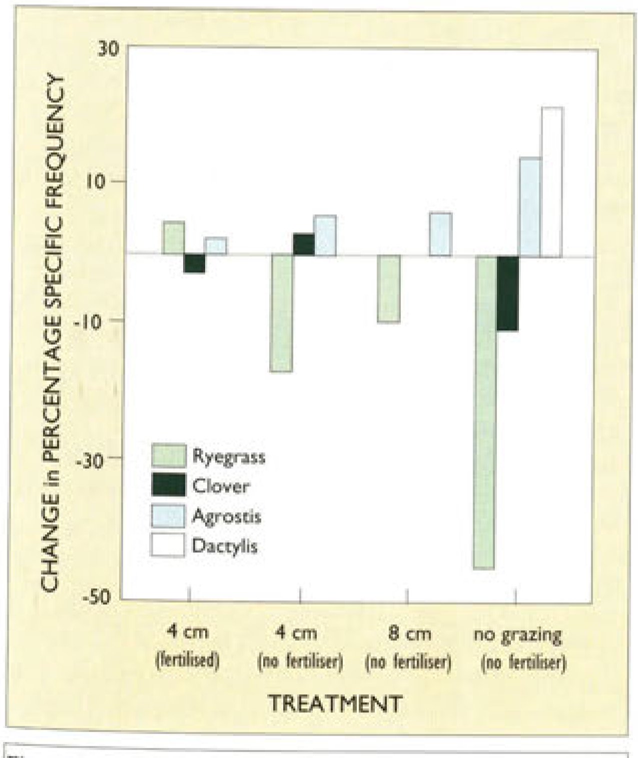


Figure 4. The effect of grazing treatment and fertiliser treatment on the change in percentage specific frequency of grasses in a predominantly ryegrass/white clover sward after 2 years of imposition of treatment at one site. (C A Marriott, unpublished data)

The extent to which periods of release from grazing can influence changes in floristic composition has been shown in ryegrass/white clover swards. Incorporation of periods of 4-6 weeks release from sheep grazing in an otherwise continuous grazing regime in the summer altered the species balance in the subsequent period, with an early season release from grazing increasing the ryegrass content and a later season release increasing the white clover content (Barthram and Grant, in press). The results can be explained by the differences between the species in their ability to elevate their leaves and capture light. At low temperatures in the spring the rate of increase in the height of clover was less than that of ryegrass. At temperatures greater than 12°C clover is able to elevate itself within the canopy at similar or faster rates than ryegrass due to a faster rate of extension of clover petioles (Barthram and Grant, in press) More generally this research demonstrates how the timing of defoliation can influence species balance depending upon the attributes of the species in the mixture.

Spatial and temporal changes in community balance

Grazed grass/clover swards have also been used to study the development of spatial heterogeneity which may have an important role in altering community balance through its influence on the grazing behaviour of large herbivores as discussed above. Clover has been adopted as a useful model for stoloniferous species. In artificially created patches of clover within a ryegrass sward, clover spread most slowly from the largest aggregates of clover and at the highest density of clover within patches. Stolon extension rate was greater at the edge of patches, which offers an explanation for the findings and which may be related to the role of light quality.

Spatial heterogeneity is also being studied in mosaics of heather and *Agrostis/Festuca* grazed by sheep and red deer. The two animal species are likely to have different effects on the dynamics of the vegetation. Although the utilisation of heather was high at the edge of grass patches with both species, the rate of decline in utilisation with increasing distance from the patch edge was more rapid with sheep than deer (see Figure 5 overleaf). There were also differences in the utilisation of heather around grass patches of different size (Gordon *et al*, in press). These are likely to have important implications for the rate and pattern of heather fragmentation. Because the functional scale at which dietary choices are made by large herbivores varies between a bite and a large patch and that of a plant species can vary between a plant and a community, the study of scale and its representation spatially are likely to be key areas for future research in the area of vegetation dynamics of grazed pastures.

Research on temporal changes in plant communities is long-term and requires considerable investment in describing such changes. An experimental approach, where the merit of the results being relatively easy to interpret. Sufficient replication over a number of sites is important so that the results can be generalised. Such an approach has been

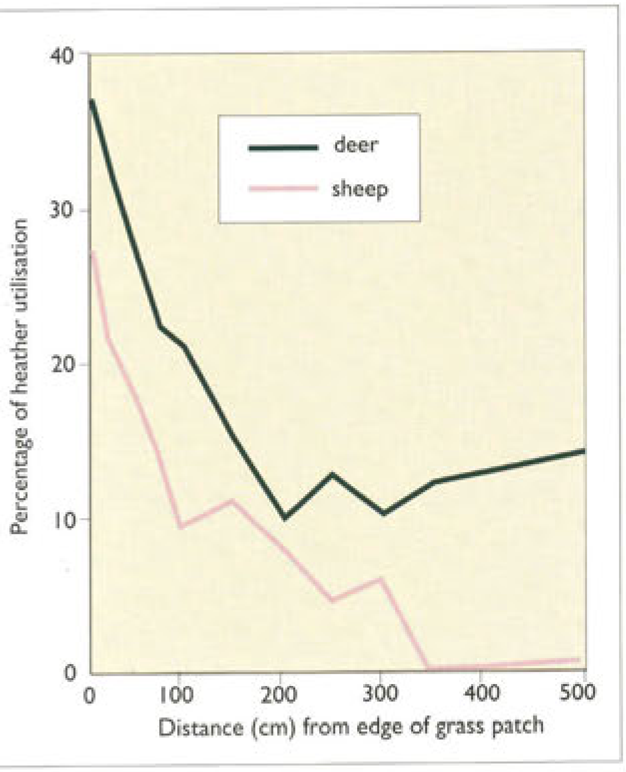


Figure 5. The utilisation of heather by sheep and red deer in relation to distance from patches of grass in a heather and grass mosaic. (Gordon *et al.*, in press)

adopted in the study of the effect of level and seasonality of sheep grazing on degraded dry heather moorland, three variants of wet heather moor, species-poor *Agrostis-Festuca* pastures and seedling regeneration of an upland broad-leaved woodland and in the extensification of sown pastures described above. Whilst these studies have been underway for less than 5 years, useful results have already been obtained. As well as quantification of the approximate grazing levels that will facilitate rehabilitation of heather cover or maintenance of species composition in the case of *Agrostis-Festuca* pastures, they have demonstrated the variability in response between sites, for example, associated with heather stand type (Merrell *et al.*, 1993). The broad-leaved woodland study has demonstrated that moderate grazing pressures will benefit tree seedling regeneration but that the growth and ultimate survival of these seedlings will be determined by differences in seasonal grazing, the impact of which will differ according to the height of the saplings (Mitchell, 1991).

An important feature of these long-term studies is that the data which they generate can be used to validate models which are being developed as a potentially powerful means of predicting vegetation change. The current Hill Grazing Management Model, which predicts the biomass production of 13 vegetation types and their utilisation rate by sheep, is being incorporated into a model which will take a data structure, such as the National Vegetation Classification, and perform transformations based on a semi-quantitative set of rules to predict the dynamics of particular plant associations. In addition, stochastic inputs, such as weather, will be incorporated.

Conclusion

The use of such a model described above should be of value to all those involved in making decisions about the use of the upland resources of the UK by large domestic herbivores. With the ever-increasing importance of achieving multiple-objective land use in such areas similar quantitative information on wild herbivores and on a wider range of vegetation types than those which have been studied to date is required. In particular there is a need to be able to predict the interactions between domestic and large wild herbivores as they influence vegetation dynamics. For example, a decision-support system to aid red deer managers in Scotland is currently being developed at MLURI which will need to incorporate the impacts of sheep as well as those of red deer on the vegetation.

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Animals

in agriculture

OPPORTUNITIES FOR CHANGE AND WELFARE IMPLICATIONS

by I A Wright

Introduction

Animal agriculture is of primary importance in many of the hill and upland areas of the UK and the rest of Europe. In these areas domestic ruminants are the principal means of utilising most of the semi-natural vegetation and improved pasture and play a central role in the rural economy.

Traditionally meat production from sheep and cattle has been the mainstay of the livestock industry in these regions, with goats being important in several southern European countries. Changes in policy, economic conditions and public concern are influencing, and will continue to influence, land use by domestic ruminants in hill and upland areas. Concern about overproduction of traditional commodities such as beef and sheepmeat throughout the European Union has resulted in the need for consideration of alternative livestock enterprises. Coupled with increasing public awareness and concern about environmental issues there is a move towards more extensive systems of production. There are now several fiscal incentives to encourage farmers to adopt less intensive systems of agriculture. Animal welfare is also assuming increasing importance in every sphere of animal production from modern intensive systems to extensive systems of rearing and across all species.

These scenarios provide opportunities for research into novel systems of ruminant land use and into the implications of some of these for animal welfare.

Animal fibre

The production of animal fibre offers perhaps one of the most potentially viable alternatives to traditional livestock enterprises. At MLURI we are exploring the opportunities for production of cashmere and fine wool, and providing information on which fibre production industries can be based.

Cashmere, the fine undercoat of the goat, is a commodity which attracts high prices on the world market. Coupled with the fact that 30% of the world's cashmere production is processed in Scotland, this makes it a strong candidate as a product which could be produced in the EU.

Breeding for fibre

The main emphasis in the genetic selection programme is on breeding for increased quantities of high quality cashmere fibre and the development of new genotypes of fine-wooled sheep.

The gene pool within UK feral goats was limited, and to achieve an acceptable rate of progress it was necessary to widen the genetic base. To this end genetic material was imported from Iceland, Tasmania, New Zealand and Siberia and used in a structured programme of cross-breeding with native feral stock. This phase of the breeding programme has now been successfully completed and a number of new genotypes have been produced. The results showed that there is considerable variation in both cashmere weight and fibre diameter within the cross-bred genotypes and significant heterosis in secondary fibre weight, but not, fortunately, in fibre diameter, the main determinant of quality (Bishop and Russel, in press). The genetics of colour pattern inheritance in goats has also been established (Adalsteinson *et al*, in press).

A cashmere production index, which takes account of the negatively correlated traits of fibre quantity and quality and which incorporates a factor for quality price differentials, has been developed (Bishop and Russel, in press). This is now being used in the second phase of the breeding programme which is based on a herd of 450 does at Sourhope Research Station - the largest herd of cashmere goats in Europe - and which comprises genetic selection lines for low fibre diameter as well as a random-bred control line. This research, conducted in conjunction with the AFRC Roslin Institute, will produce not only superior animals but also data on the inheritance of important traits, which will be essential for the development of efficient breeding programmes.

A study conducted in the Institute indicated that significant improvements in the financial returns from wool could be achieved only by producing high quality fleeces with a mean fibre diameter of less than about 22 microns (Saul *et al*, 1993) and that this could be achieved only from some Merinos or Merino cross-breds. To test the validity of this conclusion a small flock of fine-wool sheep was established at Sourhope Research Station by crossing Shetland ewes - the finest-wooled of UK native breeds - with Saxon Merino rams - the finest-wooled of the many Merino types. First crosses are producing high quality wool with a mean fibre diameter of around 21.5 microns with mean fleece weights of 2.9 kg from ewes and 3.4 kg from wethers and rams. Some second-crosses (i.e. 75% Merino, 25% Shetland) have also been produced and their suitability to a hill environment is currently being evaluated. Equally encouraging is the considerable variation in fibre diameter in these sheep, the lowest recorded values being between 17 and 18 microns. This indicates that there is considerable scope for further improvements in quality, and hence increases in returns, to be gained from genetic selection.

Although the wool from this Merino x Shetland cross is of exceptionally high quality, its prolificacy and carcass conformation leave much to be desired. The economic study by Saul **et al**, (1992) indicates, however, that in some of the physically and environmentally harshest land resources in the UK the production of high value wool from specialist wether flocks, requiring minimal inputs in terms of labour, feeding and veterinary products, would be more profitable than the maintenance of flocks of poorly performing breeding ewes. In these conditions wether flocks would also give less cause for concern regarding standards of animal welfare.

Fibre biology

Research on breeding for fibre is complemented by studies on the physiology and endocrinology of fibre growth and shedding. This research utilises a range of animal species and genotypes which show differences in the pattern of primary and secondary fibre growth. These include different genotypes of cashmere goat, angora goats and South American camelids.

It has been established that the photoperiodic control of fibres from both primary and secondary hair follicles is mediated through the hormone prolactin. In particular the initiation of the moult in spring is triggered by the rise in prolactin which occurs at that time of year. Delaying the rise in prolactin resulted in a delay in the initiation of the moult and subsequent re-activation of the secondary hair follicles (Figure 1).

The role of hormones such as growth hormone and the thyroid hormones in determining the patterns of secondary fibre growth are also being examined. Basic studies on endocrine and growth factor receptors in the cells of the hair follicle in goats are being undertaken in collaboration with the Rowett Research Institute. Although there is photoperiodic regulation of the hair follicle cycle, no melatonin receptors are present in the skin and hair follicle, indicating that melatonin does not act directly on the follicle (Lynch-Dicks *et al*, 1992). Epidermal growth factor (EGF) and insulin-like growth factor -1 (IGF-1) receptors have been identified on both primary and secondary hair follicles, indicating a local role for both EGF and IGF-1. These studies are crucial to our

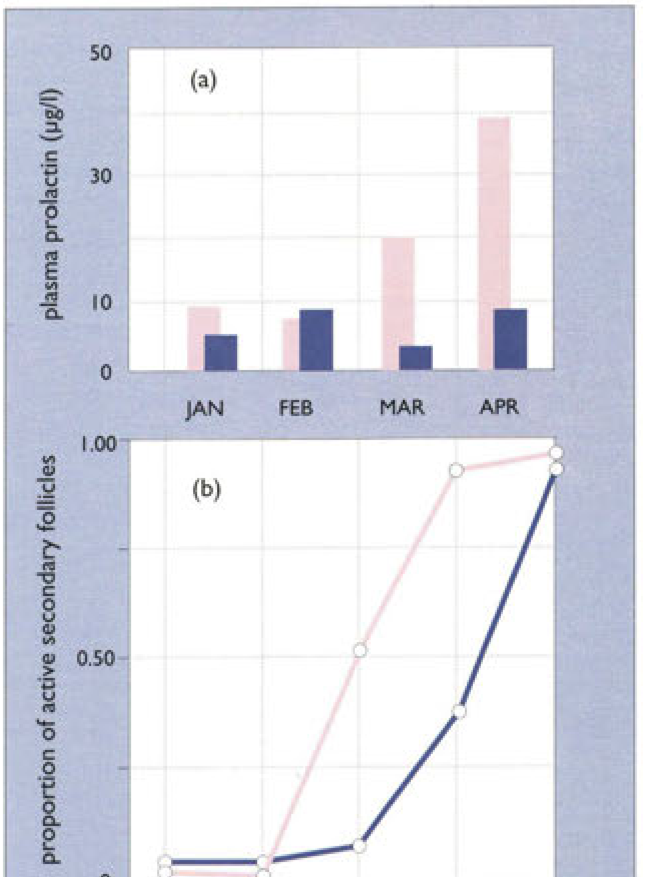

Figure 1. Suppression of plasma concentration of prolactin with bromocriptine in spring (a) causes a delay in the re-activation of secondary hair follicles in cashmere goats (b).

understanding of the mechanisms of control of the hair cycle, and in particular the relationship between systemic endocrine signals and the response of hair follicles. Such studies may also be important in explaining differences in the timing of initiation and cessation of growth and shedding of secondary fibre in different goat genotypes (Figure 2).

Preliminary studies on the physiology of fibre growth in South American camelids are being conducted. Early experiments have indicated that nutrition has little effect on fibre growth in double-coated camelids such as llamas, but that coat growth is seasonal, although unlike the goat there does not seem to be a distinct moult in camelids. Instead about one-third to one-half of the fibres seem to be shed each year (Russel and Redden, in press). It is unlikely that a significant industry based on the production of fine fibre from South American camelids will develop in Europe. However, there is considerable scope for developing and extending this industry in South America and good links have been established in a number of South American countries with a view to setting up joint research programmes.

Deer farming systems

Longevity of farmed red deer

The Institute pioneered the farming of red deer and along with the Rowett Research Institute provided much of the technical information on which deer farming industries in several countries are based (Blaxter *et al.*, 1974 and 1988). It became clear during the development of deer farming systems that the longevity of red deer hinds was greater than for the traditional farmed livestock species. One of the major determinants of the efficiency with which resources are used in animal production systems is the lifetime reproductive performance and hence breeding female replacement rate.

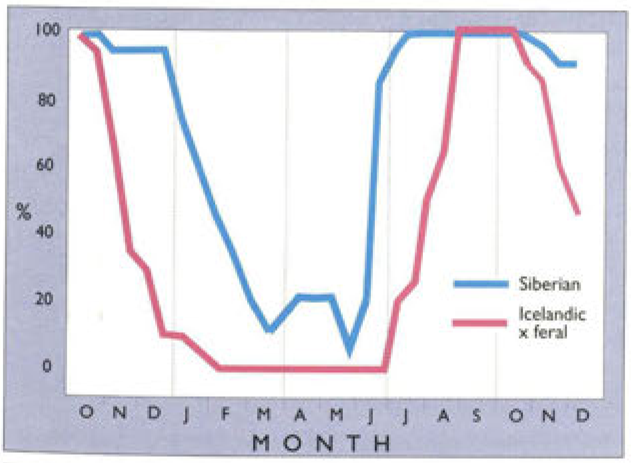

Figure 2. The percentage of goats of two genotypes which showed growth of cashmere at different times of year.

Unique data, collected over 20 years from some of the first red deer hinds to be farmed anywhere in the world, have been used to assess longevity of red deer hinds. Information was recorded on reproductive performance from 70 hinds born in 1970, 1971 and 1972 and kept at the Institute's Glensaugh Research Station until 1990. These animals grazed on a predominantly heather hill with access to some pasture during mating and calving. Calving rate remained over 90% until 1985 and fell to below 80% by 1987 and thereafter fell rapidly (Figure 3). The growth rates of the calves averaged 270 g/day for the five-year period 1973-78, but fell to 224 g/day by 1987. The death rates of the hinds were remarkably low at less than 1% per annum for the first 16 years, but increased rapidly thereafter to 40% by 1990.

The results show that red deer will perform efficiently for 15 or 16 years in hill and upland farming systems, but thereafter should be culled. This implies an annual replacement rate of about 8% compared with 25-30% for sheep and 15-20% for beef cows.

Development of large-scale deer farming in the west of Scotland

The development of a large-scale system of management producing weaned calves from farmed red deer in a West Highland environment was carried out at Rahoy, Morvern, Argyll from 1977 to 1991. The land resources comprised 686 ha of semi-natural pasture, predominantly *Molinia caerulea*, up to a height of 462 m, 32 ha of reseeded hill pasture and 20 ha of pasture at sea level. The mean annual rainfall is 2000 mm.

Animal performance up until 1982 was very low (Table 1 overleaf). In 1983 the Institute became involved in the management of the unit and implemented a system of management for both the livestock and land resources. This system was based on research conducted in the Institute; it was designed to

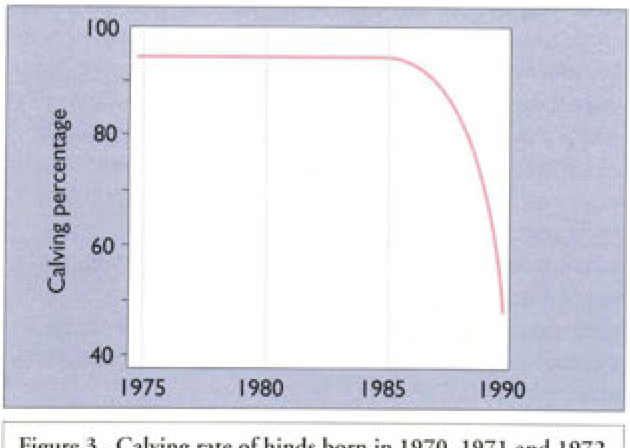

Figure 3. Calving rate of hinds born in 1970, 1971 and 1972.

take account of the requirements of different classes of stock, matching them to the productive capacity and nutritive value of the different vegetation resources at different times of year.

Deer were excluded from all sown pastures from 1 December until a sward height of 6-8 cm had been achieved in April. Following calving, mature hinds and their calves grazed hill pastures while the young hinds were maintained on sown pasture. This allowed the young growing hinds access to the best levels of nutrition while allowing herbage to accumulate prior to the rut. Following the rut all deer were overwintered on semi-natural hill grazings and provided with supplementary feed to ensure that they did not lose more than 5% of their live weight. A comprehensive prophylactic veterinary programme was also instigated to ensure freedom from parasites and trace element deficiency.

Table I shows the dramatic improvement in performance that took place between 1983 and 1990. In addition to an increase in the size of the herd from 387 to 825 there was a large increase in the weight of adult and yearling hinds which resulted in higher levels of reproductive performance. The total number of calves weaned rose by 340% from 191 to 649.

	1983	1990
Total deer numbers	387	825
Mean live weight of adult hinds (kg)	77.6	90.6
Calving rate of adult hinds (%)	76.0	96.8
Mean live weight of yearling hinds (kg)	58.0	81.0
Calving rate of yearling hinds (%)	0	91.6
Number of calves weaned	191	649

Table 1. Performance of red deer at Rahoy following the implementation of a management regime in 1983.

The results demonstrate the dramatic effect that the implementation of a management system, based on soundly researched principles of animal nutrition, animal production, grazing management and animal health can have on the efficiency of animal production systems.

Animal welfare

Increasing public concern about the welfare of animals gives rise to a need to consider ruminant land use systems not only in terms of their effectiveness in terms of productivity, or their impact on the environment, but also in terms of their effect on the welfare of the animals themselves. What constitutes an acceptable standard of animal welfare is a moral and ethical issue, and our research can provide information on which to base these ethical judgements. While welfare is a difficult parameter to measure, stress can be quantified and measured. Since it is well recognised that studies based on single types of measurements may not allow a full interpretation and understanding of the animal's response, our approach to measuring stress integrates a range of measurements including behaviour, physiology, health and production.

Physiological indices of stress

When measuring physiological indices of stress, the disturbance caused by making the measurements may affect the measurements themselves. For example, taking blood samples for measuring plasma cortisol concentrations may cause such an increase in concentration as to render the measurements useless. In a stress-susceptible species such as red deer, these considerations are very important. On the other hand, because of its stress susceptibility, the red deer is a useful model for studies of physiological indices of stress.

Using the red deer as an animal model we have developed novel, remote automatic blood sampling equipment which allows up to 12 blood samples to be collected without the need to restrain the animal. This equipment has allowed a number of studies on the effect of management practices to be undertaken (Table 2). The system is currently being developed to increase flexibility, and will allow the collection of blood samples for measurement of physiological parameters which have hitherto been impossible in free-ranging animals.

