MLURI

THE MACAULAY LAND USE RESEARCH INSTITUTE

ANNUAL 1994 REPORT

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Craigiebuckler Aberdeen

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Director's Introduction

In September 1994, the Institute was subject to a four-yearly peer group review of its research. This was carried out under the auspices of the Biotechnology and Biological Sciences Research Council. The ensuing report was a great credit to the staff of the Institute. Following the peer group's critical evaluation of on-going research, and an appraisal of our future plans, the group gave its support to our proposals and commended us on our achievements. A period of consolidation, broadening of our funding base, and a continued development of new national and international collaborative opportunities are our immediate priorities.

During the year, the Institute has developed its international status by undertaking collaborative projects with colleagues in China, the Czech Republic, Poland, Australia, Argentina and the USA, as well as with colleagues in laboratories and universities representative of most of the countries in the European Union. This activity is found to be both intellectually stimulating and financially rewarding. Locally, the Institute has continued to collaborate with the University of Aberdeen, the Robert Gordon University, the Scottish Agricultural College, the Institute of Terrestrial Ecology (Banchory), the Rowett Research Institute, the Fisheries Research Station, the Torry Laboratory, and the North Eastern River Purification Board in the development of the Aberdeen Research Consortium, and with Grampian Enterprise the establishment of a European Environment Institute. All of these activities have resulted in a greater local integration of our activities and resources, short and extended visits of scientists from abroad to the Institute, and a growing number of postgraduates working in the Institute.

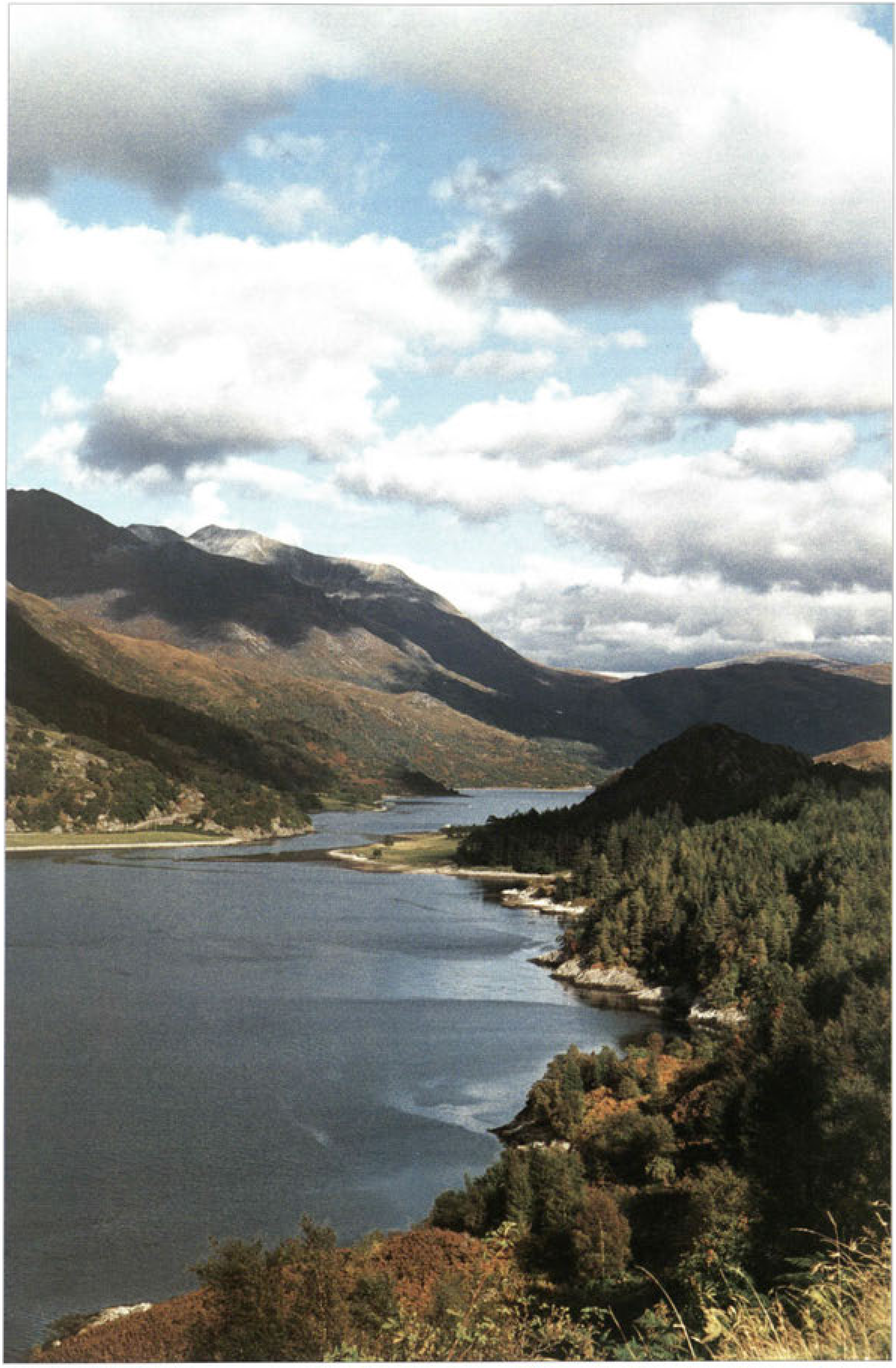
The Institute has also progressed its thinking as to how land use science and the applications arising from research can be used most effectively to contribute to the resolution of those issues which affect the use and management of land, the care of the environment, and the continued development of rural communities. The construction of models and the creation of decision support tools are integral components of our programme, and are being designed specifically to aid land managers and policy advisers to examine a range of land use options with respect to economic viability, their impact on the landscape, wildlife habitats and diversity, and soil and water quality.