The ability of the adrenal gland to secrete cortisol in response to adrenocorticotrophic hormone (ACTH) has been used as an index of chronic stress (Rushen, 1991) since if an animal has been subject to long-term stress the enzyme systems in the adrenal glands will have been more active and the adrenal cortex will respond to a challenge of ACTH to a greater extent than in an animal subjected to less stress. An ACTH stimulation test has been developed in the Institute for red deer; the optimum dose and sampling time has been established.

	Before	During	After
Cortisol (nmol/l)	23.3	48.9	22.2

Table 2. Plasma cortisol concentrations in red deer before, during and after handling in a race-way. Blood samples were collected by automatic blood sampling equipment.

It is well accepted that chronic stress can pre-dispose animals to disease because of a suppression of the competence of the immune system. This has led to the idea that measures of immunocompetence may provide an index of chronic stress in animals, even if the levels of stress are too low to cause clinical disease. Again using red deer as a model the relationship between a range of chronic stressors and immunocompetence is being established. Early results from these studies, conducted in conjunction with the Moredun Research Institute and the Scottish Agricultural College show large differences in antibody response to a novel protein between weaned calves born to wild or farmed hinds (Figure 4) suggesting that the calves born to wild hinds were under a greater degree of stress. The potential value of measures of immunocompetence in assessing chronic stress due to a range of stressors is currently being examined.

Welfare of farmed red deer

There is concern about the welfare implications of farming a wild species which unlike traditional farm livestock has not undergone centuries of domestication.

One major study investigated the welfare implications of removing red deer hinds from the wild and introducing them to farming systems. A number of post-capture management strategies were evaluated on the basis of behavioural, physiological, health and production responses. This study showed that the housing of wild deer immediately after capture, a procedure which is often used, was the most stressful of the strategies considered.

Another major project, funded by the EU, is concerned with identifying appropriate systems of management, including weaning strategies and housing conditions for weaned red deer calves. Factors investigated included stocking density, group size and trough space allowance. As floor space increased, live-weight gain and feed intake declined (Table 3). There were significant differences in the proportion of time spent standing and in activity between the floor spaces. The average distance between calves increased with floor space. The results suggest that providing large floor space allowances may not provide the lowest level of stress in weaned calves. Such basic information is essential to allow Government departments to produce soundly based codes of management practice to ensure acceptable standards of welfare for this class of stock.

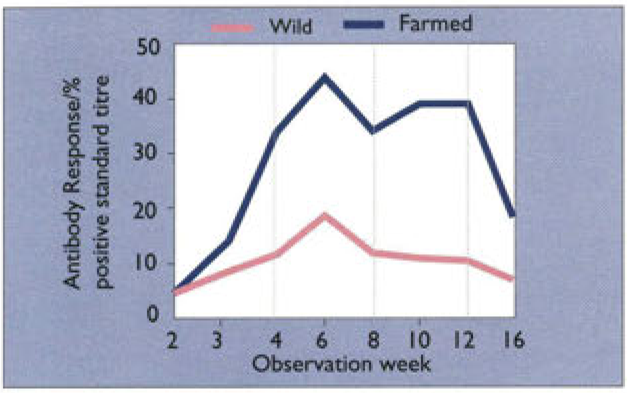

Figure 4. Antibody response of weaned red deer calves born to wild or farmed hinds.

Welfare in extensive systems

It is often assumed that extensive systems of production are more friendly to the animal's welfare. This may not be the case. The challenges facing sheep under extensive hill management systems are different to those under intensive systems of animal manage-ment, and stress due to adverse weather conditions, variation in feed supply, disease and lower levels of human supervision may all be important. Stress to animals kept under extensive systems needs to be quantified to allow assessment of welfare to be made. We intend to use many of the techniques developed using the red deer as a model to allow us to quantify stress in these extensive systems.

Conclusions

Our research on alternative forms of land use by ruminants has demonstrated the considerable potential that exists for diversification into deer farming and fibre production from a range of species. This technology is being adopted by a number of countries. Deer farming is now a major rural industry in New Zealand and is developing in other countries. Our research on fibre production has generated interest in developing cashmere-producing industries in Spain, Portugal, Italy, Greece, Norway, the Czech Republic, Bulgaria and the Falkland Islands where there are ready markets for the superior genetic stock we are producing and where the industries will be based on the results of our research. Unfortunately the current policy of providing financial support to farmers through headage payments such as the Sheep Annual Premium, Suckler Cow Premium and Hill Livestock Compensatory Allowances provides a strong disincentive to UK farmers who may wish to diversify. Financial appraisal indicates that these alternative enterprises can compete favourably with traditional livestock enterprises on an equal basis and produce products for which there is a high demand, but cannot compete economically with subsidised sheep and cattle enterprises.

Systems of animal management have traditionally been assessed in terms of their efficiency of production of product. We are also now considering their efficiency as regards their ability to manage vegetation as described on pages 28-35 of this report. Increasingly they also need to be evaluated for the effect they have on the welfare of the animals themselves.

	Floor space (m^2 per calf)		
	1.50	**2.25**	**3.00**
Live-weight gain (g/day)	126	117	111
Feed intake (g/day)	1486	1474	1428
Proportion of time spent			
active	0.149	0.111	0.162
standing	0.329	0.337	0.267
Distance between calves (m)	1.06	1.11	1.14

Table 3. The effect of floor space on the live-weight gain, feed intake and behaviour by weaned red deer calves.

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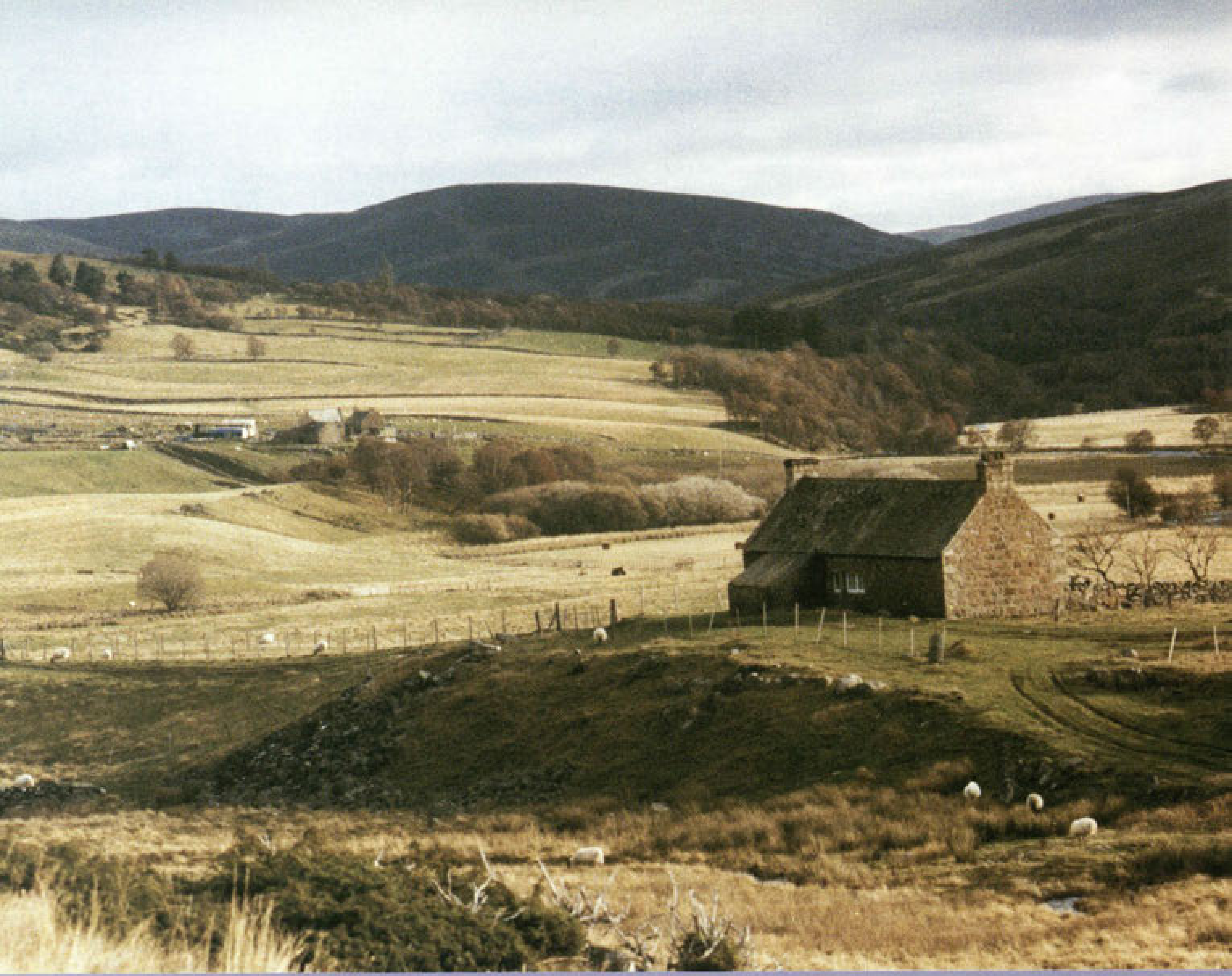

Environmental and Soc

DEVELOPING RELEVANT POLICIES FOR THE COUNTRYSIDE

by J R Crabtree

In recent years a number of new policies have been launched with the aim of making land use more sensitive to the environment. These policies were triggered off by the increasing public concern throughout the 1970s and 80s about the deleterious effects of agriculture and forestry on the environment, and new measures have been established to tackle some of the most pressing negative externalities from land use practices. The initial concentration on the environmental problems created by existing policies has turned out to be only the first step in an on-going development of land uses which are increasingly sensitive to their environmental effects. Progressively, environmental concerns have begun to shape the whole development of land use policies such that environmentally-linked payments now generate a positive flow of environmental output, rather than simply compensating farmers for moving to less damaging practices (Crabtree, in press; MAFF, 1991).

The new priorities for the countryside pose a challenge, not only for the development of effective and cost-efficient policy measures, but also for investment in research to provide supporting concepts and data. Clearly, the prime need is for environmental research to assist in understanding the environmental consequences of different land uses and the mechanisms by which particular objectives may be achieved. This scientific research underpins the policy prescriptions, since it is only by understanding the environmental, physical, chemical and biological relationships that effective policies can be developed. Economic analysis

o-economics

also has a role, which although different in scope, also depends on the scientific base. It can extend this base by identifying the market costs of environmental damage and improvement; it can identify the costs of new initiatives and indicate which instruments and approaches are best able to deliver the policy objectives. Our research is contributing to this economic framework for countryside and rural policies in the following areas:

- valuing the benefits from environmental improvement
- assessing instruments for delivery of policy
- evaluating the environmental impacts of forestry policies
- costing public access to the countryside

Valuing the benefits from environmental improvement

Two particular difficulties frequently confront an attempt to value the public benefits from protection of the countryside. The first concerns the way ecosystems respond to changes in management that are themselves responses to changes in policy. Often these are extremely complex, making prediction uncertain and policy formulation difficult. Whilst the responses of productive crop and animal species to their environments have been extensively researched because of the economic importance of the output, much less research has been devoted to how many elements of the natural and semi-natural environment respond to changes in land management. The multidisciplinary nature of the Institute has facilitated a closer linkage between the development of physical and economic models, and enables the application of economic analysis to aspects of environmental management that can be demanding in data requirements.

The extensive programme on acidification research at the Institute (described on pages 12-17 of this report) has provided an opportunity to quantify some of the economic benefits from acid rain abatement. Acid rain has been a particular focus for concern because of the disruption caused to upland ecosystems (Fry and Cooke, 1987). One commercial impact of acidification is the loss of fishing output in acidified waters. In order to explore how the economic benefits from regeneration of fishing following partial abatement of sulphur dioxide emissions are realised, we have developed a bio-economic model which links output data on water chemistry from MAGIC, a process-based catchment model for acidification, to changes in rod and line salmon catch and economic value of acidified fisheries (Macmillan and Ferrier, in press). As a case study, the model was applied to the Galloway region in South West Scotland to estimate the marginal economic benefits of alternative sulphur dioxide abatement strategies. Current planned emission reductions of 60% are predicted to gradually improve fish output, increasing the market value of the fishery to £13.7 m by the year 2038; this is an increase of £2 m in real terms over the predicted market value under constant 1988 emissions (Figure 1). Alternative emission scenarios have been modelled and we envisage a much wider application of this type of bio-economic model for economic analysis of environmental change.

The second major difficulty that has to be addressed in developing policy with respect to environmental improvement is that of valuing the economic benefits obtained when the output is not valued through market mechanisms. Clearly the improvement

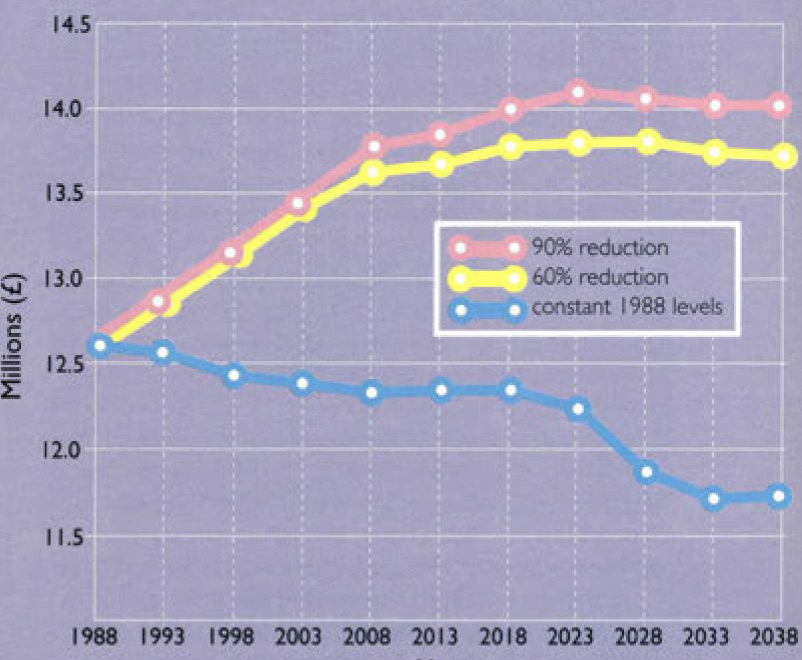

Figure 1. Change in the market value of the rod and line salmon fishery in Galloway under three sulphur abatement scenarios.

to habitat or landscape may produce some private benefits to the landowner and these may be translated into increases in property values and rents . However, public investment in the countryside aims to produce wider public benefits that are not amenable to such valuation. Economists have developed methods to value non-marketed output although the methodological difficulties can be considerable. For example, the protection of the environment may be valued by the public for a variety of reasons - for use (for example, to visit recreational sites), for the option to use, and also for the benefit of future generations, but without any current use in prospect (Pearce and Turner, 1990). Even where such values can be derived, we ideally wish to value environmental change in quite a detailed way since policy makers need to know what projects at which locations will provide the best return to government expenditure. Much of the research in the UK to date has concentrated on measuring the value to users of free access to forests, reservoirs, nature reserves and similar countryside features. The number and diversity of such valuations is steadily increasing, but there is some discussion over the reliability of the results (for example, Bowers, 1993; Garrod and Willis, 1990; Green and Tunstall, 1991; Schulze *et al.*, 1981). Despite this, it is clear that the research has provided an enormous stimulus to a more formal inclusion of environmental costs and benefits into policy development and a basis on which public sector environmental investment can be assessed (DOE, 1991). More interest is now focused on methods for valuing non-use benefits, which in some cases may exceed the direct benefits to users (Willis, 1989), and the valuation of major countryside policy measures such as those pertaining in ESAs (Willis *et al.*, 1993).

We have examined the application of contingent valuation (CV) techniques to defining the benefits from acid rain abatement. A mail survey was carried out to estimate the annual willingness to pay of the Scottish population for recovery in the upland ecosystem to its original, pristine level. In conventional markets people express their preference for a particular item of goods or services when they purchase it. For environmental goods, markets do not exist; CV therefore creates a hypothetical transaction, in which respondents are asked their willingness to pay for (WTP), or willingness to accept, a specified change in environmental quality. In the pilot testing of the questionnaire the response rate was high, reaching almost 70%, with an annual WTP per household ranging from £0-£500. The mean WTP per household was £52, which when aggregated to the Scottish level is equal to £102 m per annum. Income level, environmental attitudes and awareness all influenced the WTP of respondents which suggests strongly that responses were not arbitrary, but were both rational and in line with prior expectations. We are now completing this study which will be the first to quantify the extent to which the public is prepared to pay for measures directed at ecosystem recovery through reductions in sulphur dioxide emissions and the consequent deposition of acid rain .

Contingent valuation methods are also being applied to value the benefits to wildlife and landscape of upland grazing extensification. Incentives for reducing grazing pressure are now available in some Environmentally Sensitive Areas (ESAs) and within the proposed agri-environmental measures of CAP Reform. These incentives aim to improve the quality of upland habitat and encourage the natural regeneration of heather and scrub vegetation. Pilot trials have been undertaken to develop visual scenarios depicting alternative policy measures and outcomes. Together with relevant environmental information these will be used to give a full context on which individuals can offer a valid WTP response. We intend to compare the preferences for the application of this type of policy in different areas of Scotland and to develop methods that will account for the uncertainty and long time periods involved in the environmental change.

Assessing instruments for delivery of policy

There are a substantial number of routes through which environmental policies in the countryside may be put into operation. These include measures such as regulation, public land purchase, grant aid and voluntary management agreements based on direct payments for specified activities. Where the aim is to reduce the external costs of agricultural or forestry policy, modification to the instruments for that policy provide another route to environmental enhancement. Following on from a broad assessment of these alternatives for the Countryside Commission (Colman *et al.*, 1992), we have concentrated on the investigation of how voluntary payment approaches can best be structured and applied. Management agreements with payment rates negotiated on a one-to-one basis have never been a very successful instrument (Leonard, 1982). The public agency involved in negotiation often has limited information and is therefore in a weak bargaining position which can result in excessive payment levels. In addition the administrative costs can be high when a large number of farmers, each with a separate agreement, are involved. Standard payment systems in which payment levels are fixed are now more commonly used to avoid these problems. However, these also involve over-compensation, the extent of which increases as the target uptake level is increased. We have examined the effect of the diversity of farm situations on the uptake of such schemes and shown that where low uptakes are the aim, diversity may be advantageous, but in general, schemes are more efficient when applied to relatively homogeneous groups of farms (Crabtree, in press). This has implications for the design of ESA and extensification schemes, and indicates that careful definition of locational boundaries and prescriptions is important if excessive costs are to be avoided.

Environmental payments to farmers in order to change farming practices have to be seen against the broader background of a changing role for farmers in the countryside, with land stewardship to some degree substituting for food production (Commission of the EC, 1991). Understanding how farmers perceive this change will not only enable a smoother transition for policy but potentially allow environmental measures to be better framed and targeted.

We have therefore launched a research project which aims to gain an insight into the decision-making processes of farmers with respect to environmental schemes. The research methods employed were designed to give the researcher access to the world view of the farmer and what he or she thinks is important. The traditional methods (formal questionnaires and attitude scaling) usually used to discover the goals and values of farmers (for example, Gasson, 1973) are inconsistent with this theoretical perspective. Instead, a method which enables the researcher to discover what is important to the farmer and what meanings various concepts hold, and in turn how these might affect behaviour, must be used. Qualitative interviewing was chosen as the best way of gaining an in-depth understanding of the individual's behaviour. Farmers have been interviewed following a guideline to ensure that certain topics were covered with each farmer, but which allowed the interviewee to speak about their own views and the factors they considered relevant. The methodology chosen has not been used extensively in regard to farmers, but it is felt that developing the method in this context will provide more insights than would be possible using conventional interviewing methods. This study, which is still in progress, will also provide a wider appreciation of farmers' perceptions of conservation, their view of ESA schemes and the characteristics of the schemes which attract or deter them. The research also examines how the farmer/landowner perceives his or her role in society, for example as primarily a food producer, or perhaps as a 'custodian of the countryside' is looked at as another influence on their behaviour. With an increased understanding of farmers' behaviour, policy makers should be able to develop and deliver more targeted policies to groups who may be receptive to the schemes, or be in a position to provide particular environmental benefits.

Evaluating the environmental impacts of forestry policies

In forestry, where the environmental costs from some blanket afforestation schemes have become all too apparent (Hanley and Craig, 1991) there has been a major re-evaluation of the objectives of policy. While there were strong pressures to make new forestry planting more environmentally sensitive, at the same time the anticipated employment benefits, which helped to underpin grant aid for large-scale coniferous planting, were being questioned. Accordingly, investment incentives provided through the tax system were removed in 1988 and since then the system of planting incentives has been progressively modified to encourage broadleaved planting on less environmentally sensitive land. The recreational and carbon-fixing benefits from forestry are now being highlighted to defend the continued payment of planting incentives, but even when these are taken into account there are substantial areas of forestry in Scotland that fail to produce the Treasury's required rate of return (Macmillan, 1993a). These tend to be exposed sites on poor quality land, often in remote locations in the north and west of Scotland. Figures 2a and 2b indicate the extent to which these sites are characterised by relatively low growth rates and high risk of windthrow. It is to be doubted whether the public investment in such sites, either through Forestry Commission planting or the use of planting incentives, was ever entirely justified. This raises the issue of whether re-planting these sites can itself be justified on economic grounds. Much depends on the value of these sites in alternative uses and we are actively exploring alternative management and policy options that could produce environmental or recreational benefits.