A significant proportion of our research activity is currently focused on the impact of land use and land management within river catchments on water quality. The article on 'Integrated Catchment Management' (page 2) explores a definition of integrated catchment management and the implications for scientific research at this scale. The role of hydrological, hydrochemical and socio-economic modelling techniques in the study of catchments within the Institute is explained. Agricultural development in the remoter upland areas of Europe depends primarily upon finding new livestock options as alternatives to beef and sheep production. The production of 'Quality Animal Fibre' as an alternative is outlined in the article on page 6. The research and application of our findings with regard to the production of cashmere from goats, fine wool from Merino x Shetland sheep, and fibre from Camelids is explained and evaluated. The broad scope of our research is described within the project structure of our overall programme on pages 12 to 31. Recent results and achievements are given, and an indication of the relevance of this information to potential users is provided.

The need to transfer knowledge and the products of research to the user community was a key element of the Government's White Paper on a Strategy for Science, Engineering, and Technology, 'Realising our Potential', published in May 1993. The Institute's response has been to set up a new company, Macaulay Research and Consultancy Services Ltd which was established on 1 December 1994. This company will market our research and consultancy capability and greatly facilitate the transfer of information and software and other products, such as decision support tools, and soils, land cover and other datasets to our customers. The Board of Governors also set up a Technology Foresight and Transfer Committee to advise the Director and staff not only on the outcome of the Government's own Technology Foresight exercise but also to consult independently, the wide range of existing and potential customers of the Institute.

Also resulting from the Government's White Paper was a decision to carry out a Multi-Departmental Scrutiny of Public Sector Research Establishments. This was undertaken during the early part of 1994 and the report published in June. The report raised a number of important matters in relation to the future management and development of Science and Technology in the UK. The Institute believes that its role should be developed within the broader context of UK policy-making and that the systems in place to promote an integrated portfolio of UK research need to be kept under review. The report emphasized the need for all sectors of Science and Technology to seek ways of integrating research activities, and improving the efficiency and quality of output. The Institute has long recognized the need to be proactive in this respect and to be responsive to changing circumstances but is not persuaded that radical restructuring in terms of ownership, management or rationalization of the kind proposed by the Scrutiny Report is justified. The Institute welcomes the Scrutiny Report's recognition of the value of the contribution that institutes like the Macaulay make to Government policy formulation and implementation, and to the strategic research required to enhance the nation's ability to create wealth and enhance the quality of life. The Institute believes, however, that improvements in efficiency within Science and Technology management can be achieved by the existing machinery of Government, rather than by creating additional administrative structures which have no proven record of delivering high quality science or value for money. At the time of writing the Institute awaits, with considerable interest, the response of Government Ministers to the Scrutiny Report.

T J Maxwell
March 1995



Loch Leven and Mamore Forest

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INTEGRATED CATCHMENT MANAGEMENT

A C Edwards, R C Ferrier & R J Aspinall

Integrated Catchment Management (ICM) as a concept is finding increased usage but is rarely adequately defined. Catchments are commonly identified on a physical basis, and can be considered to represent a complete hydrological unit. Their structural diversity and, therefore, level of complexity increases with size. Many UK catchments contain a wide range of land uses, from the upland headwaters dominated by semi-natural vegetation passing through progressively more intensively agricultural and populated regions. It is clear, therefore, that there is a strong spatial aspect to the distribution of many key catchment attributes. A further complication is that many of the decisions influencing catchment management are taken regionally, nationally or even internationally. It is also possible to see multiple and contrasting effects of a single policy decision within different areas of the catchment. Ideally ICM should be considered as a unifying concept, incorporating all aspects of natural and many induced perturbations and their consequent effects on catchment attributes. While being a useful goal the idea is seldom, if ever, achievable. This is in principle due to the sheer complexity, range and interactive nature of the many factors and processes likely to be affected. It is much more likely that catchment management will be well targeted and undertaken to influence a limited number of specific problems. In this context the integrated part of ICM is most usefully defined in terms of the multi-disciplinary approach adopted to complex problem solving. In this article we focus on two topics that directly influence the quality of surface waters, and explore the methodological approach and data requirements for ICM.

ICM as it relates to surface water quality

Scientific study and management of a river catchment focuses on relationships between the water in the river and the land which the river drains. This involves describing and examining the physical resources of the catchment, their relationship with the river, and their interaction with land management and land use. The aim is to develop a view of the river and its catchment as an integrated whole - a system of interrelated and interacting components - and requires approaching the subject from a wide range of scientific and management perspectives. This multi-disciplinary approach is increasingly necessary, as awareness grows of the interdependence of environmental and socio-economic potential, options and impacts. Understanding interactions between rivers and land through catchment studies offers a powerful framework for connecting diverse land use issues and appreciating the way in which different land use practices influence one another.

The idea of Integrated Catchment Management reflects a realisation that catchments represent a unique and important functional unit within which the river shows the consequences of the integration of all catchment activity, and in which different aspects of land management can be seen to be related through 'catchment processes'. An important contribution of ICM is to focus attention on linkages and interactions in the environment, including the impact of human activity. ICM also focuses on a wider geographic context for land management and use - the catchment rather than the ownership unit.

Implicit in an 'integrated catchment management' view is that the land and water, the physical system, behave as a continuum. Traditionally catchments have been studied as a physical system of water and chemical movement and storage; the emphasis in ICM is on the 'whole catchment' unit (rather than just the river!) The system is, therefore, a reflection of physical/chemical, biological, and socio-economic attributes as an integrated, connected and functioning system of environmental resources, land uses, and socio-economic phenomena.

Data, knowledge and skills required

This view of rivers and their catchments as an integrated whole, inevitably requires that a wide range of perspectives must be taken into account. The possibilities of designing true ICM systems has only become feasible with the availability of advanced computer technology. Diverse data sets that describe various aspects of the biological, chemical and physical environment have to be incorporated within a spatial framework and be placed into a sociological and economic context. It follows that the data sources and their quality are equally varied as shown in Figure 1. Expert

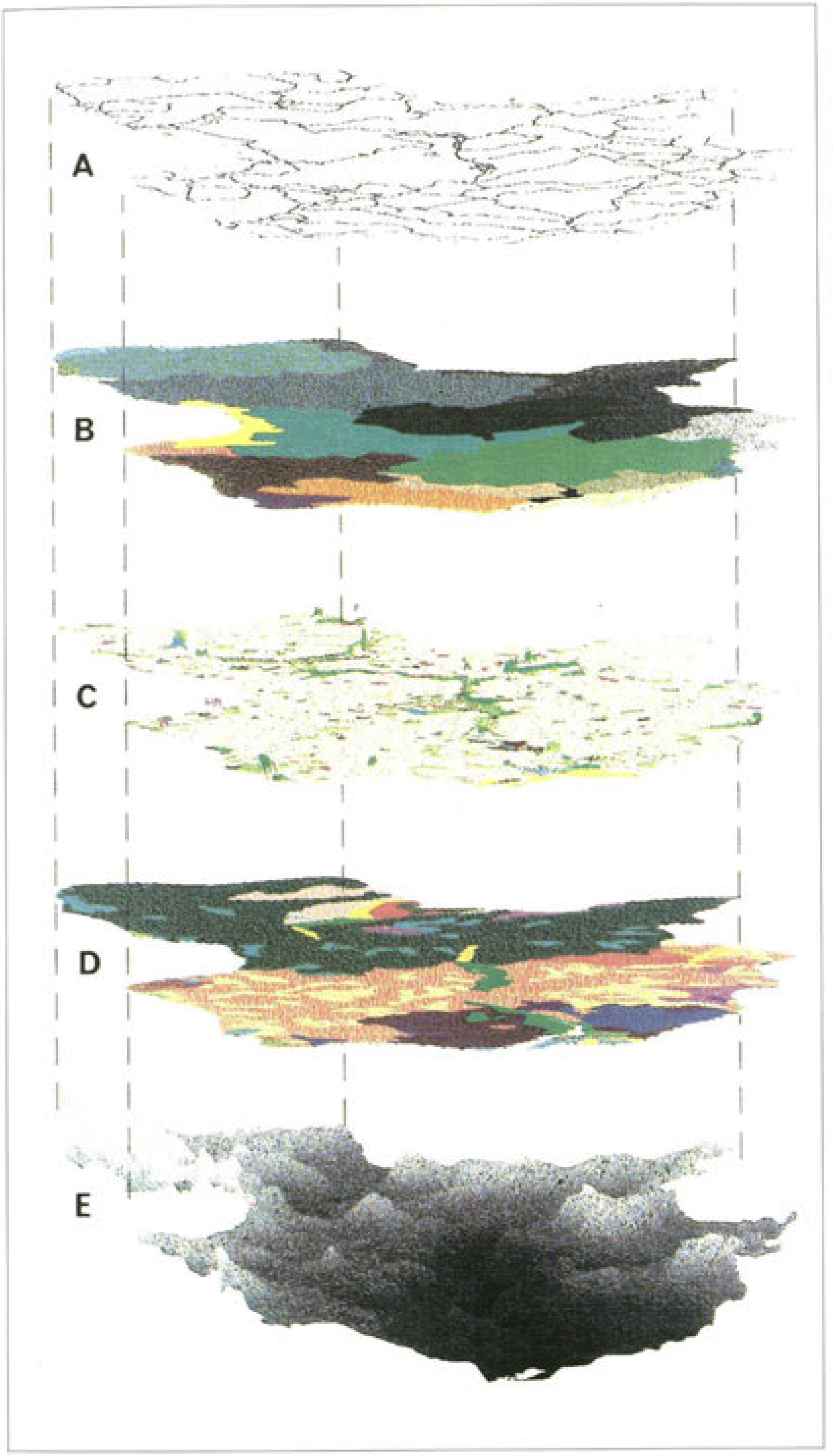

Figure 1. Examples of the diverse range of data sets required for modelling and designing an Integrated Catchment Management system. (A) ownership (B) Parishes (C) landcover (D) soils (E) topography.

knowledge must then be incorporated with models to describe the process relationships. This integrated computer environment provides the basis to explore catchment relationships, and enable the opportunity of developing various predictive responses to change.

Time scales introduce a further level of uncertainty. Many effects of management decisions/policy include a temporal aspect. The majority of natural processes operate over a different, usually longer time period. It follows that many of the effects are protracted and visible environmental improvements may take a long time to become obvious. It is, therefore, often difficult to judge the actual degree of success likely to be achieved and requires considerable reliance on modelling. Models can also reveal the weakness in our knowledge and, therefore, be used to establish research priorities. The development and application of particular models are directly related to the management objectives. The selection of the level of model complexity should always be on the basis of the problem, the system and the data available. These points are highlighted by the two following examples.