A second aspect of forestry that has long interested those concerned with woodland establishment on agricultural land is that of agroforestry - the establishment of trees in such a way as to allow continued agricultural practice until beyond the establishment phase. We have investigated the economics of agroforestry under current grant arrangement for the Countryside Commission in the context of the Community Forest initiative (Sibbald *et al.*, 1993). Silvo-pastoral systems based on sheep tended to show the greatest benefits both from the farming perspective and in terms of the objectives of the Community Forests. However, even with those systems which minimised establishment costs and where the income lost from the agriculture ultimately displaced was small, it appeared that agroforestry was unlikely to be attractive either to those farmers interested in timber output or to those

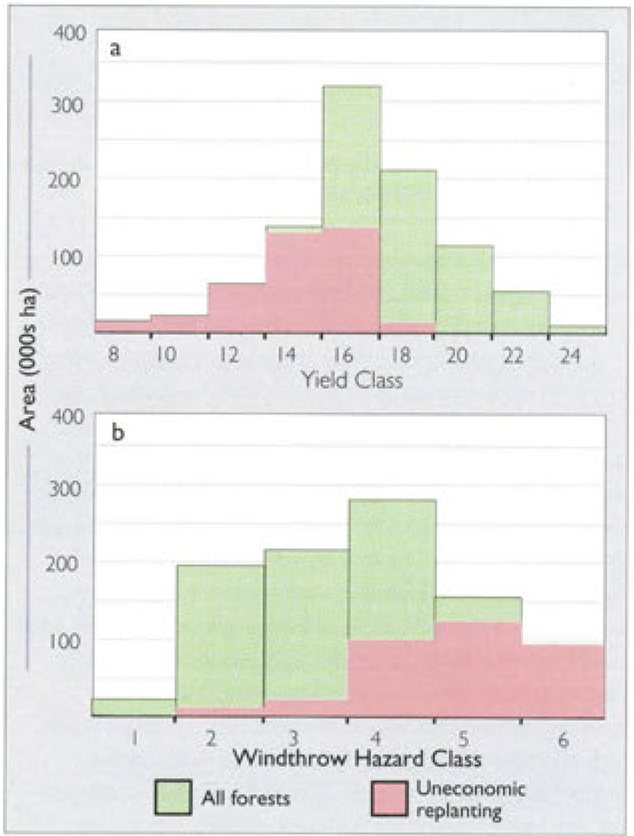

Figure 2. a) Estimated Yield Class of commercial forests in Scotland
b) Predicted Windthrow Hazard Class of commercial forests in Scotland

planting for environmental or aesthetic purposes. Thus as a route to enhanced planting in the Community Forests of England the scope for agroforestry is limited. Nevertheless, this conclusion rests heavily on the current pro-rata incentive payments in relation to planting density. We consider that agroforestry policy should be reviewed, since it provides a way in which much more diverse woodland could be planted than currently tends to be the case, and the landscape and environmental benefits from such diversity may be considerable. It seems that current incentive arrangements are too highly geared to costs of establishing forests than to the public benefits that they produce - a situation where the increasingly environmental justification for new planting (Crabtree and Appleton, 1992) should lead to much greater emphasis on the value of different types and locations of woodland in forestry policy. This is not straightforward, since insufficient research has been done to produce the valuation data ideally required. Even so, with incentives for forestry currently under review, the opportunity exists for more fully embracing environmental benefits into the incentive system.

Support for directing new planting to locations where environmental conflicts will be minimised has been provided by the Regional Indicative Strategies which most Regional authorities have now prepared. These bring an additional element of 'regulation' into the location of planting although they fall short of direct identification of areas where planting is or is not permitted. The lack of investment pressure in forestry has left the indicative strategies to some degree untested, but our evaluation of these regional strategies casts doubt on their ability to satisfactorily reconcile competing demands from commercial forestry investment and environmental protection. In Borders Region, for example, high agricultural land prices limit the area with forestry investment potential to only 36% of the Preferred category (i.e. land where there are no major or only minor constraining environmental interests) (Macmillan, 1993b). By contrast, almost 60% of the Sensitive category (i.e. land with major environmental constraints) is estimated to be attractive to forestry investors.

	Farms		Estates	
Number	543		79	
	(£ per year)	(£ per ha)	(£ per year)	(£ per ha)
Additional expenditure	62	0.28	341	0.07
Income lost	37	0.16	189	0.04
Additional time costs	37	0.17	201	0.04
Total	136	0.61	731	0.15

Table 1. Costs associated with access on units not receiving access related income (£ per year).

Costing public access to the countryside

Countryside policies must also take on board the recreational demands of the public and the benefits that access to land can produce. We have expanded our investigation originally undertaken for The Countryside Commission for Scotland (Crabtree *et al.*, 1992) into the economics of public access in Scotland. From a major postal survey of farmers and estate owners it was possible to quantify the costs of public access in terms of additional expenditure, income lost or additional time costs (Table 1). Estates had much higher total costs, although on a per hectare basis farming was more seriously affected. However, access costs tended to be very small except on the urban fringe or in scenic areas popular for recreational visits. There were marked cost differentials in relation to population density and to the presence of paths or tracks across the holding, or scenic attractions in the area.

In terms of policy development, there seemed no case for intervention in the more specialised, market-based activities such as fishing or shooting. Most other specialised activities, such as orienteering and hang-gliding, are becoming commercialised under private arrangements with estate owners. The activity of public agencies should more appropriately be focused on those activities where markets are unable to develop, most commonly due to high transaction costs involved in controlling access and charging for facilities. In our study we conclude that agencies should particularly concentrate on retaining valued by-product access, increase facilities on the urban fringe where demand is considerable, and support access in heavily used areas of high scenic attraction.

Future developments

There is no doubt that ever-more detailed policies will need to be developed to cope with the complexity of the demands on the countryside and the diversity in the land base itself. It is no longer satisfactory to produce landscapes that are simply by-products of other activities in farming, forestry and estate management. Specific management of the countryside to modify these principal activities is becoming the order of the day. With the need to underpin this broader management of the countryside we shall continue to develop methods and applications of environmental valuation. These will assist in quantifying the benefits from new policies and help guide the direction of public investment. More fundamentally, however, is the question of how far these environmental concerns can be taken to the centre of the CAP and other land use policies, with stronger linkages developed between the direct payments made to farmers and their stewardship of the countryside. A joint studentship with RSPB is now beginning to examine the effectiveness of different types of approaches to environmental policy - including the separate ESA type of measures and also those linked directly to CAP support.

Our more fundamental research on the attitudes of farmers to environmental and recreational outputs of the countryside is also planned to expand. There seems little doubt that society expects the agricultural industry to be more environmentally concerned and to provide more than food production. This suggests some gradual change in the perceived rights of those managing the land and the types of measures that may be appropriate to obtain a different mix of outputs from farming and other industries. We need to understand how those managing the land are responding to these changing demands and what this implies for the environmental measures under CAP and national policies.

Acknowledgements

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Information

Technology in support of land use science

A MLURI PERSPECTIVE

by R V Birnie

Information Technology (IT) encompasses the many areas of technology that are concerned with the capture, storage, communication and analysis of information. It has developed as a result of the considerable expansion in the availability of computer systems over the past 20 years and is now a fundamental part of all major endeavours including scientific research.

In this article we will look at IT from the particular perspective of land use science and we will demonstrate how IT is necessarily a logical instrument of the land use scientist. This area of scientific research requires the manipulation of large quantities of data and information from a great variety of sources. It will be made evident that using the facilities provided by IT gives the only possible approach. The argument is developed firstly, by examining the complexity of the subject in terms of interactions between physical, biological and socio-economic systems over space and time; secondly, by providing specific examples of the use of IT in the land use science programme at MLURI, and finally we review prospects for future research and development of IT and its applications.

Our aim is to provide an insight into why IT enables the development of the holistic approach needed for land use science. Leading from that, the continuing developments in IT research will provide many tools to aid in the creation of important products of land use research such as more effective decision-support systems for environmental resource management.

The central place of Information Technology in land use science

Dawkins (1986) observed that the human brain has evolved to comprehend 'a world of medium-sized objects moving in three dimensions at moderate speeds'. However, much scientific effort is concerned with gaining insight on processes that occur outside the human space/time domain, and uses instruments and devices such as metaphors and models to re-scale processes accordingly. The aim of this scientific effort is to develop constructs, concepts and theories which we can use to order and understand phenomena and provide the basis for prediction.

Land use science is fundamentally concerned with understanding the interactions between physical, biological and socio-economic systems that control patterns and processes in the rural and the urban environment (see the article on Land Use Science in this Report). It is also concerned with predicting how, under given changes in physical, biological or socio-economic circumstances, these patterns will change. Land use scientists need facilities for describing and representing bio-physical and socio-economic systems and how they behave and interact over time and space. It is our belief that models provide the best representation of component systems and their interactions (Birnie *et al.*, 1991). However, we recognise that there are a large number of interacting component systems, between which, relationships may be unstable and non-linear. Therefore, we need modelling methods that will allow us to explore these interactions, and gain insight into the predictability of patterns, and their stability and sensitivity to change.

The investigation of similar complex biological and economic systems has resulted in the development of the new science of complex systems (Arthur, 1990; Waldrop, 1992). Research in this area is dependent on high capacity computing facilities and is a novel branch of science that has only been possible as a result of IT. Modelling complex systems will play an important role in understanding and prediction in land use science, demonstrating that IT is the logical instrument of the land use scientist.

GIS: an example of Information Technology in land use science

The dependence of land use science on spatial data places a particular emphasis on one type of IT product, the Geographic Information System (GIS). These systems have been developed to provide the capacity and functions necessary to capture, manipulate, analyse and display data (Figure 1) that are geographically referenced. GIS facilities allow both scientists and managers to answer questions about the location of features, how they relate and what their dimensions are (for example, how much forest, on peat soils, in a river catchment). Their potential role in both geographic analysis and modelling is enormous and research on GIS, particularly the coupling of GIS to environmental models, forms a major part of the current research effort at MLURI.

These information systems are being developed throughout the world to support automated mapping, facilities management and environmental research and management. The development of GIS as a specialist IT area has been described by Tomlinson Associates (1987) and later by Guptill (1989). The former highlighted the fact that the rate of uptake of GIS was especially marked in North America (US Forest Service, US Geological Survey, Environmental Protection Agency, Environment Canada).

In the UK, the development of GIS and its adoption has been markedly slower. As recently as 1990, the Agriculture Committee on 'Land Use and Forestry' (HMSO, 1990) was re-emphasising the need for co-ordination in the context of creating a UK national land inventory. They pointed out, as the Committee of Enquiry into 'Handling Geographic Information' (HMSO, 1987) had before them, that much of the information on rural land resources is held separately by a wide variety of government sources and 'there is no overall co-ordination or integration of this information'. This lack of national co-ordination concerning data resources places a significant burden on individual institutions within the UK in

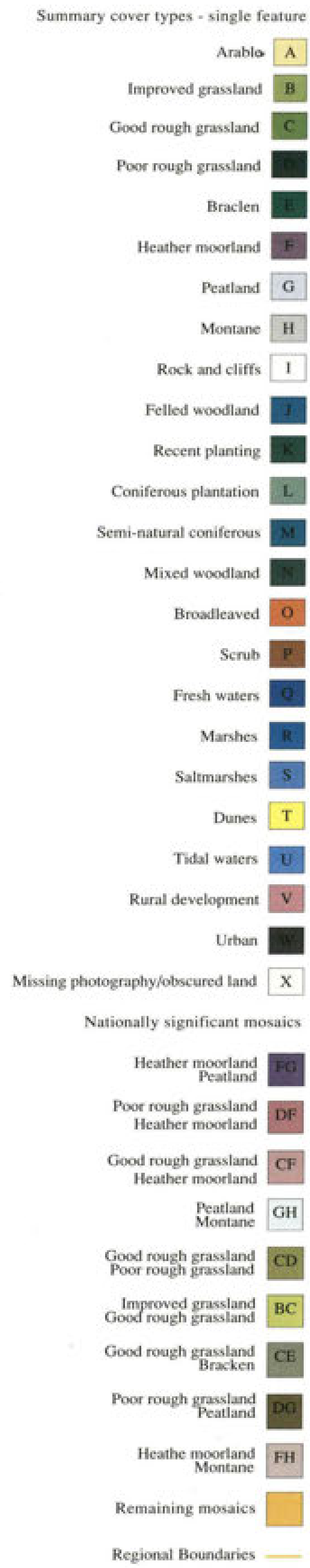

Figure 1. The Land Cover of Scotland.


The Land Cover of Scotland 1988
0
50
100 km
SCALE 1 : 2.5 million
Crown copyright 1994

developing GIS facilities, where data acquisitions and maintenance accounts for an estimated 80% of the costs.

In England and Wales, much of the lead has been taken by the Department of the Environment (DOE), who, in conjunction with the Institute of Terrestrial Ecology (ITE), have set about creating a Countryside Information System. This is based on the ITE land classification system and uses data from the DOE and sponsored Countryside Surveys which can be accessed using a specially designed graphical user interface. The whole system is designed for policy decision support at a national level, and is hosted on office standard personal computers

In Scotland, major initiatives are being taken by the Convention of Scottish Local Authorities and The Scottish Office. The former, through the creation of a GIS co-ordination committee for the local and regional authorities but which includes representatives from other government, academic and research organisations; the latter, through the sponsorship of GIS research within MLURI by the Agriculture and Fisheries Department and Scottish National Heritage by the Environment Department. Also included under this broad umbrella of Scottish Office GIS-related initiatives are the creation of a national land cover database for Scotland (Figure 1 and MLURI, 1993a and 1993b) the first of this kind anywhere in Europe, and the development of new methods, by MLURI, for handling error and uncertainty in spatial datasets (Aspinall and Pearson, 1993). Our approach at MLURI to defining, planning and implementing an appropriate GIS facility has been a valuable experience and it is important to highlight some of the differences in emphases involved in research as opposed to conventional system design.

Planning a research GIS facility: the MLURI experience

Our increasing awareness of the rapid developments in GIS and remote sensing/image processing software was combined with knowledge of the current North American experience and the need for integrated environmental resource information systems in the UK. This highlighted the need for GIS technology to enable a national Countryside Information System for Scotland and showed the great potential of such a system (Birnie and Miller, 1990). This initiative led to the Scottish Office engaging Tomlinson Associates Ltd. of Ottawa to evaluate critically MLURI's proposals for meeting its own GIS needs and to examine whether these proposals could also satisfy the broader GIS needs of other users, in particular the Scottish Office.

The conclusions of the consultancy were presented to the Scottish Office in April 1991 (Tomlinson Associates Ltd., 1991). The consultants broadly endorsed the MLURI commitment to open hardware systems, networking and shared computing resources. They recognised the key benefit of upward compatibility this commitment provided. The consultants' summary recommendations included the suggestion that 'MLURI undertake a full and comprehensive GIS planning study'. This study was initiated in December 1991, funded by SOAFD and co-ordinated by Dr Richard Aspinall (MLURI), with Dr Roger Tomlinson as consultant.

The precise details of the GIS planning process are proprietary to Tomlinson Associates Ltd. In general terms, however, it follows the steps outlined by the Federal Interagency Co-ordinating Committee on Digital Cartography's process for evaluating geographic information systems (Guptill, 1988). This begins with a 'user requirements analysis' to define information products and these in turn enable the necessary datasets, linkages, analytical functions and error tolerances to be specified.

In GIS planning, a corporate approach provides direct benefits in enabling more effective setting of priorities (for example, data capture priorities can be set by identification of key datasets), better use of resources, standardisation of data quality and reduction of costs. The key question that permeated the whole GIS planning process for MLURI was, 'can this research be done without GIS?'.

The hardware aspects of the GIS facilities were addressed through defining critical needs. The diverse and evolving requirements of the Institute's research programme dictated a facility that was itself capable of continual development based upon the principles of upward compatibility and open systems architecture (Osman *et al*., 1993). The current configuration of UNIX-based work stations connected through an Ethernet Local Area Network and encompassing digital cartographic, image processing and GIS (Figure 2) reflects this design concept.

The major problem with adopting a conventional systems design approach to planning the GIS facility at MLURI was adequate recognition of the nature of land use research. Most if not all the information products for over 30 projects (out of 62) were 'one-offs' which would stimulate a new line of enquiry! However, five core datasets were identified as supporting a wide range of research tasks. To accommodate this imbalance we adopted the concept of 'generic information products' (Aspinall, 1994) which were typical of the type of research information products envisaged and encapsulated the functionality if not the precise details of the dataset requirements. It is believed that MLURI is the first research institute anywhere in the world to adopt such a comprehensive strategic approach to its GIS requirements (Tomlinson, personal communication 1993).

Examples of Information Technology being used in support of land use research

Almost all aspects of MLURI's programme of research depend in one way or another on IT to enable the research process. This is the case from experimental design through to analysis and modelling and it would be impossible to do it justice by simply cataloguing the research projects. We have chosen to provide a range of examples where IT, either in terms of data gathering, analysis, modelling or communication, plays a central role.

i) Remotely sensed data collection

Land use research requires accurate and timely data-gathering capabilities. The remote sensing community has long been concerned with developing observation systems which are appropriate to measuring and detecting phenomena as they occur in time and space. The choice of system is closely linked to the required spatial and temporal resolution. A hypothetical taxonomy of applications is shown on the next page in Figure 3(a) in relation to data space and may be compared to Figure 3(b), which shows the coverage of data space by available remote sensing systems (after Allen, 1990).

The suite of remotely sensed measurement capabilities can be applied for two broad purposes: monitoring (and mapping) and process studies. There are a number of variables we might wish to observe on a wide area basis over a long period of time, for example, land cover or ocean

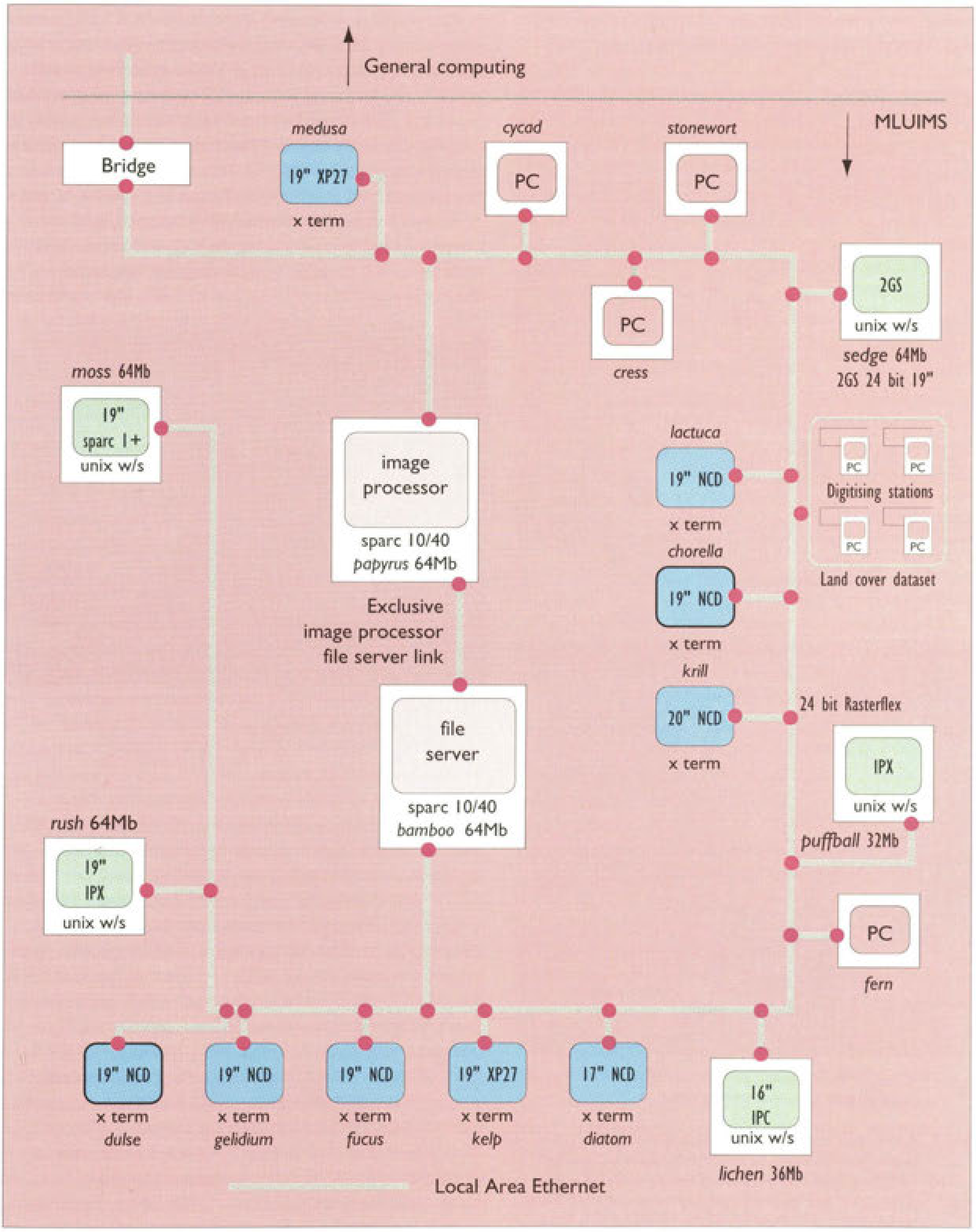

Figure 2. Essential resources for the Macaulay Land Use Information System.

surface temperature. On the other hand, process-orientated measurements might be more tightly focused on specific problems, for example, the dynamics of specific ecosystem boundaries (bracken for instance). Phenomena that change rapidly over short time periods and over small areas (for example development of crop canopies) may well be appropriately monitored by ground or airborne radiometers and scanners (Wright, 1988; Adams, *et al.*, 1990; Millard *et al.*, 1990).

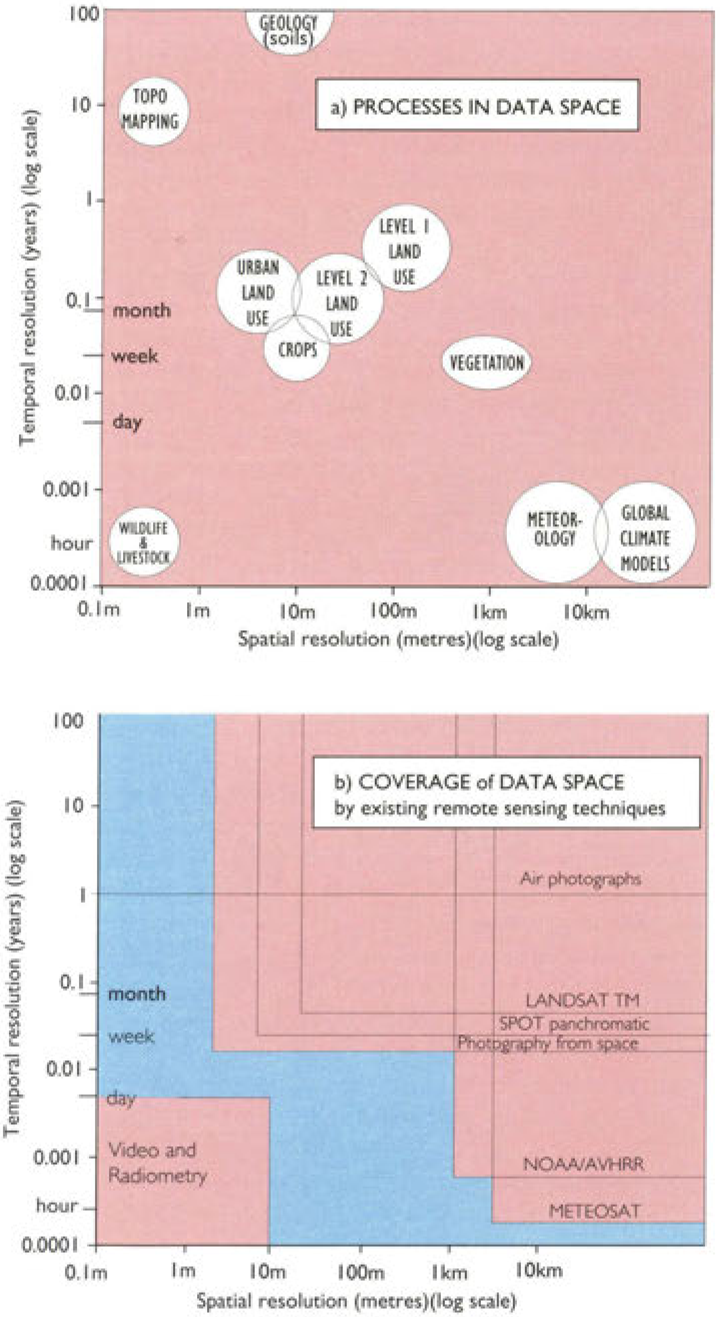

Figure 3. A two-way classification of data space in relation to time/space domains of environmental monitoring/ mapping applications (a) and the coverage of data space provided by existing remote sensing platforms/ instruments (b) (modified after Allen, 1990). Note the lack of coverage in particular areas, meaning that some applications cannot be serviced by remote sensing.