Acidification

The implications of different land use management strategies on the soil and water resource of any given catchment must involve representation of temporal changes. This can only be accomplished satisfactorily with the use of dynamic models. For example, the Model of Acidification of Groundwaters in Catchments (MAGIC) is a process orientated model of hydrology and biogeochemistry, used to make dynamic, quantitative linkages between atmospheric deposition, land use, soil and water chemistry at different spatial scales. The model has been used to assess the historical and predicted changes in base saturation of specific forest stand soils under different scenarios of deposition and afforestation (Figure 2). Such model responses under these different scenarios can be utilised in the decision making process, to assess the relative environmental impacts of changes in management. Site specific applications have also been undertaken to identify the interaction of acidic deposition and land use on water quality of individual catchments (Ferrier *et al.* 1993).

Although management strategies may be catchment specific, other spatial analyses must be considered to answer specific problems at both the regional and national level. For example, Figure 3 shows the cumulative frequency distribution of sulphur critical loads for water at 38 lochs in the Galloway region of S.W. Scotland, as estimated by steady-state empirical methods and by using MAGIC for three afforestation scenarios (cut and replant, deforestation, and increased afforestation to maximum levels). Such an analysis allows for the potentially more practical resource management of a whole region. It is highly unlikely that land use change and atmospheric deposition could be restricted and abated, respectively, to ensure a return to pre-acidification water quality in the region as a whole. For such a regional resource, a consistent multiple use planning approach for every catchment may be inappropriate. Certain catchments could be devoted entirely to afforestation at the expense of water quality to effect a substantial recovery over time in the resource of the neighbouring catchments thus regional system models might lead to more efficient management of the aggregate of all catchments. One of the key elements of integrated modelling is the linkages between impacts, the physical and

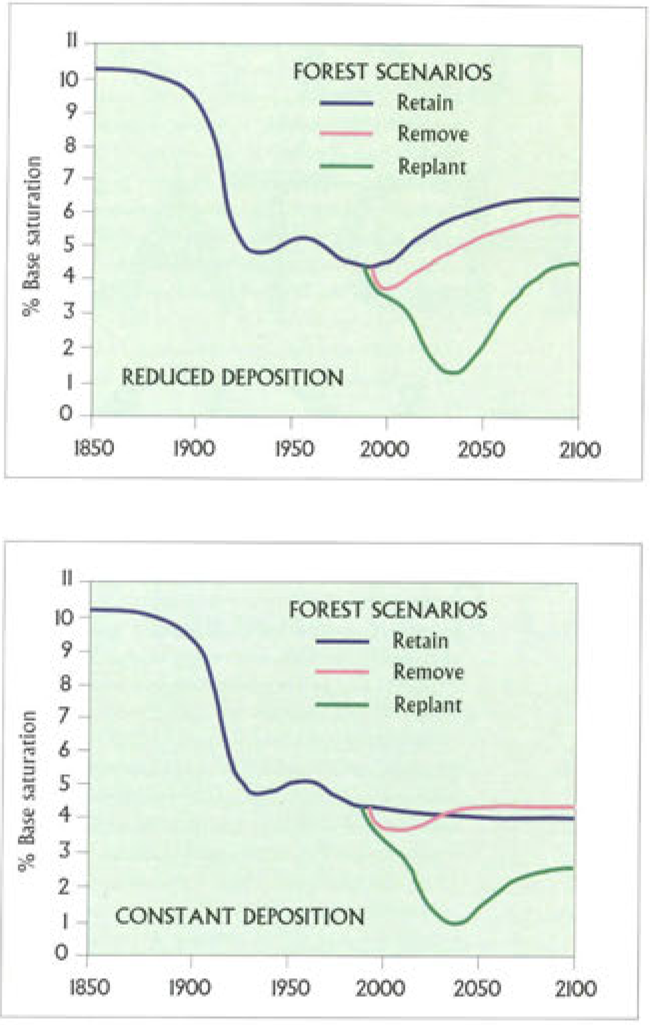

Figure 2. Base saturation in 0-90 cm soil at Solling under three scenarios of forest management and two scenarios of future acid deposition as predicted by MAGIC

chemical response of the system, and impacts on biological functioning. Socio-economic factors must also be included to provide a mechanism for feedback, policy development and evaluation of different topics.

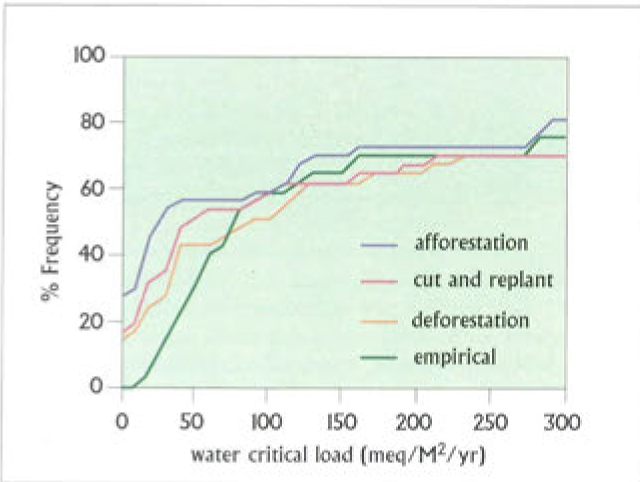

Figure 3. Cumulative frequency distribution of S critical loads for water at 38 lochs in the Galloway region as estimated by the steady-state empirical method and by MAGIC for three future forestry scenarios (cut and replant, deforestation, and afforestation)

Eutrophication and nitrate vulnerable zones

The EC Nitrate Directive (91/676/EEC) requires Member States to identify waters which are polluted by nitrates arising from agricultural sources. Thereafter they are required to designate the areas contributing to the polluted waters as Nitrate Vulnerable Zones (NVZs) and implement measures to reduce the pollution in those areas. Pollution in this context is defined not only by the exceedence of a specific limit concentration, but also by the manifestation of nitrogen-driven eutrophication. While a considerable number of NVZs have been identified using the former criteria, the Ythan estuary is unique in the UK as being the only river considered eutrophic because of its elevated nitrate concentration. The presence of substantial mats of the benthic *Enteromorpha* sp. and their effect on the numbers of mud-dwelling *Corophium volutata* affects the number of wading birds on the estuary, which is an SSSI. This example clearly shows a major problem with ICM in that the 'cause' arises from the whole catchment area (ie nitrogen loss from agricultural land), while the effect is limited to the relatively small estuarine area. In addition 'eutrophication', being a biologically based term, is extremely difficult to define and, therefore, to provide legislation for its control.