Progress in remote sensing must include the ability to overlay a variety of remotely sensed datasets from multiple sensors (and satellites) with *in situ* data. To advance beyond a simple data collection programme, many, perhaps most, of our present and future multidisciplinary studies will require the development of models using a variety of contemporaneous measurements as well as remotely sensed data. Such models will allow us to describe important variables (and processes) that currently cannot be observed or inferred from direct remotely sensed information, and place them in a conceptual framework. These may be simple visual descriptive models or complex statistically derived predictive models such as estimates of nitrate loadings (Wright, in press), which allow us to infer the responses of the system to changes in the environment.

One of the key issues in remote sensing and land use science research is how to integrate data at different spatial resolutions both to achieve good sampling design, and effective extrapolation (McGuire *et al.*, 1993; Stoms and Estes, 1993). Issues of scale are also seen as of central importance. Research and development on data-gathering systems at MLURI spans the range from videography applied to monitoring animal behaviour, aerial photography to develop a land cover database for Scotland (Aspinall *et al.*, 1991; Birnie *et al.*, 1992; MLURI 1993a and 1993b), scaled satellite photo-imagery and spectral information, from multi-temporal LANDSAT and SPOT, for detecting and quantifying land cover changes (Wright *et al.*, 1993) to the development of artificial intelligence and knowledge-based expert systems to improve detection and prediction of change.

ii) Data integration and exploratory spatial data analysis

There are four areas of research connected with data integration. The first is concerned with the development of geostatistical methods which use knowledge of spatial structure to allow point data to be used for modelling surfaces. This has been used extensively in relation to the climate change programme.

Spatial and temporal continuity characterises many phenomena in the natural world and this implies that uniform areas can be delineated on maps. (Note that continuity, variability and heterogeneity are scale-dependent terms often used interchangeably to describe spatial processes.) However, a map can be thought of as being constructed from two components: the first represents the underlying continuity of the phenomenon, the second, a coding for its representation. Recent advances in spatial statistics, particularly geostatistics, have enabled the development of new approaches to numerical coding which represent the real world situation more effectively than conventional cartographic procedures (see, for example, Lantuéjoule, 1993). Geostatistics provides a theoretical background and tools for estimating underlying continuity of phenomena from a restricted spatial sample. Continuity is usually modelled within a probabilistic framework (Isaaks and Srivastava, 1988), where theoretical models of continuity, known as variograms, are used to generate the numerical models of continuity. The output of the models are grid-based probabilistic estimates of the phenomenon. These can be thought of as probability surfaces rather than maps, where statistical properties are also known.

Geostatistical procedures have been implemented at MLURI and used to develop a climate database (Matthews *et al.*, 1993). For example, estimation of surfaces have been made with monthly mean temperature as the regionalised phenomenon. This work has revealed and quantified both seasonal and regional patterns in the current Scottish climate (Hudson and Wackernagel, in press; Matthews *et al.*, in press). This resulted in a unique, high spatial resolution (1 km) climate database, which has enabled us to examine specific regional impacts of different climate change scenarios, for example on potential crop yields (Figure 4). Further research will continue on spatial continuity of phenomena, and a particular focus will be to develop methods for ensuring coherence between estimated values in numerical models so that, for example, annual total rainfall equals the sum of each of the 12 monthly surfaces.

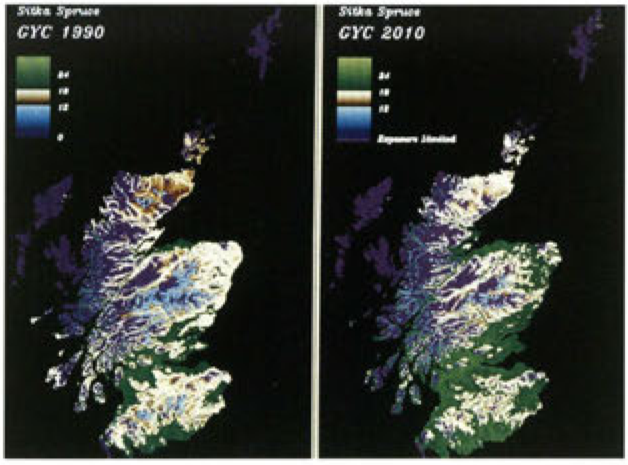

Figure 4. General yield class for Sitka spruce derived from site factors; current (1990) and 2010 predicted with climate change.

The second area is concerned with integrating different datasets which provide information on the vegetation and land cover of Scotland. This quantitative data comparison and data integration project covers, at present, the Land Cover of Scotland 1988 (LCS88) (MLURI 1993a and 1993b) from air photo interpretation census and the Countryside Survey 1990 (CS90) field sample survey (in collaboration with ITE Merlewood and ITE Brathens) (Bunce *et al.*, 1992). It is hoped that data from the National Countryside Monitoring Scheme will be included in a future fully integrated land cover dataset for Scotland.

The work has been undertaken quantitatively using the analytical and processing capabilities of a GIS. By combining sample information from the respective surveys it has been possible to examine correlations and links between land cover classes. These are shown to be strongest in semi-natural and natural vegetation communities, and for woodland communities. Where correlations have been shown to be poor, these can be explained in terms of scale differences, time of data collection or in terms of low frequency of observation or poor statistical confidence (Brooker, in press a and b).

Further, by developing algorithms in a GIS it has been possible to use the LCS88 dataset as a framework for statistical predictions of local and national distributions of the detailed CS90 sample information. They also provide the ability to use the large scale CS90 data to better define LCS88 classes.

The comparison involved the development of an original approach to the study of the nature of boundaries between vegetation communities, traditionally represented cartographically as solid, precise lines. By combining an assessment of the uncertainty in boundary location in the LCS88 dataset with the detailed vegetation information of the CS90 it has been possible to produce representations of vegetation gradation between communities. Subsequently it has been possible to indicate the suitability of precise boundaries or transition zones for particular land cover classes. This is being enhanced by incorporation of variable widths of boundary zones between individual LCS88 classes based on statistical and cartographic error and uncertainty parameters (see below). The next stage in the research will incorporate land cover information from the Land Cover of Great Britain from Satellite Imagery project (ITE Monks Wood) into the integrated dataset (Bunce *et al.*, 1992).

The third area is concerned with developing methods for exploring spatial datasets, developing correlations and inductively generating hypotheses about relationships between them. The integration of GIS, spatial analysis and environmental modelling provides a useful toolbox for environmental management and research. By generating spatial and ecological hypotheses about species distribution we can make suggestions about why species are found where they are. The output from the analysis can describe and locate geographic areas where species might be expected to occur on the basis of the environmental data and can define ecological relationships between species and environmental conditions. This approach is based on hierarchy theory (Aspinall and Pearson, 1993) and allows the relationships between distribution and environmental variables to be investigated for the different source scales and environmental variability to which species respond.

Spatial analysis has been applied to model the distribution of a number of species (e.g. chequered skipper butterfly, Scots pine, capercaillie) throughout Scotland (Aspinall, in press; Aspinall and Matthews, in press). This exercise integrates biogeographic data with environmental datasets, which include climate, soil and land cover information for Scotland. The analytical method used is based on Bayesian probability statistics and has been developed as a process for inductive exploratory spatial data analysis in GIS (Aspinall, 1992a). This approach facilitates decision-making by an inductive learning process for pattern recognition which emulates the way a wildlife expert would expect to make decisions about habitat suitability for a species. Differences in resolution and data quality issues are important to this approach since they effect the reliability of the output, so the effects of uncertainty in the data and modelling assumptions are tested throughout the analysis (Aspinall, 1992a, 1992b). By comparing the results of analysis of species distribution against different environmental data the extent to which the data explains distribution can be understood.

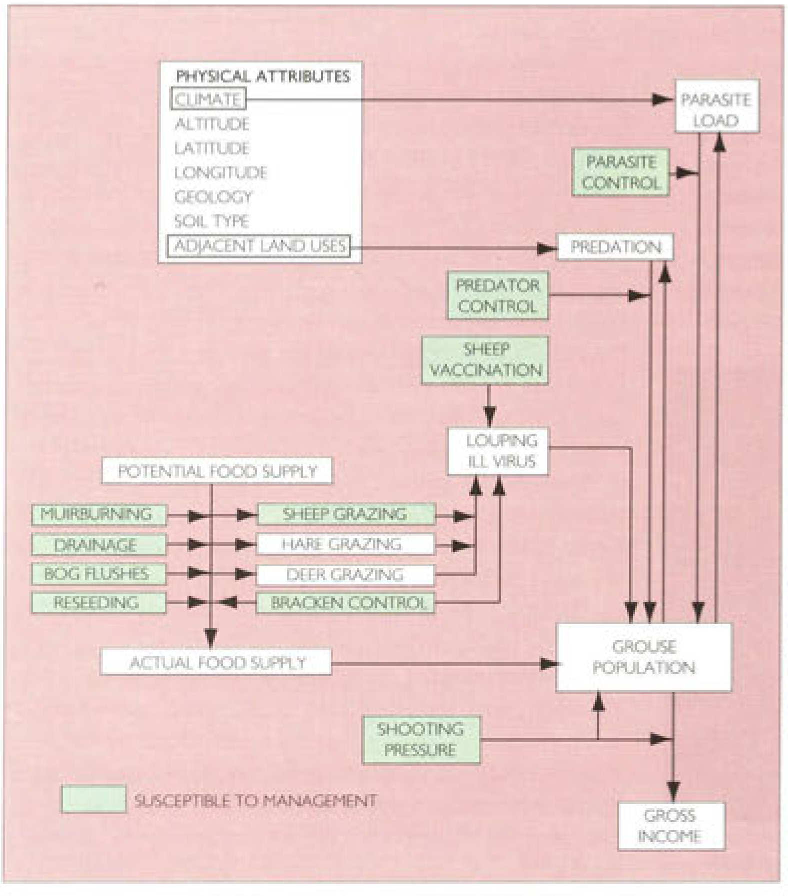

Figure 5. Systems representation of factors affecting grouse populations.

The approach has potential for hypothesis generation from species data and as a tool for inductive generation of synthetic spatial data (fine resolution spatial data from coarse resolution inputs) with known error tolerances. It also provides useful information which could be applied to the assessment of the impacts of climate change and automated generation of testable hypotheses about process-based relationships between species and environment.

Physical	Biological	Management
latitude	fox density	keeper number
topography	raptor density	sheep numbers
altitude	vegetation	heft frequency*
rainfall	heather cover	muirburning
adjacent land uses		shooting policy

* (hefting refers to the driving of sheep over the hill by the shepherd. This procedure reduces over-grazing.

Table 1. Data requirements of the expert system.

The fourth area of research connected with integrating data types is in the coupling of process-based models with GIS using a knowledge-based approach. The knowledge base is developed for managing spatial analysis, information flow between data and functions, and includes the use of both qualitative and quantitative expressions of uncertainty assessed against desired output accuracy. An implementation of this approach has been in the coupling of vegetation growth and vegetation dynamics models of bracken and heather to the knowledge base, in order to describe and explain measured changes in these vegetation communities (Miller *et al.*, in press).

iii) Computer modelling

A review of the role of mathematical modelling in land use research is given by Birnie *et al.*, (1991). This includes a broad categorisation of models in terms of the outcome they predict (deterministic, stochastic) and the level of understanding on which they are based (empirical, mechanistic). Modelling work at MLURI ranges from the development of models for improving our understanding of ruminant foraging strategies on mixed indigenous hill vegetation which links GIS with an expert system shell, through the modelling of upland livestock and silvopastoral systems, to the coupling of GIS and hydrochemical process models to extend our understanding of the environmental impacts of pollutants on surface waters.

While many of these models are being used as tools to develop scientific understanding, some are being specifically developed as decision-support tools. These include models at management unit level for the management of hill vegetation (Armstrong and Sibbald, 1992; Sibbald, *et al.*, 1987) and for the allocation of land to farm forestry on upland farms (Butcher and Sibbald, 1991). They also include models which are appropriate at regional or national planning levels, for example, in relation to sewage sludge disposal (Towers, in press) and critical loads of acid deposition (Langan and Wilson, 1992).

Expert systems models have also been explored within the context of decision-support systems. Edwards-Jones *et al*, (1991) report on the development of a system for reconciliation of sheep grazing and gamebird production on heather moorland in the Scottish uplands (Figure 5 and Table 1).

iv) Visualisation and multi-media

Developments in IT have led to a considerable number of tools to aid the research scientist in the manipulation and analysis of data. Visualisation tools allow the scientist to 'see' their data by converting the numerical values to patterns of colour in two or three dimensions. These tools provide many ways of displaying complicated data that allow the scientist to see and interpret the inherent patterns that are present.

Within land use science these tools have already been applied to the development of landscape visualisation (Miller *et al.*, in press) and in the display of the results from modelling the climate of Scotland (Matthews *et al.*, 1993). There are many other areas of the scientific research of the Institute that will benefit from this aspect of IT in the near future.

Land use science is a multidisciplinary research topic that relies heavily on further analysis of data and information from a wide range of scientific research. To handle these data, and allow the land use researchers to understand both their implications and limitations, there is a need for specialised information systems that can both hold the data and explain its background and significance. This is the area where multi-media and hyper-media (Buttonfield, 1993) systems come to the fore. In such systems, information and data are stored alongside pictorial and audio explanations in such a way that a researcher new to the data can quickly understand how to use it effectively.

Both visualisation and multi-media are components that will be important parts of future systems developed for decision support. Where people are involved in using IT to make decisions it is required that all the necessary information is presented in an understandable way and that the system can give the enquirer an understanding of the data and information used.

Forward look

In this article we have examined the role of IT in land use science. We have shown its critical importance and outlined the strategic approach MLURI has taken and some of the current achievements. Comparisons have also been drawn between the nature and level of activity in North America as opposed to the UK and we conclude that there appears to be a significant difference in relation to co-ordinated approaches, particularly as regards geographic data and GIS research.

From this review, it would appear that continued initiatives are required in terms of the management of IT facilities and research support. Some of the objectives which are regarded as fundamental to the Institute's future role in land use sciences in Scotland are:

- creation of a land use database for Scotland;
- creation of a logical and consistent data model for the above which accommodates the multiplicity of software tools available and the need for interfaces to external models;
- setting of data standards and quality assessments with particular respect to the inclusion of error and uncertainty measures in accompanying meta-data (information about the data) and for visualisation;
- investigation of the opportunities for institutional sharing of data and IT facilities - particularly through the concepts of data clubs, co-laboratory arrangements and networking particularly broad-band (for example, extensions of super Janet and Internet);
- investigation of the opportunities for supercomputing facilities.

From a research viewpoint, there continue to be many opportunities for IT developments, including:

- remote sensing image analysis, particularly the role of expert-system/artificial intelligence techniques and the potential for systems to detect land use change. This is particularly relevant in the context of updating the Land Cover of Scotland 1988 dataset;
- determination of error propagation and error control in complex GIS-based modelling;
- creation of simulation modelling tools which enable research on complex systems and to investigate the phenomena of emergent patterns, stability and feedbacks, particularly in the context of predicting effects of policy or environmental change;
- research on the nature and structure of decision-support systems and particularly the opportunities for incorporating expert knowledge or related soft data in decision-support systems.

This article has deliberately taken a fairly broad view of IT in support of land use research, using some examples only to highlight progress in selected areas. We hope that this approach has demonstrated that not only do we feel that IT is essential to effective land use research, but also that we can demonstrate the breadth and depth of its impact on the MLURI's own programme of research. The field of IT is a rapidly developing one and there is no doubt that computer networks, software tools and data availability will continue to expand. However, the critical limitation will continue to be the human capital which is required to enable the technology. The education and training of scientists not only to perceive the need for holistic science, but also to have the skills, both intellectual and organisational, to tackle the issues and harness the appropriate instruments and methods is a major challenge.

Co-authorship

This article has been written jointly with R J Aspinall, N A Brooker, G Hudson, A N R Law, K B Matthews, D R Miller, C H Osman, Diane Pearson, A R Sibbald and G G Wright.

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Science, Technology and th

The 17th T B Macaulay Lecture, given by J Maxwell Irvine, P
University of Aberdeen, 25 November 1993

Environment

pal and Vice-chancellor

There is a very simplistic model and it goes like this – scientific understanding begets technical innovation, applied technology leads to industrial growth which leads to wealth generation and benefits for all. It is a model to which many analysts believe the United Kingdom has failed to perform. Because of its importance to all of us for our social and economic wellbeing it is important that it be tested. It is a model, which, if it is valid, gives a justification, in part, for the general support of the public at large, for universities and research institutes. This is because it is in these environments that the scientific knowledge which underpins the rest of the model is acquired.

I want to take you on a brief historical tour through the development of universities in Britain to examine at various points whether the model is sustainable. I want to examine what the impact and what the interaction has been between higher eduction and technical development and the extent to which this has led to industrial development. If I take my examples very largely from the physical sciences I hope you will accept my apologies in advance. This is my field and I am much less capable of making the same kind of analysis in the biological sciences although I suspect that parallels could be drawn from that disciplinary base equally well.

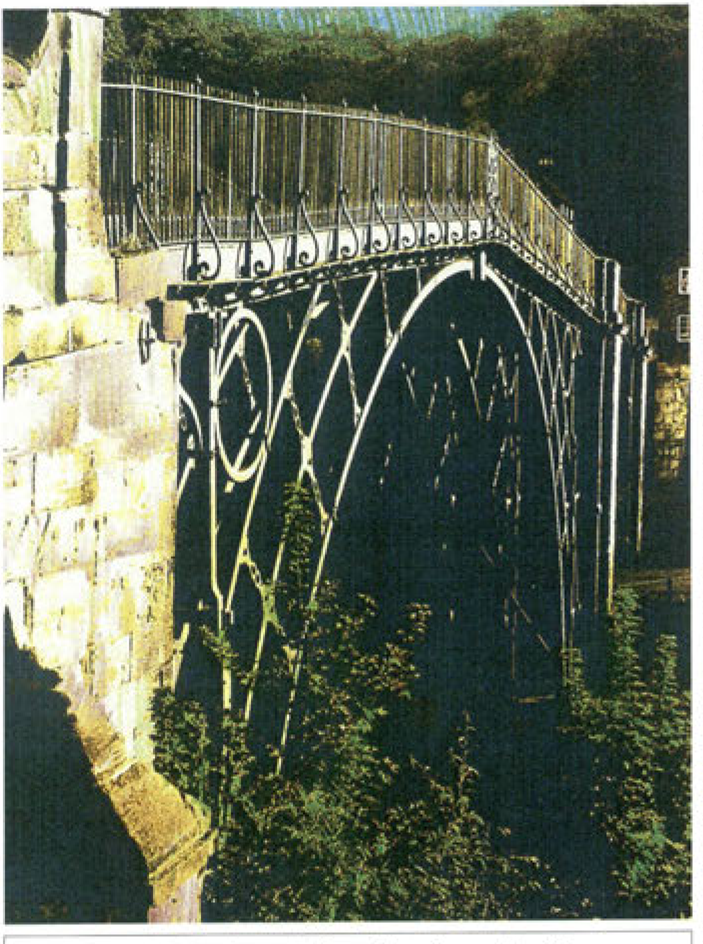
The European universities are medieval institutions in origin but they have their roots in a much older tradition. One thinks, for example of the great library at Alexandria and the academic schools that developed in Greece; one thinks also of Aristotle and Archimedes, Pythagoras and Euclid and of the social sciences of Socrates and Plato. Schools which could give rise to the saying 'give me a lever and I will move the world' were not unaware either of the importance of the mechanical arts. When the universities were established they were vocationally oriented. In Aberdeen for example, the three founding chairs were in Canon Law, to produce a skilled class to run the affairs of the church, which at that time was economically and socially a much more important component of society than it is today; a Chair in Common Law to run the affairs of the State, and a Chair in Medicine to take care of the medical needs of the population. The image of the latter was spoilt somewhat recently when I was reading some old records which indicate it was really to get rid of the pox amongst the clergy, but that is by the way.

During that initial phase, between 1100 and 1600, the Reformation swept through Europe and it led to many universities having their curricula reformed because virtually all of them had grown out of church institutions. Aberdeen is a wonderful model because it was unique within the British Isles in having a university that did not reform its curriculum. That is why we have two universities because the reformers established a second one. This also occurred in many other university cities throughout the Continent of Europe. The teaching patterns in the two universities in Aberdeen were quite distinctive and I think this distinction is important. I can perhaps best illustrate the differences by describing first the Regency form of education which was established at Kings.

The illustration shows
The School of Athens, fresco by Raphael, 1509-10
Vatican Museums and Galleries, The Bridgeman Art Library

I do that in terms of one of my predecessors, William Guild, who was Principal in the early part of the 17th century and was a major figure in establishing the Incorporated Trades in Aberdeen. William Guild's contract required him to teach Hebrew and Syriac, rhetoric and logic, anatomy and physiology and a little astronomy. It was a form of instruction which today seems bizarre. Students came to University or College and were given a tutor, (a mentor) who educated the student in all the arts and sciences then known to mankind. It is a tradition of which we see the residue today in Oxbridge in the tutorial system which, down through centuries, has evolved to take account of greater disciplinary specialisation. The Marischal tradition was much closer to what is, and grew to be, the Germanic tradition; the tradition of *Herr Professor*, a person who professed a discipline and who was an expert in a sub-field. The immediate relevance of this tradition to modern research, where it is impossible to be an expert in all fields, is obvious. In Oxbridge the College Fellows provided the academic leadership whereas in the Germanic universities the Professors provided that same academic leadership in their own fields of speciality. That then, was the form of education that was available to support the first Industrial Revolution. In England the two great universities of Oxford and Cambridge and in Scotland the five universities, with two in Aberdeen, one reformed and one not.