Designation as a NVZ will mean various management options must be put into place with the aim of reducing the concentration of nitrate in surface waters. We are assessing how best to meet these specific objectives. A comprehensive N balance is being compiled at the scale of individual field and farm. This information will be assessed in conjunction with physical aspects, such as soil texture, slope and distance from a water channel to produce a range of loss coefficients. Effectiveness of the management plan will be assessed against the combined environmental and agricultural economic considerations. The approach adopted here relies on the use of a wide range of contrasting types of data sets with all the associated problems discussed above.

Approximately 5000 kg of nitrogen and 50 kg of phosphorus enter the estuary from the river per day (MacDonald *et al.* 1994). Overall only 2% of the nitrogen, compared with 48% of the phosphorus, entering the estuary derives from sewage discharge (Pugh, 1993). It is, therefore, concluded that the elevated nitrogen status of the catchment derives from soil processes associated with land use practices, which, for this catchment is 90% agricultural.

An important characteristic of the Ythan catchment is the relatively uniform pattern of land use throughout. This results in a relatively constant nitrate concentration profile down the whole river system, in marked contrast to the rivers Dee and Don, which both receive considerable quantities of drainage water from semi-natural/upland areas with low nitrate concentrations. However, it is important to stress that there is no evidence to suggest that the Ythan farming community is responsible for any greater loss of nitrogen per unit area of land than equivalent farms in other UK catchments. There is no consistency in the changes to land management recommended between different NVZs for what appears to be similar causes. This reflects the site specific and complex nature of the nitrogen cycle. While similar structural approaches may be possible to the general form of ICM, each case must be developed on its own merits.

The role of socio-economic modelling in ICM

In order to better understand the causes of catchment pollution and to develop appropriate solutions, it is important to take account of social and economic factors operating both in and outwith the catchment. At MLURI a multi-disciplinary approach which integrates understanding of the physical/chemical and biological processes with socio-economic perspectives is evolving in relation to catchment eutrophication and acidification.

For example, in the Galloway region of south-west Scotland, Macmillan and Ferrier (1994) have developed a bio-economic model to predict the economic benefits to the local salmon fishery of alternative acid deposition abatement strategies. The model is based in a regional application, covering the six dominant river catchments of the area. The project, although restricted to Galloway, illustrates how complex hydrochemical-biological modelling, linked to economic analysis, can predict the impact of national environmental policy on local, resource-based economies.

In the case of eutrophication in the Ythan estuary, proposed environmental regulations to protect an internationally important nature reserve are likely to have an adverse effect on agricultural profitability, land values and local employment in the catchment. Modelling the interaction and trade-offs between agricultural activity and measures to protect the natural environment is an essential step towards a practical programme for ICM.

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QUALITY ANIMAL FIBRE
RESEARCH and APPLICATION

A J F Russel

THE PRODUCTION OF HIGH QUALITY, HIGH VALUE ANIMAL FIBRE has the potential to make substantial contributions to the economy of hill and upland farms, not only in the UK but also in those countries in Europe and beyond which have a tradition of ruminant livestock enterprises.

At one time the annual income from wool was sufficient to pay the rent of the average UK sheep farm. Now the income from wool does little more than pay the cost of shearing, and in some cases does not do even that.

The main reason underlying the change in profitability of wool production is the poor quality of the product in relation to present day demands. As with other commodities, the expectations of consumers as regards quality have risen with improvements in living standards; the quality of wool produced in the UK, and indeed in most European countries, has changed little if at all. Recent research in the Institute has shown, however, that the production of high quality, high value wool is eminently feasible and that the opportunities for generating income from quality animal fibre are not confined to wool. Other fibre-producing species merit serious consideration.

CASHMERE GOATS

The Institute's interest in cashmere dates back to 1982. Feral goats captured in south-west Scotland for use in grazing studies on reseeded and indigenous blanket bog vegetation, with the aim of improving the quality of grazing for sheep, were found to be carrying an undercoat of fine cashmere (Russel, 1987). Weights of cashmere per individual - generally less than 50 g - were too low to justify farming these animals for their fibre, but the fibre diameter of the cashmere, at 14 microns or less, was exceptional and as good or better than the top quality cashmere imported from China. It was considered, however, that the population of Scottish feral goats had the potential to serve as the basis of a research programme on cashmere production.