Did the Industrial revolution, however, depend on the universities? It certainly followed the creation of the universities but to what extent did it depend on the scientific thought that was available and generated by them at the time? Perhaps I can give an illustration of what occurred during that period with the story of James Watt, clearly a key figure in the Industrial Revolution. Born in 1736, the son of a Greenock merchant whose business failed through unwise investments, James Watt was sent to London to an apprenticeship with John Morgan's, the instrument makers. For various personal reasons he stayed only for a year and then returned to Glasgow. He was not recognised by the Guilds in Glasgow as being properly time served and therefore was not allowed to set up business in the burgh of Glasgow. He found employment, however, as mathematical instrument maker to the University. There he came into contact with two academics, Joseph Black, who was professor of chemistry and introduced the concept of latent heat in chemical reactions, and one John Robinson, a physicist, who was later to become professor of natural philosophy at the University of Edinburgh. So he certainly had academic scientific mentors and under their guidance he worked on the problem of improving the efficiency of the steam engine.



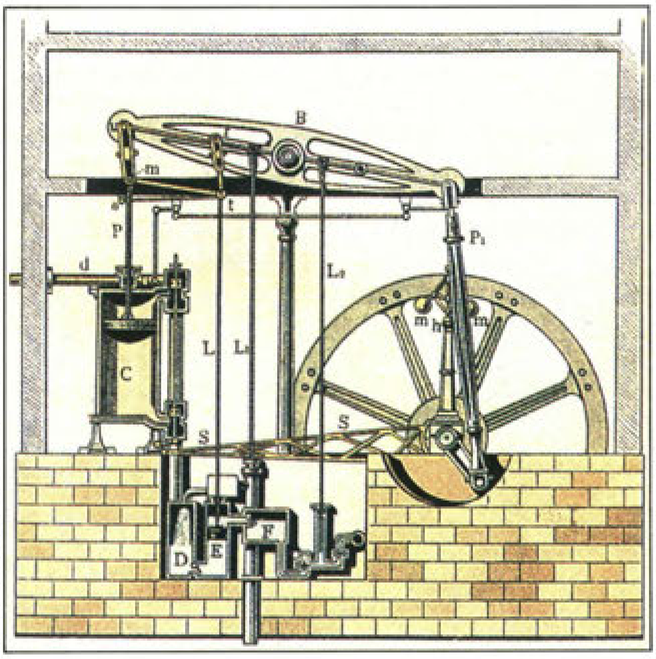
Ironbridge Gorge in Shropshire, the cradle of the Industrial Revolution. *Image: Words & Pictures, Aberdeen*

There were lots of steam engines working at that time: they were cumbersome, they were inefficient but they worked after a fashion and they were used to pump water from mines. In 1769, Watt was granted a patent for an improved and more efficient steam engine. To market it and manufacture it, he went into partnership with the founder of the Carron Ironworks on the basis of a one-third, two-thirds profit split. The company took two-thirds and the patent holder, the intellectual property rights holder, kept one-third. These terms would be considered very favourable by today's standards. Within a few years, however, the Carron Ironworks interest was bought out by a Birmingham engineering firm and a very happy relationship was established between Watt and the company and on that his reputation lies.

This story contains a number of points; first, that there are such things as restrictive practices which can inhibit technical innovation; second, that there were, there had to be, technical skills, but it was the marriage of the instrument maker with the academic skills which were generated in the university which led to a technological advance. James Watt, however, did not invent the steam engine; it was an incremental development which yielded great profit but there had to be a source of venture capital for the project to take off and be successful. So the very simple linear model, which I introduced at the beginning of this lecture is perhaps still intact but there are a lot of 'ifs' and 'buts' that have to be added to it, if it is to be realised fully.

The last element of the model states that industrial development will lead to wealth generation and benefit to all. The Industrial Revolution certainly generated great wealth. There was a huge flood of people from the country into the towns. Indeed, there was an enormous growth in population. But was there benefit for all? That I think was problematic. It was certainly true that the land could not support the large population that developed after the Industrial Revolution but would that population have developed without the Industrial Revolution? Were the bulk of the people who lived in slums and who worked in the 'satanic mills' or dug coal from under the earth really better off? Was their quality of life improved? I think it is problematic, and a question to which I don't have a unique answer. Certainly, the environment was polluted as never before and it was never to be the same again. The great growth in industry did, however feed back into the system which may have helped to generate it; that is the universities. In the mid 19th century we had the second phase of university development.

In Scotland it led to a reduction in the number of universities by one, through the merger of Marischal and Kings to form the present University of Aberdeen. It led to the growth in higher education because of the establishment of a new kind of institution such as the Royal Technical College in Glasgow and Heriot Watt Technical College in Edinburgh which subsequently became the University of Strathclyde and Heriot Watt University. South of the border, however, it led to a massive increase in the number of universities. The pressure had been building for many years. During the Reformation, Oxbridge had wedded itself to the Crown, and the religious constraints which were imposed upon the British Monarchy were transferred to the institutions of higher eduction. That is, no one could be a student or a member of a university, unless they were a member of the established church. The growth of universities in Britain in the mid 19th century, therefore, was not just a consequence of the Industrial Revolution; it was also a response to the pressure to find a home for the nonconformist talent which was awash in the country. Scotland had benefited greatly in the century before from the availability of such talent in what is known as the Scottish Enlightenment when arguably Scotland was the intellectual capital of Europe.



James Watt's steam engine, 1792.

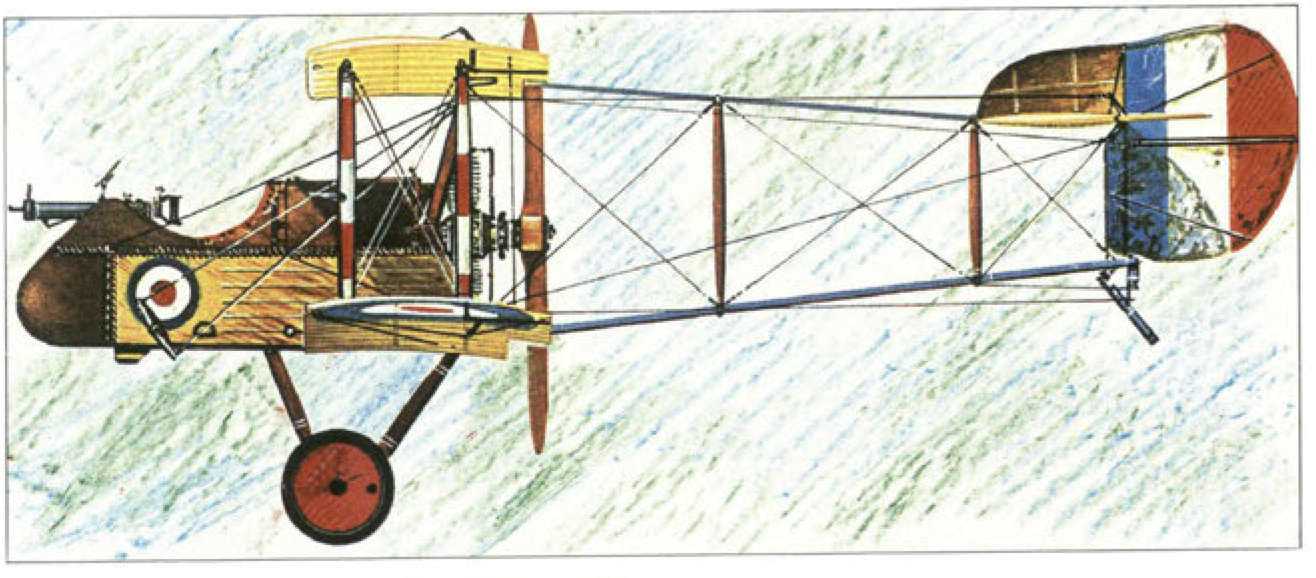
Many people could not find a home in the two great universities south of the border until the religious restriction was removed in 1919. The new universities created at Durham, the Victoria University of the North of England in Manchester with its colleges in Leeds, Liverpool and in Sheffield and Bristol, became the centres for nonconformist talent. These universities were able to build very quickly into world class institutions because they were able to tap a field of talent which was not available to Oxford and Cambridge. The shape that the development took is, however, perhaps best illustrated by the story of two people. The first is Alexander Humboldt, a Prussian, probably the first environmental health expert, a biologist, a geologist, a geographer, an adventurer, a traveller, a European. He worked successively for the British Government, the French Government, the Russian Government and his reputation grew so large that he was summoned back to the Court in Berlin. He probably found that very constraining but he then set about creating a University in Berlin which today is the model of the research university that you will find throughout the world. The other figure is John Henry Newman. John Newman was an Anglican ordained priest and a fellow of Oriel College. He was the archetypical regent, he was a scholar and a cleric. He was seriously concerned about the nature of the university and wrote extensively on it. He was aware he was the great defender of the liberal arts tradition in education and a generalist. He was aware of the importance of higher education in the training of the professions but he wanted to keep it at arms length. His thesis was that a student must first of all obtain a broad education, then select his profession and undertake post-graduate training to fit himself for it. In mid career Newman converted to Catholicism and had to leave Oxford but went on to create the National University in Ireland and become a Cardinal. The point of this story is to highlight the distinction between the professor-led culture and the generalist-led education which in Britain was maintained right through the Industrial Revolution. It was these two traditions which shaped our Government leaders and indeed our Civil Service.

It is said that necessity is the mother of invention. In consequence, wartime produces a denser string of necessities than peacetime; times of war have been periods of tremendous technical change. The First World War was arguably the first technical war: it was, after all, the war in which the horse was replaced by the mechanical vehicle, when aircraft were first used, when telegraphy was replaced by the new wireless transmissions, when submarines and tanks were tested for the first time and we moved from sail to steam. Nevertheless, after the war it was quite clear to the British Government that the nation, which had been the home of the Industrial Revolution and ruled a third of the world with an empire on which the sun never set, had been overtaken in industrial technology by Germany. The question was why? The view was, that in part, it was due to the growth of the research-based University that von Humboldt had designed. The question was how to generate a similar situation in the United Kingdom.

The first thing was to create a channel for money from the public purse, through Government into higher education. So in 1919, the University Grants Committee was created and it should be remembered today that the reason why it was established was to make the universities the research engine of the nation. The nation did not have long to experiment before it was thrust into the Second World War and if the First World War had been a time of technical advance the Second World War saw that greatly accelerated. When the United Kingdom entered the Second World War, aircraft were still things of string, sealing wax and paper: when the war was over we had the jet engine and rockets that were to take us to the moon. Communications had been transformed; radar and sonar had appeared on the scene; across the board technical advance proceeded at an incredible pace and ultimately we entered the nuclear age. The innovativeness of British scientists during that period was staggering. In almost every scientific endeavour, we had, by the end of the war, established a technical lead. The vast majority of the people who led these programmes had actually come out of the universities. They were aided by armies of highly skilled technicians from all walks of life. There was clearly no defect in the national character as far as inventiveness was concerned: given the mission, given the job, the skills were there. It was recognised, at the end of the war that the pace of technical advance had to be maintained. There was a national imperative to continue the momentum, but to do that needed another channel with greater resources and much more freedom to support research than the University Grants Committee: so the Department of Scientific and Industrial Research (DSIR), later to be transformed into the Science Research Council and then the Science and Engineering Research Council was established. A story of how this interacted with one returning scientist after the war is well worth telling.

Bernard Lovell had worked on the radar programme during the war and at the end of it he returned to Manchester University with two truck loads of 'scrap metal' which had been left over from the radar programme. With this 'scrap metal' he set himself up on the Biological Research Station in the Cheshire plains that belonged to the University of Manchester at Jodrell Bank. Within a few years he had demonstrated to himself, and to his colleagues, that if astronomy was to advance, then what was required was a completely new kind of instrument – a radio telescope. Lovell's proposal to build a radio telescope was an ambitious project; it was to be 200 feet across, steerable in all directions and tiltable at all angles. It was at that time, the leading engineering project in the world. Since it was an engineering project, he made his bid to the DSIR for the money, all quarter of a million pounds of it. To put that in perspective, in the years before the war a typical professor in the physical sciences would have had an annual research budget of £1000 a year. In the intimacy of war Bernard Lovell had got to know all the people who sat on the committee which controlled the substantial funds which would be required. Everyone knew everybody else. They had worked together in laboratories. They had, late at night, shared their concerns. Lovell knew them all; he talked to them all and they all told him what a wonderful project it was. They would support it, every one of them, and so he built his telescope. The committee met, decided it was a good project and voted 10% of what he had asked, for a feasibility study! The telescope was built, so a feasibility study was hardly relevant. However the cash was, and there was no money to pay for the telescope. Eventually the engineering firm which had built it decided that they had to protect themselves and sued.

At this point the Russians inadvertently came to the rescue with the launch of *Sputnik*. This was a tremendous challenge to American technology. Washington suddenly



The DeHavilland DH2 single seater fighting scout plane, 1915.

discovered that, overhead, was a basketball going around, beep, beep, beeping at them, and they decided they wished to know where it was. How could they detect it? How could they chase it? The best instrument, indeed, the only instrument, in the world capable of doing it, was the new Jodrell Bank radio telescope. So, within 48 hours, all bills were paid by the United States Air Force. Instead of being a villain, Bernard Lovell became a national hero.

There is a whole series of morals in this story, not least of which is that every major piece of instrumentation on the scale such as that of a radio telescope, or nuclear accelerator has rarely ever been used primarily for the purposes for which it was sought in the first place. This confirms an old Chinese proverb which says something like 'if you can ask the question, then it's the wrong one', and if that's true anywhere, it must surely be true in research.

Bernard Lovell's telescope is probably one of the most familiar symbols of British technology that exists. The disappointing thing about it is that it is now 40 years old and if a tender were to go out today to build it there is no British company that could successfully tender for it. Yet in the 1950s we had launched the first commercial jet aircraft, the Comet; we had built the first commercial nuclear power station, Calderhall; we had come out of the war having developed radar. Television after all, was pioneered by Logie Baird, and even if that was before the war, the developments after the war made it a practical household object. Our electronics industry was the equal of any in the world. There was a feeling, which I grew up with, and many people in this room would have shared, that science was going to provide a bright future, where clean cheap energy would be available for all, the standard of living would rise, and we would live in a brighter and better world. Scientists were heroes for young people thinking about careers; the physical sciences were an enormous attraction. Space was just around the corner. It was an exciting time. If we had the inventiveness in the '30s, '40s and '50s to lead the world in so many areas, what went wrong? Was it the universities?

Whatever was wrong there followed, nevertheless, the third great wave of university building on the back of Harold Wilson's 'white heat of modern technology'. We saw the creation of new universities like Stirling and the promotion to university status of colleges of advanced technology like Heriot-Watt and Strathclyde. We saw the expansion of the existing universities, a doubling of the system. We had the technology, we invested in the education and yet our economy has been in constant decline for 40 years. Personally, I do not think it has anything at all to do with the university system or with the imagination of our population. I think it is the consequence of a completely different aspect of our society and economy.

After the Second World War there were other tasks to be performed: such as the rehousing of the population. Years of neglect of the building stock and the need to replace buildings that had been damaged during the war required a rebuilding programme that took priority over all else. In the 1950s, '60s and indeed much of the '70s, if you wanted to make money, property was the name of the game. Investing in property, on an island where there is a finite resource, is an inevitable driver of inflation. House inflation and property inflation developed on an unprecedented scale as the population of the UK became a property owning democracy. Inflation forced up interest rates. High inflation and high interest rates meant that the stock exchange failed unless there were high dividends. High dividends could only be paid if you did not invest in your future. The country was caught in a spiral that was inevitably going to go down. If you contrast the situation in Britain with that in Japan, where inflation was low, there was no pressure for a large dividend return: indeed for many years many Japanese companies made no dividend payments but capital growth through reinvestment compensated the shareholder for the lack of dividend. In this country that was not to be. There was no investment by industry in modernisation. There was no spare cash to build the kinds of links between industry and higher education which we saw evolving in the rest of the industrial world. I believe that the failure was a fiscal failure and not a failure of the scientific and technical institutions in this country. I think it was compounded by a fortress mentality forced upon the Government by the Treasury and indeed the abdication of responsibility by the Cabinet to the Treasury somewhere around 1974, and thereafter there has been no government policy. There are lots of fine words but there is no government policy; there is existence from one budget to the next and that short termism is a disaster for planning. We still live in that climate.

The recent publication of the White Paper, *Realising our Potential* is in itself interesting. But it has been a greatly missed opportunity. It has been a missed opportunity because the powerful spending Departments of Government decided that they did not want to be part of it. The Office of Science and Technology borrowed a little bit from the Department of Education and Science but was virtually told by the Department of Trade and Industry, the Ministry of Defence, the Departments of Energy and the Environment to go and play in its own back yard and not to interfere with their plans. If Government had been serious about the future of science and technology in the UK then it ought to have been a Cabinet matter with all the spending Departments united together in a concerted effort to develop a comprehensive policy. If you question my judgement that there is no Government policy, let me point out some of the realities of the Department of Education and Science, now the Department for Education. In 22 years there have been eleven different Secretaries of State. Two of them, Margaret Thatcher and Keith Joseph both served for 5 years. Two of them, and just to show that this is not a party political point, Shirley Williams and Mark Carlisle each served for 3 years. In the remaining 6 years we have had seven Secretaries of State for Education and Science, responsible for policy all the way from nursery schools to universities, including, until last year, all our Science and Technology policy. The statistics speak for themselves and highlight the seriousness with which strategic planning has been taken by Government over the period since the war. Compare that with the situation last year when I was at the Council of European Rectors, the body that represents the Heads of European Rectors where several Ministers of Education from around Europe were present - except of course, the Minister of Education from the UK who never attends. The Dutch Minister was there and he had just finished an 11 year stint. Maybe that is too long but at least he had time to catch up with what the real problems were.

I would like to conclude by picking up on a few of the remarks made by our Chairman at the beginning. What can we do locally? What can we do to make sure that we are in the strongest possible position to make a contribution in the future? The name of the game has to be critical mass. You cannot sustain a broad research programme without having a range of talents available. It is obvious where the talents lie in Aberdeen and where the major areas of expertise and centres for growth must be developed: it is in the Research Centres of the Aberdeen Research Consortium. Your Chairman was kind enough to say a word about my role in its formation but I should tell you that though it was an idea which was in my mind, I received a letter from the Directors of the major institutions in Aberdeen proposing that idea to me long before I came here and had a chance to utter it. So it was a happy marriage of minds and the University is delighted to be a part of the consortium. There has, of course, always been collaboration between members of the University and this Institute and as a person who has had an active research career I know that research can only be done by freely consenting individuals. It is not something that can be dictated from on high. You cannot in the normal working environment of the university or the research institutes, force such collaborations. In order to make it work we have to demonstrate what the benefits are. I believe the benefits are already beginning to emerge. Failure to achieve success in collaboration will show the down side.

The research climate for funding for research is going to get more and more difficult for the remainder of this century and the only way that we can compensate for that is by pooling our resources. We have to make the best use of our intellectual resources and research facilities and establish Aberdeen as a credible international research centre that can compete effectively with the other centres in the world who will all be chasing the same money. So if we wish to do research in Aberdeen it has to be done co-operatively. As I have said, I think we have made a beginning but it is just the beginning.

I would like to tell you a little bit more about another initiative which, although not at present part of the Research Consortium should, in my view, become so. The initiative is a joint collaboration between the University, the Hospital Trusts and the medical charities. We are establishing at Foresterhill an Institute of Medical Sciences where we will bring together not just the clinical disciplines in the hospitals but also the underlying biological sciences that support them. We have already appointed nine professorships to the Institute. We will be advertising before Christmas another four professorships and we have others in the pipeline. There will be a minimum of fifteen chairs created in the next twelve month period. Each one of the nine appointees already holds very substantial grant earning capacity. Most of them already run research teams in double figures. I will consider it a disappointing failure if within 3 years we have not added two hundred additional research scientists to the Foresterhill site. I am sure that there will be many opportunities for that institute to interact strongly with the Research Consortium.

The last initiative I would like to talk about very briefly is the European Environmental Institute. The concept of the European Environmental Institute actually has a long history. I think Brian Clark of the Centre for Environmental Management and Planning at AURIS was the original author. The idea of creating a European Environmental Centre in Aberdeen came at the time when various countries were being asked to bid for the EC Environmental Centre. Despite that having gone to Copenhagen the Aberdeen Initiative remains in place. The European Environmental Institute has emerged and it has got its champions in Grampian Enterprise through a long and tortuous history. It has also been recognised that what we are creating in the Aberdeen Research Consortium is exactly the research component which the Environmental Institute needs. Consummating a marriage between the Research Consortium and the Environmental Institute broadens its remit to include education as well as a role in informing the public more widely about environmental issues. A prime requirement of such an institute is that it should be on the most advanced information technology highway. Many communities have suffered economic decline because they did not have the proper communications network. Many communities have failed to grow because they were not on a road or a rail link.

But the communications network of the next century is not a physical road. It is an Information Technology (IT) network and we are determined that Aberdeen will be an integral part of that network. If it is not, then it will be choked off just as in the past its economy has been inhibited by the lack of a rail or a road link or failure to build a tunnel or a bridge. So it is important that Aberdeen is on the UK's most sophisticated computing and information communications network. In the United Kingdom this network is called SuperJANET and we are bidding to be on that network. Locally, of course, it is important that all the members of the Research Consortium are linked; it is not sufficient for the highway to come and stop at some centre in Aberdeen, it is important that all of the component parts are linked together and it is our intention to achieve that aim as soon as practicable.

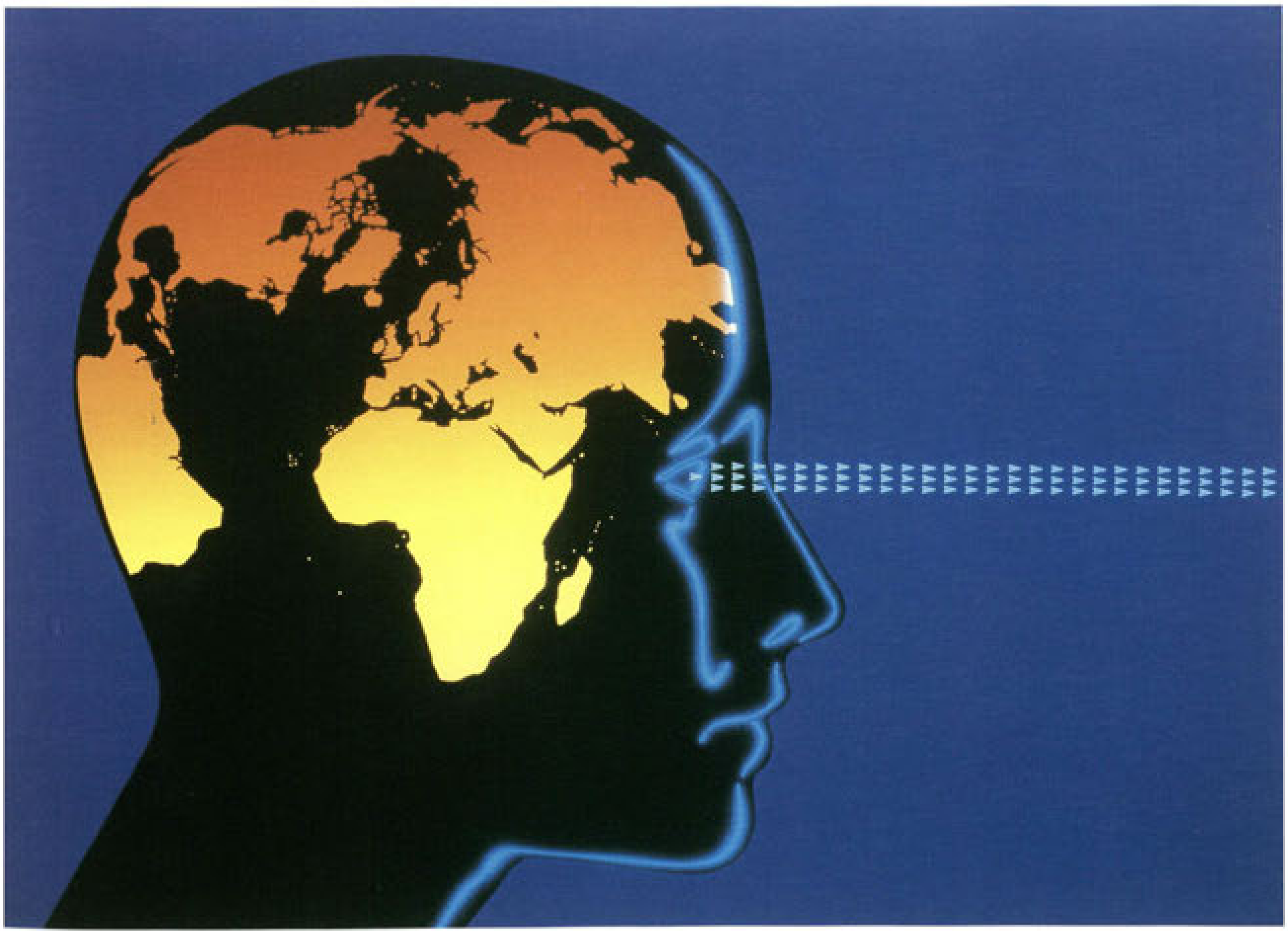
Universities grew up, as I mentioned at the very beginning on the basis of the great libraries such as that at Alexandria. Universities are not just centres where information is passed on from one generation to the next; they are centres where information is collated systematically and stored. Consequent upon the accumulation of information down the centuries, all the great universities have great libraries, but in future they won't just be traditional libraries of the printed page, they will be information services that connect you to the world. The library of the 21st century will be open 7 days a week, 24 hours a day. It will not require you to go out in the snow and take a book off a shelf; you will turn to a screen in your office or home. The library of the future will be global whether it is the British Museum or the National Academy of Sciences, or the Smithsonian: it will be available to you where ever you are in the world and whenever you want it.

This is just the beginning – recently we had our inaugural lecture for our Professor of General Practice. It was a beautifully presented lecture with slides on our back projection system at Kings College Centre. When he finished, he pressed a button and down came the back projector and up went the front projector and there was a classroom of students in Peterhead who had been listening to exactly the same lecture, connected by video conferencing and who could have participated fully in the discussion. When we create the institute of medical sciences at Foresterhill it will not be necessary to bus students or staff to different locations in Aberdeen. It will be possible to give a lecture anywhere in the University and to any group of students: the timetabling of classrooms will disappear as a problem. So too, if we can do it up and down the road in Aberdeen we can do it to Thurso, or Orkney, or Shetland, or you can do it out to an oil rig, and if we can do that, we can deliver our medical training to Kuwait, or our forestry courses to Malaysia. When the material of a lecture or a demonstration is stored in digital form the student can access it at any time. If he misses a lecture or wants to review a lecture it can be provided at his convenience, not with some timetabled constraint or dependence on the availability of a lecturer. But the biggest challenge of all, for all of us involved in education, is that of meeting the expansion in world-wide higher education and the teaching of practical skills in laboratory subjects, for example in anatomy or in medicine generally. It cannot continue to be taught in the traditional form, it is too expensive. The anatomy class of the 21st century will involve donning a pair of gloves and a helmet and immediately entering an anatomy dissecting room with instruments and organs to be selected in a virtual reality world; to be reassembled as digital records for the next student. The chemical laboratory will be similar – just imagine the savings in the consumable budget.

Unless you should think that the virtual reality laboratory is science fiction just think how astronauts or pilots are trained today. The bulk of their training is done on simulators and the technology is advancing at a great rate.

However, while virtual reality may provide a training ground in teaching terms it will not replace the research laboratory where we seek to uncover the secrets of the real world.

Global Vision: ***Telegraph Colour Library***



Resource Consultancy Unit

The Resource Consultancy Unit (RCU) undertakes contract work and consultancy on all aspects of land use research, with particular emphasis on the application of soils data to land management and environmental issues. The Unit addresses not only systematic soil survey, soil database appraisal and land evaluation queries but also makes available, through multidisciplinary studies, the comprehensive resources and expertise available at the Institute. The excellent facilities available for contract research vary from soil studies or land evaluation in the field to those involving detailed scientific technology and knowledge; indeed, in recent time, clients have welcomed the opportunity to utilise the full Institute resources, in particular the sophisticated computing facilities. Whilst such facilities can be dedicated to contract work of a confidential nature or for discussion within the wider scientific community, the Unit also contributes to research projects within the Institute, for example with soil characterisation.

The Land Cover of Scotland

New work has focused not only on marketing this comprehensive dataset but also on the potential use of this work in current and future land management and environmental work. Several direct applications of land cover data have been undertaken, and other uses to augment existing environmental data have been explored. A data-leasing officer has been appointed to market the dataset and administer the leasing arrangements. A range of publicity material is available with reference to the specifications, costs, technical details and potential applications of the data. The production of land cover plots, at a variety of scales on both paper and film, has been appreciated by clients.

A moorland map for Scotland

A series of maps at 1:25 000 scale, based on the Land Cover of Scotland dataset, have been compiled for SOAFD after detailed discussion with their staff. Existing land cover categories were amalgamated into units compatible with those being mapped by the Agricultural Development and Advisory Service in England and Wales in a similar project to delineate moorland. Such maps are intended for strategic planning, being an essential prerequisite in the development and implementation of policy to maintain moorland areas which may be under threat from overgrazing or other inappropriate forms of land management.

The Distribution of indigenous ground vegetation in Scotland dominated by, or containing heather (Calluna vulgaris)

A series of maps at 1:250 000 scale, also based on the Land Cover of Scotland dataset, that record the distribution of indigenous vegetation in Scotland dominated by, or containing, heather and dwarf shrub heathland were produced for SOAFD. The areal extent of such land was recorded.

Soil and land capability for agriculture surveys

Detailed and systematic field examinations of land subject to development or opencast mining/gravel extraction were carried out for a number of clients. Soil and land capability for agriculture maps were prepared at a variety of scales, and reports were produced.

Carbon sequestration by soils

There is a clear need to provide quantitative estimations of the amount of carbon which might be sequestrated by soils and vegetation in Great Britain under different types of land use and climate as a basis for policy decisions relating to managed carbon in soils. The RCU has completed studies for the Institute of Terrestrial Ecology (ITE) that quantify the mean carbon content of soils in Scotland using data within the comprehensive MLURI soil dataset and land use data provided by ITE.

Biological monitoring within the Scottish ESAs

For SOAFD, RCU staff have continued to monitor botanical change within the ESAs and to determine the extent to which the management prescriptions of the scheme have been responsible for such change. This represents the final year of monitoring prior to the compilation of a report on potential change over the last five years.

Land suitability for sewage sludge application

With disposal of sewage sludge to the sea being regarded as environmentally unfriendly, disposal on land is seen as a viable alternative. Contracts have been undertaken which market the Institute's research work on land suitability and the risk assessment in relation to the disposal of wastes rich in heavy metals. Land suitability predictions relevant to the clients' specified study area were prepared at scales ranging from 1:25 000 to 1:250 000.

Contact: Dr J H Gauld

Analytical Division

Analytical and technical support for the research programme is provided by centralised facilities. The high demand for access to the facilities necessitates that analytical equipment is replaced and upgraded on a regular basis. To service the research programmes in which information is required on inorganic element content an additional inductively coupled plasma-optical emission spectrometer has been purchased. This state-of-the-art instrument with associated ultrasonic nebulisation sample introduction system will increase substantially the output of analytical data and allow lower detection levels of elements to be achieved. This will have important implications for studies in which accurate quantification of certain elements present in very low concentrations is a major consideration. Such elements are analysed currently using graphite furnace atomic absorption spectrophotometric techniques. Most of the studies relating to environmental monitoring and water quality have a high dependency on inorganic element analyses.

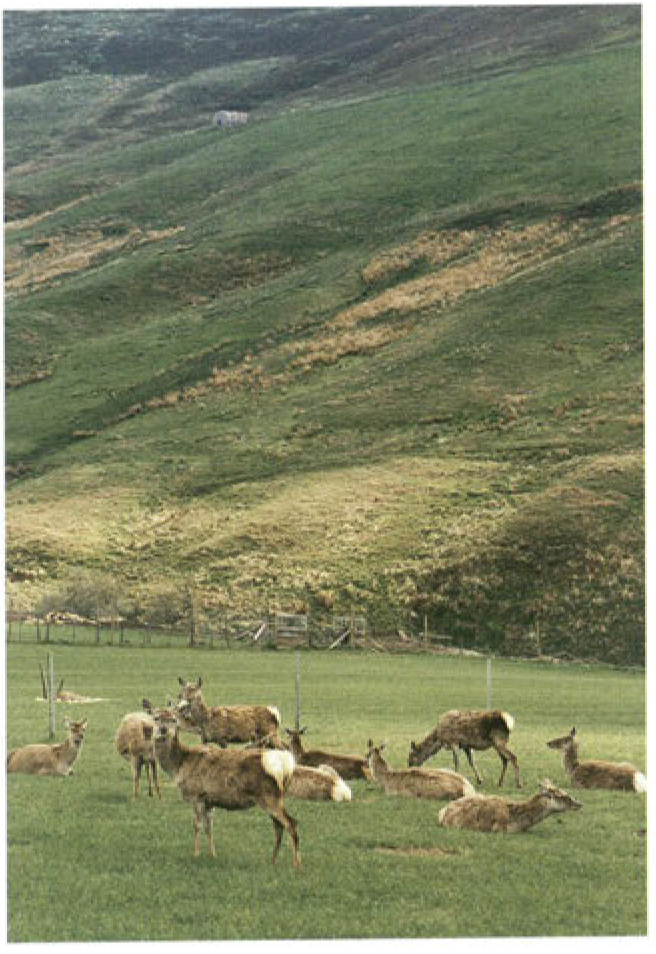
Facilities within the gas isotope ratio mass spectrometry service have been improved by upgrading an instrument to enable the automated analyses of gases containing deuterium and ^{18}O. The upgrade comprised the provision of automated inlet valves, an inlet manifold and a computer interface. A system has been built in-house to allow the production of these isotopes in gaseous form from samples of water and physiological fluids. These analyses are required in connection with investigations concerned with energy expenditure in animals and isotope hydrograph separation technique. Continuous flow isotope ratio mass spectrometers continue to be in constant use for the estimation of ^{15}N abundance in (mostly) plant material.

The grounding and subsequent break up of the MV *Braer* oil tanker off the Shetland Isles resulted in the dispersal of oil by aerial deposition over a substantial area of land. The Institute was commissioned by SOAFD to undertake a programme of monitoring to assess the extent of contamination on vegetation, soil and vegetables as well as to ascertain the presence of oil-derived products in animal tissues. To undertake these studies, recourse was made to gas chromatography linked to mass spectrometry (GC-MS) and the system was upgraded by the addition of an automatic sampling device and improved computing facilities. GC-MS continues to be used for the analysis of a wide range of compounds derived from organic fractions of soils and waters. The provision of new gas chromatographs has increased the capacity to undertake the analyses of alkane compounds used in estimating herbage intake and digestions.

The electron microscopy service has been augmented with the purchase of a state-of-the-art scanning electron microscope and associated micro-analysis system. This will allow examination of a variety of materials to be examined at higher resolution than was previously possible.
Other facilities are in constant demand and included among these are ion chromatography, rapid flow analysis techniques, radioisotope counting and the analysis of feedingstuffs and soils by manual methods.

A major emphasis is placed on the control of quality of analytical data and formal quality control procedures are in operation for many of the analytical techniques. These procedures are in the process of being extended to cover all the data. A quality assurance manual is being written as a first stage towards accreditation of the analytical laboratories. Technical Services continue to provide a facility for the construction of scientific equipment and the maintenance of services and plant; the latter requirement has increased substantially since the move into the new building.

Contact: Dr A Smith



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.

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 300 Scottish Blackface ewes, 340 Greyface ewes and 440 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.

The picture shows red deer at Glensaugh Research Station

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, about 770 North and South Country Cheviot ewes, 55 Thoka cross ewes, 32 Shetland/Merino cross ewes, and about 50 suckler cows, mainly Blue Grey and Aberdeen Angus-Friesian. In addition there are some 390 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 160 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.

The Scottish Agricultural Statistics Service (SASS) is a group of 30 statisticians and mathematicians, with its headquarters in Edinburgh. It is responsible for statistical consultancy and training at the Scottish Agricultural Research Institutes and the Scottish Agricultural college and for conducting methodological research.

Scottish Agricultural Statistics Service

Consultancy is provided by small groups of statisticians assigned to particular institutes who are usually based on site. Training is given through one or two day courses, most of which use the statistics package GENSTAT. Research is conducted: in areas of cross-site interest by staff in the Research and Training Group at SASS HQ; by appointment of staff for commissioned projects; and by consultants in the discipline related to the work of their host institute.

SASS has two groups in Aberdeen. One group is based at the Rowett but also does consultancy work at SAC. The second group, comprising 5 posts, is the Environmental Modelling Unit of SASS based at MLURI. The primary duties of the Unit are to provide a consultancy service to MLURI scientists and to develop a land use modelling programme.

The consultancy service is operated through a well-advertised open door policy, in which a member of staff is on duty each afternoon of the week. The four staff concerned each take responsibility for one of the major MLURI Division. This service is well used: in the 12 months to 31 October, 1993, advice was given to over 70 MLURI scientists and 16 students or visiting workers.

Consultancy work is often the first stage in building collaborative links with MLURI scientists. In the past year, existing collaborative links have been strengthened and new collaborations begun. Joint work on the analysis of stream chemistry data with staff from Soils Division has involved David Hirst (SASS RRI). Methodological work on estimating root densities non-destructively has been published. A new, four year, post funded by SOAFD has recently been established in association with Professor Buckland, University of St. Andrews, to build management models for red deer in Scotland. This post is linked to a MLURI project to study the effects of deer grazing on Scottish hill vegetation. Professor Buckland left SASS in September to take up the established Chair in Statistics at St. Andrews.

The Land Use Modelling programme has seen its first publication, covering statistical aspects of modelling wildlife distributions at different resolutions and an overview of statistical aspects of modelling with GIS data. The work on wildlife distributions has been extended to consider the long-term behaviour of populations, whilst methods of correcting estimated areas of land cover of misclassification have been reviewed and extended.

A quarter of the income of the Environmental Modelling Unit comes from external funding, mostly in the field of wildlife resource management. Much of this work involves modelling spatial data, both terrestrial and oceanographic, and this is a source of strong links with the Land Use Modelling programme. Internationally funded projects on subjects of wide public interest include estimating whale numbers in the Antarctic and modelling the change in abundance of dolphins in the tuna fishery grounds in the eastern tropical Pacific Ocean, whilst a project of more local interest is the estimation of mackerel populations in EC fishing grounds.

The picture shows members of SASS discussing the contribution of work by student Mark Lennon (4th from right) to collaborative projects with Jess Griffiths (MLURI, 4th left) and with Phil Bacon (ITE, 2nd left). Trevor Ringrose (Aberdeen University) is seated far left.

Institute Staff

1 January, 1994

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,
Lucy M Burnett
Carol A Smith (Environmental & Socio-Economics)

1. Land management systems

Project leader,
Alan R Sibbald

Research objective leaders,
Gordon Hudson, B.Sc., GAeostat. (ENSMP Dipl.)
Jacques-Eric Beargez, B.Sc, Agron. eng (ENSAR Dipl.), Ph.D.
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.
Andrew J I Dalziel, B.Sc.

Staff undertaking doctorate,
Allan Lilly, B.Sc., M.Sc.

Postgraduate student (Ph.D.),
Leonard Nwaigbo, University of Aberdeen

2. Remote sensing and Geographic Information Systems

Project leader,
Richard J Aspinall, B.Sc., Ph.D.

Research objective leaders,
Gary G Wright, B.Sc., M.R.S.Soc., M.I.C.D.Dipl.
David R Miller, B.Sc., Ph.D., RICS
Neil A Brooker, BA, M.Sc.

Other staff,
Jane G Morrice, MA
Paula L Horne, HNC
Diane Pearson, B.Sc., M.Sc.

Postgraduate students, (Ph.D.),
Robert MacFarlane, MA, M.Sc., University of Aberdeen
Charles H K Muchoki University of Aberdeen
Alessandro Gimono, B.Sc., M.Sc., University of Aberdeen
Rachel Bettis, B.Sc., Heriot-Watt University

Visiting worker
John Blakeway-Smith, B.Sc., M.Sc.

Postgraduate student, (M.Sc.),
Paul Finch, B.Sc.

3. Information technology methodologies

Alistair N R Law, MA, M.Sc., Ph.D., C.Phys., M.Inst.P.
Matthew G Wells, B.Sc., M.Sc., PhD.

Postgraduate student, (Ph.D.),
Chris Skelsey, University of Aberdeen

4. Environmental and Socio-Economics

Project leader,
J Robert Crabtree, B.Sc., M.Phil., Ph.D.

Research objective leaders,
Douglas C Macmillan, B.Sc., MS (USA)
Craig H Bullock, BA, M.Sc.

Other staff,
Neil Chalmers, B.Sc. (Consultant)
Helen L McHenry, B.Agr.Sc.
Alison Brown, LLB, B.Sc.

Staff undertaking doctorates,
Douglas C Macmillan, B.Sc., MS (USA)
Helen L McHenry, B.Agr.Sc.
Alison Brown, LLB, B.Sc.

Postgraduate students, (Ph.D.),
Rebecca Badger, B.Sc., M.Sc., University of Aberdeen
Mike Christie, B.Sc., University of Aberdeen

Staff who have left Land Use Division since last the Annual Report
Alex W Blyth, B.Sc., BA, M.I. Biol.
Helen R Edmond, B.Sc, M.Sc.
Christian T Garden
Daniel Rogers
Anna L Tyler, B.Sc., M.Sc.

Soils & Soil Microbiology Division

Head of Division,
M Jeffrey Wilson, B.Sc., Ph.D., D.Sc., FRSE

Divisional secretary,
Aileen Stewart

1. Acidification

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

Institute Staff

Research objective leaders,
Hamish A Anderson, B.Sc., Ph.D.
Derek C Bain, B.Sc., Ph.D.
Claire N Bedrock, B.Sc., Ph.D.
Martin V Cheshire, B.Sc., Ph.D.
Stephen J Chapman, B.Sc., Ph.D.
Robert C Ferrier, B.Sc., Ph.D.
Simon J Langan, B.Sc., Ph.D.
David G Lumsdon, B.Sc., Ph.D.
John D Miller, C.Chem., MRSC

Other staff,
Anthony R Fraser, LRSC
Donald M L Duthie, B.Sc
Alan Hepburn, C.Chem., MRSC
Moira Stewart, HNC
Sheila Gibbs
Ann Kelly, HNC
Angela Norrie
Patricia Cooper
Caroline M Thomson, HNC
Frank W Milne
Michael Thomson

Postgraduate students, (Ph.D.),
Saman Hettiarachichi, University of Aberdeen
Simon Peacock, B.Sc., M.Sc., University of Aberdeen
Kirsty MacPhee, University of Aberdeen

2. Pollution

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

Research objective leaders,
Martin V Cheshire, B.Sc., Ph.D.
Colin D Campbell, B.Sc., Ph.D.
Edward Paterson, B.Sc.
Jeffrey R Bacon, B.Sc., Ph.D.
David G Lumsdon, B.Sc., Ph.D.

Other staff,
David Jones, B.Sc., M.Sc., Ph.D., M.I. Biol., FRMS
Anthony R Fraser, LRSC
Mitchell S Davidson, HNC
Donald M L Duthie, B.Sc.
Alan Hepburn, C.Chem., MRSC
Irene J Hewitt, HNC
Raymond Swaffield, LRSC
Madeline Thurlow, B.Sc.
Angela Norrie
Caroline M Thomson
Kimberly A Wood, HNC
Clare M Cameron
Lynn M Clark, HNC

Postgraduate students (Ph.D.),
Jason Owen, B.Sc., University of Aberdeen
Rory Maguire, University of Aberdeen
Graeme Paton, University of Aberdeen
Diane Mitchell, University of Aberdeen

Staff who have left Soils & Soil Microbiology Division since the last Annual Report
Catherine Bryder, B.Sc.
Julie Robertson, B.Sc.

Plants Division

Head of Division,
Peter Millard, B.Sc., Ph.D.

Divisional secretary,
Iona M Shand

1. Nutrient assimilation and cycling

Research objective leaders,
David Jones, B.Sc., M.Sc., Ph.D., M.I.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,
Eileen FIsher
David Hamilton, B.Sc., PGD
Kenny Hood
Stuart M Allison, B.Sc., Ph.D.
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, M.Phil.
Shona Smith, LRSC
Yvonne E M Cook, HNC
Julie Sutherland
Miriam E Young, HNC
David W Nelson

Postgraduate student, (Ph.D.),
Loutfy Ibrahim, University of Aberdeen

Staff undertaking M.Phil. degree,
Shona Smith, LRSC

Staff undertaking doctorates
Eileen Fisher, University of Aberdeen
Charles Russell, University of Aberdeen

Staff who have left Plants Division since the last Annual Report
Stuart M Allison, B.Sc., Ph.D.
Alistair S Lings, B.Sc., M.Sc.

Animals & Grazing Ecology Division

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

Divisional secretary,
Margaret W Forsyth

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

Other staff
Jerry Laker, B.Sc., M.Sc.

1. Vegetation dynamics

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

Research objective leaders,
Colin P D Birch, BA, Ph.D.
Alison J Hester B.Sc., M.Sc., Ph.D.
Peter D Hulme, B.Sc., Ph.D.
David J Henderson, B.Sc.
Carol A Marriott, B.Sc.
Andrew J Nolan, B.Sc.