Integration of research

In the early 'eighties it was clear that the research on cashmere production as a possible land use option would require to be multi-disciplinary. Little was known about the growth of cashmere or the factors influencing it; there was no experience in Europe of the harvesting of this potentially valuable commodity; the scientific literature on nutritional requirements and the grazing ecology of goats was sparse and what little was available referred either to dairy goats or goats kept under very different environmental conditions; little was known about the health of goats other than that they were probably susceptible to a similar range of diseases as were sheep. These areas of work have been addressed in recent years by the development of an integrated research programme. This programme has benefited greatly from collaboration with other institutes, notably the Rowett Research Institute and the Medical Research Council's Reproductive Biology Unit in the fields of fibre and seasonal biology, the BBSRC Roslin Institute in the work on genetics and animal breeding, and the Moredun Research Institute in research on animal health and particularly parasitology. A close association with textile companies, and in particular Johnstons of Elgin, has been invaluable in ensuring that the characteristics of the final product accord with the rigorous specifications of the textile industry.

At the outset it was clear that if cashmere production were to be seriously considered as an avenue for diversification, one of the first priorities had to be an appraisal of the possibility of substantially increasing fibre production to economically viable levels. The two principal means of achieving this objective were considered, at that time, to be through breeding and by nutritional manipulation.

Breeding

Two options were available for increasing cashmere production through breeding, namely selection within the existing feral population and crossbreeding with cashmere goats from other countries. It was considered that the latter was likely to result in more rapid progress in the first instance and a programme of importation of animals, semen and embryos was initiated by a cooperative, Cashmere Breeders Ltd (CBL), of which the Institute was a founder member and for which it still acts as managing agent (Russel, 1987).

Goats were imported from Iceland, semen and later live animals from Tasmania, and embryos from New Zealand and Siberia. These were used in a structured programme of crossbreeding in the Institute and on CBL members' farms. In this programme, feral goats were crossed to one of the exotic breeds and the resulting progeny crossed again to either the same or a different exotic genotype to produce goats which had 25% feral ancestry, the remaining 75% being made up of one or two exotic breeds.

Estimates of annual production (EAP) of cashmere and measurements of mean fibre diameter were made on samples of fibre collected from kids at five months of age. Mean values for these traits in the native feral goats and the four exotic genotypes are contained in Table 1 (Bishop and Russel, 1994). These data illustrate the positive relationship observed between weight of cashmere and fibre diameter which is, of course, a negative relationship between quantity and quality. The variation between genotypes was substantial, with the feral goats producing small quantities of very high quality cashmere at one end of the scale, and the Siberians producing high weights of very coarse fibre at the other.

	Feral	Icelandic	Tasmanian	N.Z	Siberian
Live weight (kg)	15.7 (2.16)	17.65 (0.93)	16.39 (0.83)	16.53 (1.28)	21.88 (1.28)
Cashmere production (g)	37.3 (71.3)	91.4 (31.7)	227.1 (28.1)	275.1 (42.5)	579.8 (44.7)
Fibre diameter (μm)	13.75 (0.82)	14.04 (0.41)	16.13 (0.35)	16.63 (0.49)	17.97 (0.50)

Table 1. Mean values (±se) for live weight, estimated annual cashmere production and fibre diameter measured at 5 months of age in cashmere goat genotypes used as the basis of the cross-breeding programme. Bishop and Russel, 1994.

These quantitative and qualitative traits were combined by their relative economic values in a cashmere production index (CPI):

$$CPI = EAP \{1 + k\ (\text{fibre diameter} - \text{mean fibre diameter})\}$$

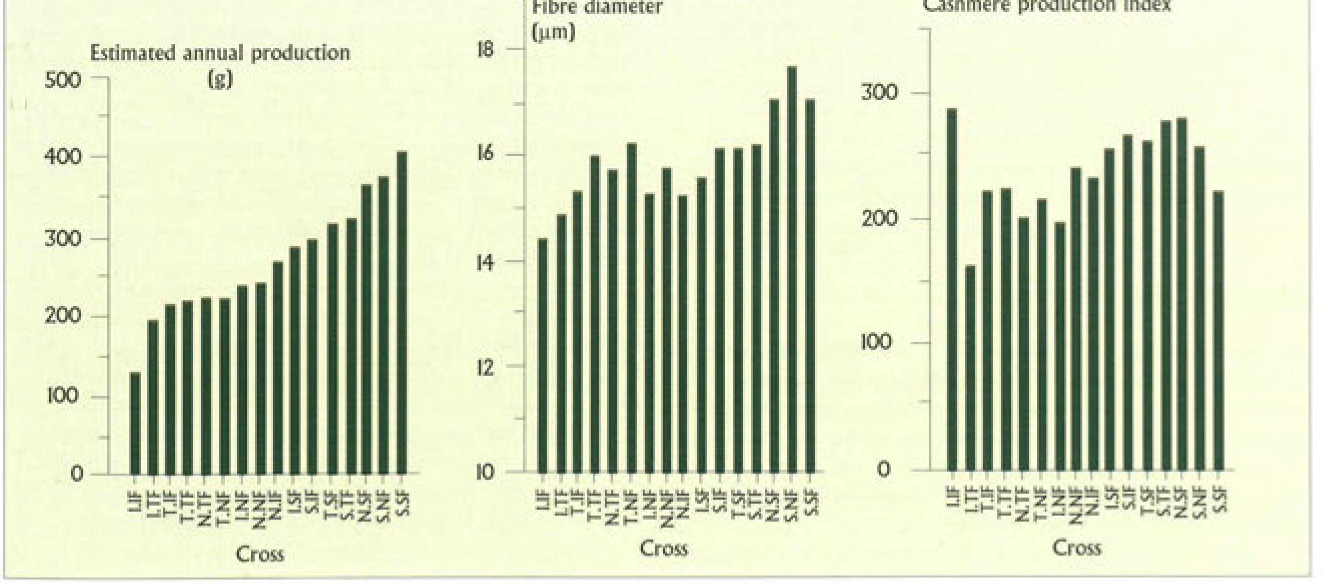
where k describes the price differential paid per unit decrease in fibre diameter (Bishop and Russel, 1994).