Other staff,
Gordon J Baillie, HNC
G Titus Barthram, B.Sc. (H)
David E Suckling, JP, 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,
Meng Xian Min, B.Sc., Changchun Institute of Geography, Chinese Academy of Sciences, The People's Republic of China

2. Herbivore foraging

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

Research objective leaders,
Richard H Armstrong, B.Sc. (Agric.) (H)
Alan J Duncan, B.Sc., M.Sc., Ph.D
Peter Dennis B.Sc., Ph.D.
Keith D Farnsworth, B.Sc., M.Sc.
Iain J Gordon, B.Sc., Ph.D.
Glenn R Iason, B.Sc., Ph.D.
Robert W Mayes, B.Sc., M.Sc., Ph.D.
Donald B McPhail, B.Sc.
Lucas Partridge, B.Sc.
Angela M Sibbald, MA

Other staff,
T Gordon Common, HNC (S)
Elaine Foreman
Grant C Davidson, B.Sc.
C Stuart Lamb, B.Sc. (Agric)
David A Sim, HNC
James L Small (S)
Alison J Smith, HNC (H)
Iain L Thomson
Patricia Wilson, B.Sc.
Sheila Young, HNC

Postgraduate students, (Ph.D.),
Jane Cooper, B.Sc., University of Aberdeen
Mariecia D Fraser, B.Sc., University of Edinburgh
John Hadjigeorgiou, B.Sc., University of Aberdeen/ Agricultural University of Athens
Iain Stevenson, B.Sc., University of Cambridge

Postgraduate student, (M.Phil.),
Anna Murray, B.Sc. University of Aberdeen

Visiting workers
Paloma Cuartas, M.Biol ed., Ph.D., Instituto Pirenaico de Ecologia (Yaca), Spain
Torstein Garmo, Ph.D., Agricultural University, As, Norway
Francisco Javier Giraldez Garcia, Ph.D., University of Leon, Spain
Dale Whittaker, Ph.D. Assistant Professor of Agricultural Engineering, Texas A&M University

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

Ruminant resource use
Iain A Wright, B.Sc., Ph.D.

Research objective leaders,
Jonathan A Beecham, BA
Pamela Dicks, B.Sc., Ph.D.
Peter J Goddard, B.Vet.Med., Ph.D., MRCVS
William J Hamilton, BA, NDA, NDD, C.Biol., M.Biol. (G)
Alison J Hanlon, B.Sc. M.Sc. (G)
Claire L Howard, B.Sc., Ph.D.
Michael S Lonergan, BA
Margaret Merchant, B.Sc., Ph.D.
Stewart M Rhind, B.Sc., Ph.D.
Angus J F Russel, B.Sc., M.Sc., Ph.D. (H)

Other staff,
Patricia M Colgrove, HND (H)
Brenda Copeland
A Robson Fawcett, AIMLS (G)
Alastair J Macdonald, SDA, NDA
Stuart R McMillen, HNC
Hilary L Redden, B.Sc.
David J Riach
Carol A Soanes, HND (G)
Audrey R Stephen
Thomas K Whyte, HNC, SDA

Postgraduate students, (Ph.D.),
Susan Borwick, B.Sc. (H), University of Aberdeen

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

Postgraduate student, (M.Sc.),
Aberash Wolansa, University of Aberdeen

Staff who have left Animals & Grazing Ecology Division since the last Annual Report
Helen Armstrong, B.Sc., Ph.D.
Sheila A Grant, B.Sc., M.Sc.

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
Alistair G Inglis, B.Sc.,
Lesley Sinclair
Alison M Stewart, HNC
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
Gordon Stott
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 Bradberry, B.Sc.
Susan M McIntyre, HNC
Corina Mavrodin
Gillian L Sim, B.Sc.
Arlene M Taylor, HNC
Anna Hendry
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
Jim Normington

Staff who have left Analytical Division since the last Annual Report
Martin S Davidson
Yvonne F Riach
Sheila A Young (transferred to Animals & Grazing Ecology Division)

Computing & Information Services Division

Head of Division,
Christopher H Osman, B.Sc., M.Sc., Ph.D., C.Phys., M.Inst.P.

Divisional secretary,
Carol A Smith

Geoffrey A Reaves, B.Sc., MBCS (network manager)
Lindsay Robertson, B.Sc. (database manager)
Alexander D Moir (spatial data manager)
Tony H Sunman (systems manager)
Jane D Haughey, B.Sc., M.Sc.
Susan MacLeay, B.Sc.
Ruth A Morrison
Ann M Teale
Jacqueline Thorpe

Resource Consultancy Unit

Head of Unit,
James H Gauld, B.Sc., Ph.D.

Unit secretary
Nicola G Paterson

Staff
John S Bell, B.Sc.
Frank T Dry, B.Sc. (H)
Andrew G Richman, B.Sc., M.Sc.
Margaret J Still, B.Sc., Ph.D.
Sarah Madden, B.Sc., M.Sc.
Ann Malcolm, B.Sc., DMS

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)
Jessie P Black (cleaner)

2. Red deer

Officer-in-charge,
William J Hamilton, BA, NDA, NDD, C.Biol., M.Biol.

Staff,
Duncan Murray

3. Animal house

Officer-in-charge,
A Robson Fawcett, AIMLS

Staff,
Stuart F Wright, B.Sc.
Craig A MacEachern
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
John B Ferguson

Administration Division

Institute Secretary,
Robert B Devine, DPA, MIM

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

Secretary's typist,
Joyce H Pirie

Personnel administration
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
Lucy M Burnett
Iona M Shand
Carol A Smith
Aileen Stewart
Susan King
Nicola G Paterson
Graham Thomson

Telephonist,
Roberta M Simpson

Stores,
Lynne Thomson

Library,
Anne H W Dickie, ALA, M.I.Inf.Sc.
Lorraine E Robertson, BA, ALA, 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
Ruth Penny

Cleaners,
Jacqueline Argo
Margaret Kindness
Jill Evans
Irene Hillcoat
Agnes M Rennie
Margaret A Walker

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

Institute Staff

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

Others,
James Robertson

Staff who have left Administration Division since the last Annual Report
Catherine Boyes
Fred Brand
Heather Cunningham
Christian T Garden
Elsie M Gardiner
Joyce McAllan
Kellie McKenna
Vilma Main
Patricia Robertson
Elizabeth M Strachan

SASS staff based at MLURI

Head,
David A Elston, BA, M.Sc., C.Stat. (acting head)

Other staff,
Gayathree Jayasinghe, Grad.IS, M.Sc.
Susan Ahmadi, B.Sc.
Verena M Trenkel, Dip.Biol., M.Sc.
Elizabeth I Duff, B.Sc.

Staff who have left SASS since the last Annual Report
Steve T Buckland, B.Sc., M.Sc., Ph.D.
Steve J Beaney, B.Sc.
David L Borchers, BA., B.Sc.
Karen L Cattanach, B.Sc., M.Sc.

Honorary Fellows

G Anderson, B.Sc., Ph.D.
Miss E J Dey, MBE
J Eadie, B.Sc.
P Newbould, B.Sc, B.Agr., D.Phil.
Miss E A Piggott, OBE
Mrs A F Stewart, MA
T S West, CBE, FRS
E G Williams, B.Sc., Ph.D.

Honorary Associates

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

(G) staff based at Glensaugh
(H) staff based at Hartwood
(S) staff based at Sourhope

Visiting Workers

Land Use Division

Dr A P Leone, Istituto per lo Studio dei Problemi, Agronomici dell'Irrigazione nel Mezzogiorno (ISPAIR), Via Capa Patacca 70, 80056 Ercolano (NA), Italy

John Blakeway-Smith, St Mary's College, London

Soils & Soil Microbiology Division

Carla Andrade, Instituto Politechnico de Castelo Branco, Portugal

Mats Åstrom, Åbu Agricultural University, Finland

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

Christophe Courousse, Ecole Superieure d'Agriculture, Angers, France

Stanislaw Dudka, Environment Research Programme, Trent University, Ontario, Canada

Ekaterinar Filcheva, Poushkarov Institute for Soil Science, Sofia, Bulgaria

Friedrich Graner, University of Kiel, Germany

Zhenli He, Zhejiang Agricultural University, Hangzhou, The People's Republic of China

Ken-ichi Kanda, National Institute of Agro-Environmental Sciences, Tsukuba, Japan

Benoit Pelle, Ecole Superieure d'Agriculture, Angers, France

Paula Piatti, Facultá di Agraria, Universitá di Torino, Italy

Edeltrauda Helios-Rybicka, University of Mining and Metallurqy Kraków, Poland

Milan Sanka, Institute for Nature Protection, Brno, Czech Republic

Marianna Steegstra, Landlouivuniversiteit, Wageningen, The Netherlands

Haruo Tsuruta, National Institute of Agro-Environmental Sciences, Tsukuba, Japan

Plants Division

Dr Sveinn Adalsteinsson, The Swedish University of Agricultural Sciences, Department of Horticulture, Alnarp, Sweden

Dr Anna Gancheva, Nikola Poushkarov Institute of Soil Science and Yield Programming, Bulgaria

Pierre Laviolette, Department Forestier, UCL Eaur et Forets, Louvain-La-Neuve, Belgium

Professor Meng Xian Min, Changchun Institute of Geography, Chinese Academy of Sciences, The People's Republic of China

Thomas Undabeytia, Instituto de Recursos Naturales y Agrobiologica de Sevilla, Spain

Miguel Vidal, Department of Chemistry, University of Barcelona, Spain

Dirk Wessels, Department of Botany, University of the North, Sovenga, South Africa

Animals & Grazing Ecology Division

Dr J Alfonso Abecia Martinez, University of Zaragosa, Spain

Mrs Ana Teresa Belo, Estacio Zootecnia, Nactional, Santerem, Portugal

Dr Paloma Cuartas, Instituto Pirenaico de Ecologia (Yaca), Spain

Dr Torstein Garmo, Agricultural University, As, Norway

Dr Javier Giraldez Garcia, University of Leon, Spain

Miss Isabella Lemaitre, Ecole Superiere d'Agriculture, Angers, France

Miss Teresa C Magro, Universidade de Sao Paulo, Brazil

Professor Meng Xian Min, Changchun Institute of Geography, Chinese Academy of Sciences, The People's Republic of China

Dr Masahiko Okubo, Hokkaido University, Japan

Dr Dale Whittaker, Texas A&M University, USA

Postgraduate Research Students

(with University and Funding source)

current workers, December 1993 are shown thus*

Land Use Division

PhD

- * Rebecca Badger, University of Aberdeen, MAFF CASE Studentship
- * Rachel Bettis, Heriot-Watt University, MLURI
- * Mike Christie, University of Aberdeen, Aberdeen Research Consortium
- * Alessandro Gimona, University of Aberdeen, MLURI
- * Rob MacFarlane, University of Aberdeen, ESRC
- * Charles Muchoki, University of Aberdeen, Rockefeller Foundation
- * Leonard Nwaigbo, University of Aberdeen, Commonwealth Scholarship
- * Chris Skelsey, University of Aberdeen, Aberdeen Research Consortium

MSc

- John Blakeway-Smith, University of Aberdeen, Local Authority
- * Paul Finch, University of Dundee, EU Social Fund
- Anna Tyler, University of Aberdeen, Scottish Forestry Trust

Soils & Soil Microbiology Division

PhD

- * Saman Hettiarachchi, University of Aberdeen, Sri Lankan Government
- * Kirsty MacPhee, University of Aberdeen, DOE
- * Rory Maguire, University of Aberdeen, EC
- * Diane Mitchell, University of Aberdeen, SNIFFER
- * Jason Owen, University of Aberdeen, Thomas Tait Studentship
- * Graeme Paton, University of Aberdeen, Aberdeen Research Consortium
- * Simon Peacock, University of Aberdeen, EEC
- * Maureen Young, Robert Gordon University

MSc

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

Plants Division

PhD

- Peter Anderson, University of Strathclyde, SERC, CASE
- * Eileen Fisher, University of Aberdeen, EC
- James Green, University of Stirling, NERC
- * Loutfy Ibrahim, University of Aberdeen, Self-financed
- Alex MacDonald, University of Aberdeen, Self-financed
- Zakia Parveen, University of Aberdeen, Commonwealth Commission
- * Charles Russell, University of Aberdeen, AFRC
- Lola Ron Vaz, University of Aberdeen, Spanish Government

MPhil

- Denise Donald, University of Aberdeen, MLURI
- * Shona Smith, University of Aberdeen, MLURI

MSc

- Martin Hall, University of Aberdeen, EC Social Fund
- Kevin Larmer, University of Aberdeen, ESF
- Hari K Pant, University of Aberdeen, ODA

Animals & Grazing Ecology Division

PhD

- Luis Pinto de Andrade, University of Edinburgh, Portuguese Government/JNICT
- * Susan Borwick, University of Aberdeen, SERC CASE Studentship
- * Amanda Cook, University of Aberdeen, MLURI
- * Jane Cooper, University of Aberdeen, Aberdeen Research Consortium
- * Mariecia D Fraser, University of Edinburgh, SOAFD
- * John Hadjigeorgiou, University of Aberdeen, Greek Government
- Ian Hulbert, University of Aberdeen, NERC
- * Manuel del Pozo Ramos, University of Edinburgh, INIA, Spain/British Council
- * Iain Stevenson, University of Cambridge, SERC
- * Fiona Stewart, University of Aberdeen, NERC CASE Studentship

MPhil

- * Anna Murray, University of Aberdeen, SOAFD

MSc

- * Aberash Wolansa, University of Aberdeen, World Bank/Ethiopian Government

Staff Visits Abroad

(funded by SOAFD unless stated otherwise)

Director's Group

Professor T J Maxwell. XVII International Grassland Congress, New Zealand and Australia (Massey University, Palmerston North, NZ; Waikato University, Hamilton, NZ; Lincoln University, Christchurch, NZ and Rockhampton, Australia), 5-26 February 1993.

Professor T J Maxwell. DLO-Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, The Netherlands, 14-15 June 1993.

Land Use Division

R J Aspinall. Association of American Geographers Annual Conference, Atlanta, Georgia, USA, April 1993

R J Aspinall. Environmental Information Management and Analysis Seminar. National Science Foundation, Albuquerque, New Mexico, USA May 1993 (part funded by NSF)

R J Aspinall. Department of Biology, University of New Mexico, USA, May 1993 (self funded)

R J Aspinall. Sevillieta Long Term Ecological Research Station, New Mexico, May 1993

R J Aspinall. Khoros Group, University of New Mexico, USA, May 1993 (self funded)

R J Aspinall. Santa Fe Institute, Santa Fe, New Mexico, USA, May 1993 (self funded)

R J Aspinall. Second International Conference/Workshop on Integrating GIS with Environmental Modelling, NCGIA, Breckenridge, Colorado, USA, September 1993

R J Aspinall. GIS/LIS Conference, Minneapolis, USA, November 1993

R J Aspinall. Natural Resources Institute, Duluth, Minnesota, USA, November 1993 (self funded)

R J Aspinall. CSIRO Division of Tropical Crops and Pastures, Brisbane, Australia. Joint MLURI-CSIRO workshops, 8-17 November 1993 (MLURI Trust funded)

R J Aspinall. CSIRO Division of Wildlife and Ecology, Canberra, Australia, November 1993 (MLURI Trust funded)

R J Aspinall. Australian Urban and Regional Information Systems Association (AURISA) Annual Conference, Adelaide, Australia, 22-26 November 1993 (MLURI funded)

R J Aspinall. Department of Geography, Australian National University, Australia, 28 November - 3 December 1993 (ANU and self funded)

R J Aspinall. Centre for Resource and Environmental Studies, Australian National University, Australia, December 1993 (ANU and self funded)

R J Aspinall. Environmental Resources Information Network, ACT, Australia, December 1993 (ANU and self funded)

R J Aspinall. CSIRO Division of Water Resources, Canberra, Australia, December 1993 (ANU and self funded)

R J Aspinall. Natural Resources Information Centre, ACT, Australia (ANU and self funded)

R J Aspinall. Edith and Joy London Foundation, New South Wales, Australia (ANU and self funded)

R J Aspinall. National Avian Research Centre, Abu Dhabi, United Arab Emirates, December 1993 (self funded)

R V Birnie. Norway Study Tour (organised by Reforesting Scotland) 8-16 May, 1993

R V Birnie. CSIRO Division of Tropical Crops and Pastures, Brisbane, Australia. Joint MLURI-CSIRO Workshops. 8-17 November 1993 (MLURI Trust funded)

R V Birnie. CSIRO Division of Wildlife and Ecology, Canberra, Australia 18 November, 1993 (MLURI Trust funded)

R V Birnie. Department of Geography, University of Canterbury, New Zealand 22-23 November, 1993 (MLURI Trust funded)

R V Birnie. Landcare Research, Lincoln, New Zealand, 24 November, 1993 (MLURI Trust funded)

R V Birnie. Rural Resources Unit, MAF Policy, Wellington, New Zealand, 25-26 November, 1993 (MLURI Trust funded)

N A Brooker. ESRI 13th Annual Users Conference, Palm Springs, California, USA, (SOEnD funded)

J H Gauld. Conference on the Future of the Land, Wageningen, The Netherlands

G Hudson. Workshop on Geostatistical Simulation, Centre de Geostatistique, Fontainebleau, France, 28-29 May 1993

G Hudson. Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, The Netherlands, 25-26 November 1993

G Hudson. International Soil Reference and Information Centre, Wageningen, The Netherlands, 24 November 1993

N J Hutchings. Research Centre, Foulum, Denmark. Sabbatical, August 1992 - August 1993

N J Hutchings. Lecture at CHEAM, Saragossa, Spain, 26-27 April 1993

N J Hutchings. Pasture Ecology Meeting, Wageningen, The Netherlands, 28-29 April 1993

N J Hutchings. CEC, Brussels and various research Institutes in Holland, 30 April - 7 May 1993

A Lilly. International Soil Reference and Information Centre, Wageningen, The Netherlands, 24 November 1993

A Lilly. Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, The Netherlands, 25-26 November 1993

D R Miller. Centro National Informacão Geografica, Lisbon, Portugal (British Council funded)

D R Miller. Reserche, Genova, Genoa, GIS and Land Resource Research (self funded)

D R Miller. EGIS '93, Genoa, Italy

D R Miller. Joint Research Centre, Ispra, Italy (self funded)

D R Miller. GSF, Munich, Germany (self funded)

D R Miller. NSF, Long Term Ecological Research Site, Sevillieta, New Mexico, USA (self funded)

D R Miller. Botany Department and Khoros Development Group, University of New Mexico, Albuquerque, USA

D R Miller. Santa Fe Institute, Santa Fe, New Mexico, USA

D R Miller. Erdas Inc, Atlanta, Georgia, USA (self funded)

D R Miller. Association of American Geographers, Atlanta, Georgia, USA

D R Miller. Environmental Information Management and GIS Ecosystem to Global Scale, Albuquerque, New Mexico, USA (part funded by NSF)

Staff Visits Abroad

D R Miller. NCGIA, 2nd International Conference on Environmental, Modelling and GIS, Breckenridge, Colorado, USA

D R Miller. National Center for Atmospheric Research, Boulder, Colorado, USA (self funded)

D Pearson. NCGIA, 2nd International Conference on Environmental, Modelling and GIS, Breckenridge, Colorado, USA

D Pearson. National Center for Atmospheric Resesarch, Boulder, Colorado, USA

A R Sibbald. INRA Laboratoire de Recherches Forestières Mediterranéennes, Avignon, France. First International Meeting of EC Project Participants, 11-15 January 1993

A R Sibbald. 4th International Symposium, Windbreaks and Agroforestry, Viborg, Denmark, 26-30 July 1993

A R Sibbald. 44th Annual Meeting of the European Association of Animal Production, Aarhus, Denmark, 16-18 August 1993

A R Sibbald. Workshop on modelling grazing systems and a decision support system, CSIRO Division of Tropical Crops and Pastures, Brisbane, Australia, 8-17 November 1993

Soils & Soil Microbiology Division

J R Bacon. BCR, Brussels, Belgium. Discussion of contract work, 22-25 February 1993 (EC funded)

J R Bacon. 3rd Soil and Soil Contaminant Workshop, Winnipeg, Canada, 8-12 August 1993

J R Bacon. 9th International Conference on Heavy Metals in the Environment, Toronto, Canada, 12-16 August 1993

D C Bain. 10th International Clay Conference, Adelaide, Australia, 16 - 29 July 1993 (part funded by the Mineralogical Society)

S J Chapman. National Institute of Agro-Environmental Sciences, Tsukuba, Japan. 30 July - 3 September 1993 (Royal Society funded)

S J Chapman. XI International Symposium on Environmental Geochemistry, Salamanca, Spain, 26 September - 2 October

M V Cheshire. Danish Institute of Plant and Soil Science, Foulum, Denmark, 1 August 1993 (EC funded)

M V Cheshire. EC Commission DG6, Brussels, Belgium, 1 October 1993 (EC funded)

R C Ferrier. Modelling workshop, NIVA, Oslo, Norway, 22 June - 1 July 1993

R C Ferrier. Workshop on MAGIC model, Captiva, Florida, USA, 8-17 January 1993

R C Ferrier. Workshop on Solling experiment, Leusden, The Netherlands, 8-14 May 1993

S J Langan. University of Lund, Sweden, 11 - 15 October 1993 (DOE funded)

M Thurlow. National Institute of Agro Environmental Sciences, Tsukuba, Japan, 18 January - 6 March (Japanese Government funded)

M J Wilson. NIAES, Tsukuba, Japan. Discussion of NIAES/MLURI collaboration, presentation of seminar, 1-7 March 1993 (Japanese Government funded)

M J Wilson. Institute of Soil Science and Plant Cultivation (IUNG) Pulawy, Poland - Discussion of IUNG/MLURI collaboration, presentation of seminars. 15-20 March 1993 (British Council funded)

M J Wilson. Eurolat Summer School, Orleans, France, 1 - 2 July 1993 (Eurolat funded)

M J Wilson. 10th International Clay Conference, Adelaide, Australia, 16-29 July 1993

Plants Division

A C Edwards. Braunschweig Institute, Germany, May 1993 (part funded by IMPHOS)

A C Edwards. Institute fur Bodenkunde, Freising, Germany, January 1993 (EC funded)

C A Marriott. Pasture Ecology Group Workshop, Wageningen, The Netherlands, 26-30 April 1993

C A Marriott. White Clover Meeting of the FAO sub-network on Lowland Pastures and Fodder Crops, Aarhus, Denmark, August 1993

P Millard. Department of Forestry, University of Tuscia, Viterbo, Italy, May 1993 (EC funded)

P Millard. 2nd International Symposium on Diagnosis of Nutritional Status of Deciduous Fruit Orchards, Trento, Italy, September 1993 (funded by Conference Organisers)