At the outset of the cross-breeding programme it had been anticipated that this stage of the work would serve as a screening process, allowing the subsequent breeding work to concentrate on the superior 3-way crosses and resulting in the inferior crosses being discarded. The results showed, however, that although those crosses with an Icelandic component were generally superior in terms of quality, those with a predominance of Siberian ancestry were better as regards quantity. When these traits were combined using the CPI, differences between genotypes become less clear (see Figure 1). It was also demonstrated that changes in the quality price differential (k) and the extent to which fibre colour was taken into account in estimating relative economic values could radically alter the ranking of genotypes as illustrated in Figure 1. It was accordingly decided that subsequent breeding work would be conducted without regard to genotype and that individuals would be selected on the basis of genetic merit.

The second and current phase of the cashmere goat breeding programme is therefore concerned with genetic selection. Two selection lines and a random bred control line, against which the rate of genetic progress can be measured, were established at mating in 1991, using goats from the cross-breeding work outlined above. In the first line, comprising 190 breeding does, selection is for maximum value of cashmere. The second line, consisting of 95 breeding does, is selected for high quality cashmere, i.e., for low fibre diameter. The control comprises 70 does. Does are kept for three breeding seasons, bucks are selected on the basis of their index scores at 5 months of age and are used only once, at 1 year of age. To date, results are available from only the first two years of selection, which is too short a time for any meaningful evaluation of progress.

Goats in general are more susceptible to helminth parasites than are sheep and consequently require more frequent treatment with anthelmintics. This, in turn, can lead to the rapid emergence of multiple anthelmintic resistance. On hill and upland farms the opportunities for controlling helminth infestations by the use of non-susceptible livestock or by cropping or conservation are severely limited and the only alternative to intensive chemotherapy lies in the breeding of stock with an enhanced helminth resistance. It was against this background that a third selection line, this one for helminth resistance, was added to the cashmere goat breeding programme in 1992.

Figure 1. Means of estimated cashmere production and fibre diameter measured at 5 months of age and calculated cashmere production index of 3-way cross genotypes. (F = feral, I = Icelandic, N = New Zealand, T = Tasmanian, S = Siberian). Bishop and Russel, 1994.



Nutrition

The second major avenue for increasing cashmere production considered at the outset was through nutritional manipulation. Early research showed that differences in the level of feeding and in the concentration of undegradable dietary protein in the intake had little or no effect on either the growth rate of cashmere or on the diameter of the fibre (Russel, Lippert, Ryder and Grant, 1986).

More recent research in the Institute has shown that this conclusion requires to be revised. Although nutrition may not influence the contemporary rate of growth of cashmere or the diameter of the fibre, it is now clear that it can affect the timing of events in the annual cycle of fibre growth and shedding. The results shown in Figure 2 indicate that goats on high levels of feeding and gaining weight shed their cashmere earlier than those on a submaintenance diet and which consequently lost weight. The effect of shearing goats fed 1.2 times the maintenance energy requirements of a fully-fleeced animal was a substantial loss of weight and a significant delay in the time of shedding to beyond that of animals receiving 0.8 maintenance (Merchant, 1995).

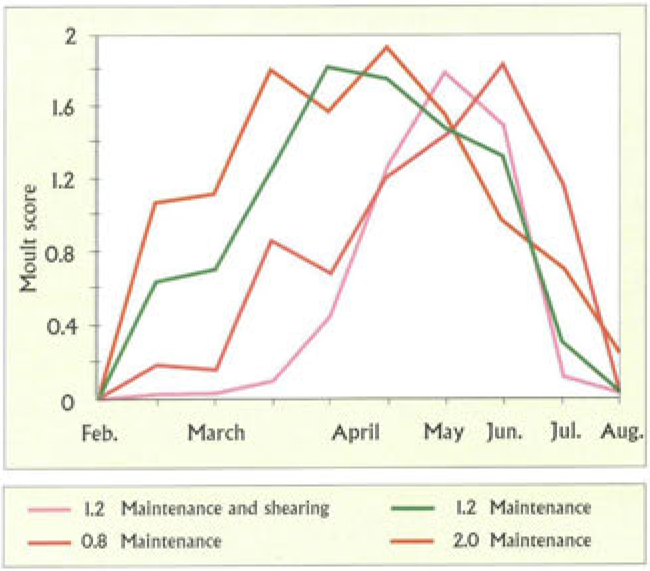


Figure 2. Fibre shedding in cashmere goats is delayed by low levels of feeding and by shearing

The consequence of this finding with respect to the annual weight of cashmere produced is not clear at this stage. In this particular experiment the moult appeared to finish at about the same date in animals on all treatments. It is not yet known, however, whether the treatments have had any effect on the time of initiation of the subsequent growth cycle or, if such an effect is found, whether the duration of the period of active fibre growth (the anagen phase) will be altered or whether that duration remains constant in length but occurs over a different time of year.

Fibre biology

The timing of the shedding of cashmere in the spring has important practical implications for the harvesting of this valuable commodity. Goats can be shorn either at or immediately before the moult, in which case, at least under UK conditions, they require to be housed for a period of some weeks or months; alternatively they can be kept outdoors throughout the year and combed after the initiation of the moult.

The 'indirect' effects of nutrition referred to above suggest that it may be possible to manipulate the timing of the moult, and perhaps also to condense its duration, to facilitate the operation of harvesting. The development of a practicable means of manipulating the timing and duration of the moult must be based on an understanding of the mechanisms controlling the annual cycle of fibre growth and shedding. It has been known for some time that the timing of events in the fibre growth cycle is influenced by photoperiod and that the cue of changing daylength is mediated through the hormone melatonin. The initial research designed to provide an understanding of the mechanisms controlling fibre growth was therefore concerned with the effects of melatonin on the duration of the anagen phase of the growth cycle and on the timing of the moult.