M F Proe. IEA Workshop, New Brunswick, Canada, May 1993 (ETSU funded)

M F Proe. CEC/IUFRO Symposium, Sweden, June 1993 (ETSU funded)

R Wendler. STEP Programme, University of Bayreuth, Germany, June 1993, July 1993, August 1993 (EC funded)

R Wendler. Instituto Superior de Agronomia, Lisbon, Portugal, November 1992 - April 1993 (EC funded)

B L Williams. NATO Advances Workshop on Biodiversity, Temperate Ecosystems and Global Change, Chateau Montebello, Quebec, Canada, August 1993 (NATO/Forestry Canada funded)

Animals & Grazing Ecology Division

R H Armstrong. Agricultural universities of Warsaw, Poznan, Wroclaw and Lublin, Poland to give seminars and discuss research on grassland management, 27 September - 5 October 1993 (British Council funded)

R H Armstrong. XVII International Grasslands Congress, Palmerston North, New Zealand, 8-20 February 1993

G T Barthram. Pasture Ecology Group Workshop, Wageningen, The Netherlands, 26-30 April 1993 (EC funded)

P Dicks. EC Workshop on seasonal biology of fine fibre-producing animals, INRA, Toulouse, France, 13-14 December 1993 (EC funded)

A J Duncan. Unite de 'Ecologie et de Physiologie du Systeme Digestif, INRA, Jouy-en-Josas, France, 10 June - 15 December 1993 (AFRC fellowship)

K D Farnsworth. Workshop on modelling of grazing systems and of decision support systems, CSIRO Division of Tropical Crops and Pastures, Brisbane, Australia, 8-17 November 1993

Staff Visits Abroad

P J Goddard. National Veterinary Institute, University of Uppsala, Sweden, to assess use of MLURI automatic blood sampling equipment for reindeer, 1-5 December 1993 (University of Uppsala funded)

I J Gordon. XVIIth International Grasslands Congress, Palmerston North, New Zealand, 8-20 February 1993 (Congress funded)

I J Gordon. VIIth World Conference on Animal Production, Ontario, Canada, 28 June - 2 July 1993 (Conference funded)

A J Hanlon. International Congress on Applied Ethology, Berlin, Germany, 26-30 July 1993

C L Howard. Coordination meeting of EC project on mixed grazing, INRA, Montpellier and Salon de Provence, 7-10 June 1993 (EC funded)

G R Iason. Department of Animal Science and Department of Plant Science, Massey University, New Zealand, 15 January - 30 March 1993 (British Council and Royal Society funded)

J Laker. EC Workshop on seasonal biology of fine-fibre producing animals, INRA, Toulouse, France, 13-14 December 1993 (EC funded)

M J Lonergan. Co-ordination meeting of EC project on sheep and goat cheese production, Institute per la Zootecnica, Potenza, Italy, 9-10 December (EC funded)

R W Mayes. Chernobyl, Ukraine, to set up collaborative experiments with Ukranian Scientists, 26-30 April 1993 (EC funded)

R W Mayes. CSIRO Division of Plant Industry, Canberra, Australia to co-lead work on the use of n-alkane techniques, 10-21 October 1993 (Australian Meat Research Cooperation funded)

R W Mayes. Meeting on radionuclides, University of Athens, Greece 12-15 November 1993 (EC funded)

M Merchant. EC Workshop on seasonal biology of fine fibre-producing animals, INRA, Toulouse, France, 13-14 December 1993 (EC funded)

J A Milne. Department of Veterinary Science, University of Madrid, 4-6 May 1993, to deliver paper on sustainability of animal production (University of Madrid funded)

J A Milne. DNLO, Wageningen, The Netherlands, to discuss collaborative research, 14-16 June 1993.

J A Milne. Workshop on modelling grazing systems and a decision support system, CSIRO Division of Tropical Crops and Pastures, Brisbane, Australia, 8-17 November 1993.

S M Rhind. Instituto Politecnica de Castelo Branco, Portugal, 1-7 December (British Council funded)

S M Rhind. EC Workshop on seasonal biology of fine fibre-producing animals, INRA Toulouse, France, 13-14 December 1993 (EC funded)

A J F Russel. Visit to China (Liaoning Province and Inner Mongolia) under auspices of UK-China Governments Memorandum of Understanding to study cashmere production, 27 March - 11 April 1993 (MAFF funded)

A J F Russel. Agricultural University of Norway - Seminars on Cashmere Production and Ultrasonic Diagnosis of Pregnancy in Small Ruminants, 28 August - September 1993 (Agricultural University of Norway funded)

A J F Russel. German Wool Research Institute, Aachen, Germany, 28-29 September 1993 (EC funded)

A J F Russel. European Symposium on South American camelids, University of Bonn, Germany, 30 September - 30 October 1993

A J F Russel. Bulgarian Ministry of Agriculture, Institute of Animal Science, Sofia, Institute of Upland Stock-breeding, Troyan, Bulgaria, 14-20 October 1993 (Cashmere Breeders Ltd. funded)

A J F Russel. EC Workshop on seasonal biology of fine fibre-producing animals, INRA, Toulouse, France, 13-14 December (EC funded)

I A Wright. Co-ordination meeting of EC project on sheep and goat cheese production, CSIC, Leon, Spain, 1-5 March 1993 (EC funded)

I A Wright. Co-ordination meeting of EC project on mixed grazing, INRA, Montpellier, France, 7-10 June 1993 (EC funded)

I A Wright. Workshop on modelling of grazing systems and on decision support systems, CSIRO, Brisbane, Australia, 8-17 November.

I A Wright. Ruakura Research Centre, Massey University and Lincoln University, New Zealand, 18-26 November

I A Wright. Politecnica de Castelo Branco, Portugal, 1-7 December (British Council funded)

I A Wright. Co-ordination meeting of EC project on sheep and goat cheese, Instituto per la Zootecnica, Potenza, Italy, 9-10 December (EC funded)

Analytical Division

A J Midwood. International Symposium on Applications of Isotope Techniques in Studying Past and Current Environmental Changes in the Hydrosphere and the Atmosphere, Vienna, Austria, 19-23 April 1993

Programme of Research

January 1993 to December 1993

Research projects in Programme Units 11 - 16 are funded by SOAFD

PROGRAMME UNIT 11

Land use options and impacts on natural resources

Research projects completed since December 1992

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

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

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

Current research projects

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)

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 (K B Matthews)

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)

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 Fund]

011281 Assessment of tourist attitudes to landscape amenity value in Scotland (R V Birnie)

011342 Environmental and socio-economic implication of low input upland sheep systems(A R Sibbald)

11343 Data architectural development (R V Birnie)

011354 Developing and testing methods for detecting changes in land cover types and configuration using satellite remote sensing (R V Birnie)

011355 Automated detection of land cover change in Scotland (A N R Law)

PROGRAMME UNIT 12

Soil and the environment

Research projects completed since December 1992

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

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

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 Fund]

Current research projects

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

012166 Quantify the principal hydrological and hydro-chemical 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 (DG Lumsdon)

012171 Mineral weathering in relation to the vulnerability of catchments to acidification in Southern Scotland (DC 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)

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

012328 Long term effects of sewage sludge application to agricultural land on crop yields and soil microbiological activity (J R Bacon)

012329 The occurrence, mobility and persistence of organic pollutants in soils (A Smith)

PROGRAMME UNIT 13
Plant-soil relations

Research projects completed since December 1992

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

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)

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

Current research projects

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

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

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)

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)

013322 Root growth and below ground competition between grasses in relation to nutrient availability and grazing (L A Dawson)

013323 Comparison of the phosphorus cycle in natural and managed ecosystems (A C Edwards)

013336 The effect of rhizosphere carbon flow on microbial diversity and activity (S J Grayston)

013344 Carbon partitioning: rhizosphere carbon flow regulation of soil microbial activity and diversity in relation to mycorrhizal partitioning and nutrient transfers (P Millard) [SOAFD Flexible Fund]

PROGRAMME UNIT 14
Plant-animal relations

Research projects completed since December 1992

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

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

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

Current research projects

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

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)

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 (I J Gordon)

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)

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)

014223 Measurement of energy expenditure in grazing sheep (R W Mayes)

014284 Development of computer models to predict the effects of grazing by herbivores on plant community composition and dynamics (C P D Birch)

014285 Effect of grazing on the competitive ability of tussock and prostrate species (A J Hester)

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 (P Dennis) [SOAFD Flexible Fund]

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

014324 Effects of sheep and red deer grazing on the vegetation dynamics of grass/heather mosaics (A J Hester)

014325 Effects of changes in sheep grazing intensity on competitive interactions with rabbit populations and on plant community dynamics (G R Iason)

014332 Impact of variability in the capacity of large herbivores to degrade plant secondary compounds on their foraging behaviour (A J Duncan)

014333 Environmental Change Network: measure long term environmental changes in soils, vegetation and wildlife populations at two upland agricultural sites in Scotland (D J Henderson)

014335 Host/parasite interactions in a herbivore-grazing ecosystem: the behavioural control of helminth infection by sheep (I J Gordon)

014347 Development of a decision support system for managing the impact of red deer on vegetation dynamics and habitat density (I J Gordon) [SOAFD Flexible Fund]

PROGRAMME UNIT 15

Ruminant resource use

Research projects completed since December 1992

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

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

Current research projects

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

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

015227 The complementarity of sheep and cattle grazing indigenous hill vegetation (C L Howard)

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 (N J Hutchings)

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)

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

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 (J A Beecham) [SOAFD Flexible Fund]

015326 Sequential and mixed grazing of grass/clover swards by sheep and cattle (I A Wright)

015334 Development of automatic blood samplers (P J Goddard)

015352 The welfare of deer during transport and slaughter (P J Goddard) [SOAFD Flexible Fund]

PROGRAMME UNIT 16

Land use options and impact: environmental and socio-economics

Research projects completed since December 1992

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]

Current research projects

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 (H L McHenry) [non-commissioned research]

016337 Agricultural policy impacts on socio-economic and environmental sustainability in sensitive rural areas (J R Crabtree)

016338 Measuring the public benefits of environment and landscape change arising from agri-environmental policy measures (C H Bullock)

PROGRAMME UNIT 09

External contracts with source of funding

Land Use Division / Resource Consultancy Unit

Contracts completed since December 1992

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

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]

090321 Agroforestry potential in community forests (A R Sibbald) [Countryside Commission]

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

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

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 (DC Macmillan) [Forestry Commission]

Current contracts

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 (RCU)) [SOAFD]

090269 Commercial contracts [miscellaneous] [J H Gauld (RCU)]

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

090307 Alternative agricultural land use with fast-growing trees (A R Sibbald) [EC]

090316 Data leasing (C H Osman)

090320 Commercial contracts [Miscellaneous] (J R Crabtree)

090351 Feasibility study of a systems approach to modelling agriculture and land use in Scotland (A R Sibbald)

090356 Production and sale of MLURI land cover reports (R V Birnie)

090357 The evaluation of alternative policy measures for the protection of inland waters from agricultural pollution in the market economy and an appraisal of their application in the UK and Poland (J R Crabtree/ H Manteuffel) [EC Research Fellowship]

090360 Development of a GIS-based screening procedure for assessing the potential effects of climate change on Scottish agriculture (R V Birnie) [MLURI]

Soils and Soil Microbiology Division

Contracts completed since December 1992

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]

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

090340 Toxic metals in polluted soils using a range of analytical techniques and procedures (M J Wilson) [EC]

090345 Effects of spatial variation and harvesting technique on the chemical composition of peat and the consequences for potential self-heating (C D Campbell) [Fisons Plc]

090350 Heavy metal pollution through wastes disposal, sewage sludges and industrial emissions in the aquatic environment and soils; clay minerals as the protecting barriers (M J Wilson/E Helios-Rybicka) [EC PECO]

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

090341 Organic matter in soil forming processes (M V Cheshire) [EC]

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 [miscellaneous] Clay mineral analysis of soils and rocks (D M L Duthie)

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

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

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]

090314 Monitoring at Halladale (J D Miller) [Forestry Authority]

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

090317 MLURI/Eastern Europe (M J Wilson) [SARIC]

Plants Division

Contracts completed since December 1992

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

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

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

Current contracts

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

090270 Commercial contracts [miscellaneous]

090308 Influence of N deposition on the C balance in peatland ecosystems (B L Williams) [EC]

090353 Biogeochemical cycling in agriforestry systems network (BAFNET) (A C Edwards) [EC]

Animals and Grazing Ecology Division

Contracts completed since December 1992

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

090313 The aversion threshold for the ingestion of Bitrex by red deer and roe deer (I A Wright) [MacFarlan Smith]

090330 Software development of the hill grazing management model of sheep on hill systems in the UK (J A Milne) [English Nature]

090358 Research and technological development in the field of nuclear security with the USSR (R W Mayes) [NERC]

Current contracts

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

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

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

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 L Howard) [EEC]

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 [miscellaneous] (J A Milne)

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]

090305 Co-ordination of research activities in the development of animal fibre production systems (J A Milne) [EC]

090306 Production of high quality cheese from extensive systems of sheep and goat production in less favoured areas (I A Wright) [EC]

090315 Shetland oil spill (J A Milne) [SOAFD]

090318 Rannoch Moor grazing experiment (J A Milne) [SNH]

090319 Selection of goats with enhanced immunity to gastro-intestinal nematode infection (A J F Russel) [Moredun Research Institute]

090348 Ben Lawers grazings - baseline survey (A J Hester) [NTS]

090331 The influence of vegetation pattern in diet selection by sheep and red deer (I J Gordon) [EC]

Analytical Division

Current contracts

090272 Commercial contracts (miscellaneous) (A Smith)

Staff Publications

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Financial Statement

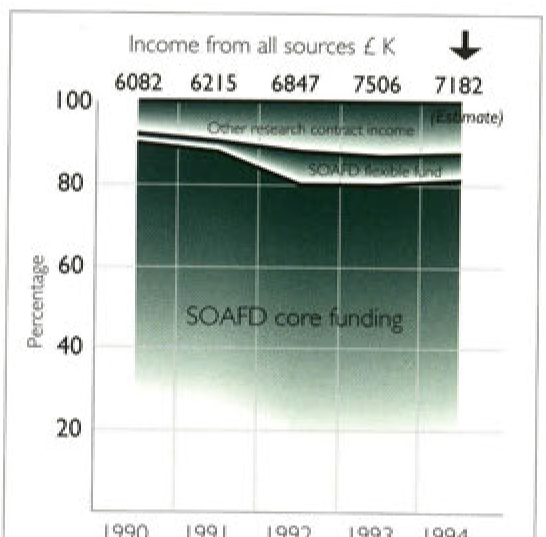
Annual financial statement for the year ending 31 March, 1993

Income	£K
Scottish Office Agriculture and Fisheries Department (SOAFD)	6,064
SOAFD Flexible Research Funding and other SOAFD contracts	560
European Union research contracts	387
Funding from other Government Departments, Public Bodies and Agencies	202
Private research and consultancy contracts	147
Other income	213
less funds held for future work	67
Equipment purchased from revenue grants	135
Total income	7,371

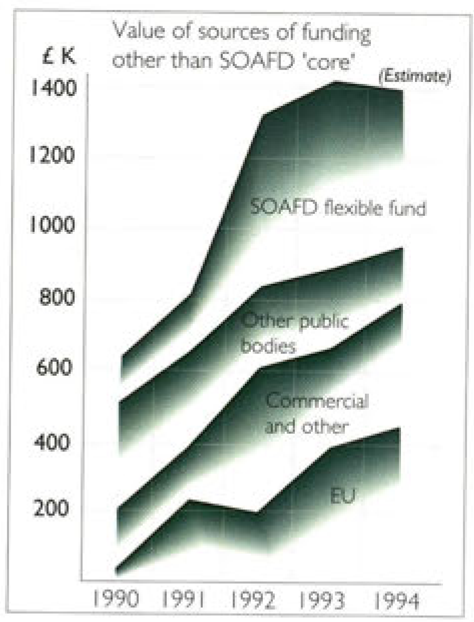
Expenditure	£K
Staff costs	4,505
Research expenditure including Research Station costs	1150
Other operating costs	1,465
	7,120
Surplus (Deficit)	251

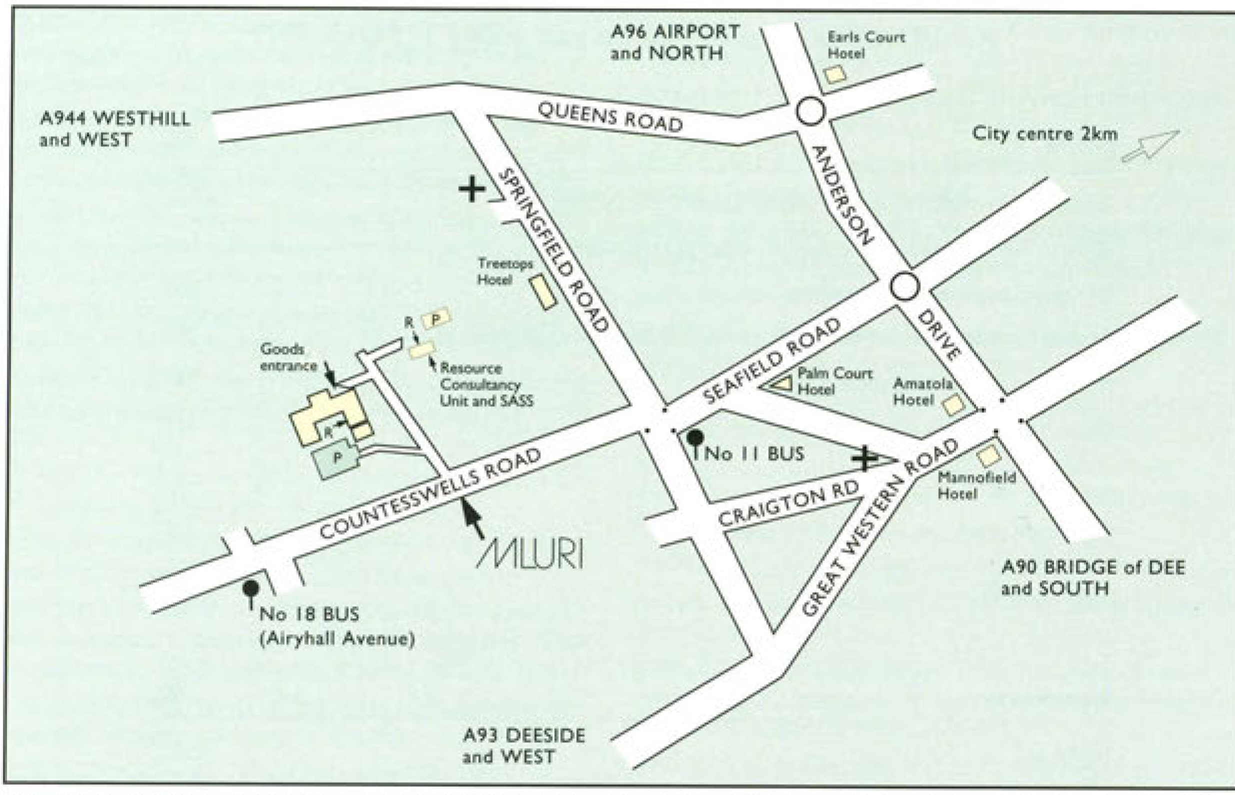
The capital funds received from SOAFD totalled £1,201,844 of which £790,935 was for capital works; £416,775 was received from the Trustees of the Macaulay Endowment.

During the year the turnover of the Resource Consultancy Unit was £185,088

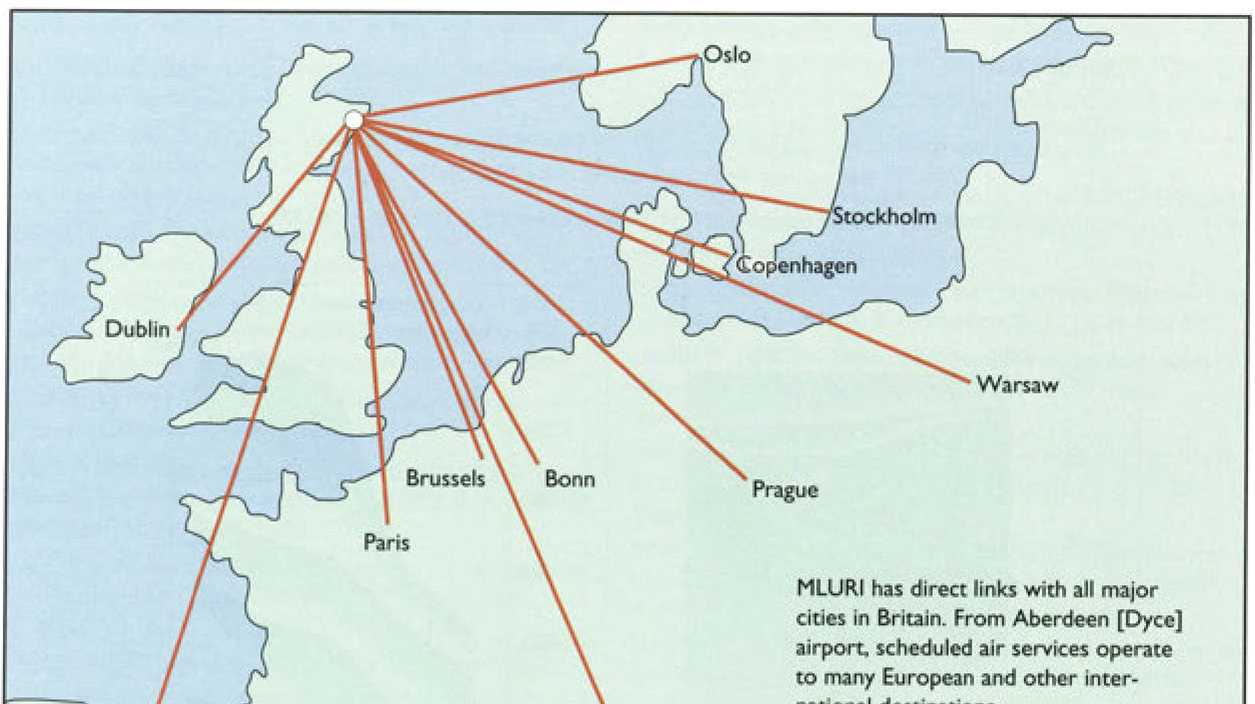


Actual and estimated sources of funding (1990-1994)





MLURI is on the east coast of Scotland on the western outskirts of Aberdeen. It is well served by direct British Rail *Intercity* and *Scotrail* links. By road from the south the A90 runs directly from the motorway network at Perth. From the North follow the A96 from Inverness.



MLURI has direct links with all major cities in Britain. From Aberdeen [Dyce] airport, scheduled air services operate to many European and other international destinations.