It was considered that the administration of melatonin prior to the winter solstice might counteract the subsequent naturally occurring increase in daylength and consequently delay fibre shedding. It was found, however, that the treatment had the opposite effect; the moult was advanced by some seven weeks and it is now considered that continuous melatonin treatment under short-day photoperiod induces photorefractoriness (Dicks, Russel and Lincoln, 1995a). The important finding to come out of this work was that the advancement of the moult was accompanied by a corresponding advance in the timing of the naturally occurring increase in circulating concentrations of the hormone prolactin. This work also showed that melatonin treatment in April resulted in a suppression of plasma prolactin concentrations, although, because goats have already shed their cashmere by that time, it was not possible to study the effects of the treatment on the timing of events in the fibre growth cycle. This did, however, lend weight to the hypothesis that prolactin was an important intermediary in the pathway linking changes in daylength to events taking place in the hair follicle. It also suggested that means of manipulating plasma prolactin concentrations might be effective in delaying the time of the moult (Dicks *et al.*, 1995).

A subsequent experiment demonstrated clearly that the administration of prolactin was effective in advancing the timing of the moult and that suppression of the seasonal increase in prolactin secretion, which normally occurs in the spring, could be delayed significantly by treatment with bromocriptine (Dicks, Russel and Lincoln, 1994).

It is unlikely that prolactin is the only hormone implicated in controlling the timing of cashmere growth and shedding and indeed recent work by Rhind (1994) confirms that the thyroid hormones may have a role in this respect.

Evidence from this work also demonstrated that the effect of the methylthiouracil treatment on the timing of the moult was not mediated through prolactin. It therefore appears that there are at least two avenues by which the timing of the moult could be manipulated; the use of bromocriptine to suppress the naturally occurring spring rise in plasma prolactin concentrations and of methylthiouracil to reduce the conversion of T_4 to T_3. Practicable, ethically acceptable and economically viable means of administering either of these compounds in systems of cashmere goats husbandry remain to be developed.

An improved understanding of the mechanisms controlling the growth and shedding of cashmere fibres has also been pursued through studies of hormone receptors. Recently, receptors of IGF-1 have been localized to the inner and outer root sheaths, the sebaceous glands and the follicles of both cashmere and Angora goats. In the cashmere goats there was a progressive increase in the concentration of receptors present as the follicles switched from the resting (telogen) to active (anagen) growth phases. In the Angora goats, in which rate of fibre growth is known to be sensitive to nutrition, an increase in receptor concentration coincided with an increase in level of feeding (Dicks, unpublished results).

Although IGF-1 has been known to be implicated in the seasonal growth of antlers and velvet production in red deer, it had not previously been demonstrated as having a role in fibre growth. The precise nature of that role will be the subject of further research.

Fine Wool

The Institute's involvement and interest in fine wool stems from studies carried out in 1989 in collaboration with Geoffrey Saul, an Australian visiting worker from the Pastoral and Veterinary Institute in Hamilton, Victoria. The work involved an examination of the potential for increasing income from wool in hill and upland sheep flocks in the UK (Saul, Russel and Sibbald, 1992, 1993).

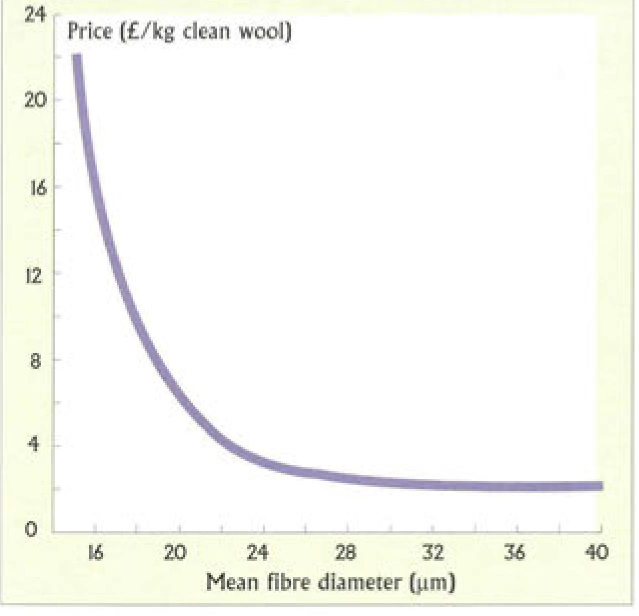


Figure 3. Relationship between wool prices and fibre diameter

An analysis of wool value in relation to quality, based on Australian Wool Corporation prices over the four years 1987-90 inclusive, gave the relationship illustrated in Figure 3.

This shows clearly that at fibre diameters greater than about 25µm, price is insensitive to changes in fibre diameter, and that at diameters of less than about 22 µm price increases rapidly as fibre diameter decreases.

Other analyses indicated, that in Australian Merino x UK breeds selection for reduced fibre diameter would be likely to result in small increases in fleece value over the 25-35 µm range and in very substantial increases in value at finer diameters, despite inevitable reductions in fleece weight. It was further concluded that a cross between the finest of the Australian Merinos, the Saxon, and the finest of UK native breeds, the Shetland, might produce a sheep with a fleece combining attributes of quantity and quality in such a way as to ensure a high value.

To test this conclusion, some 50 Shetland ewes were mated in 1989 to two Saxon Merino rams to establish a small crossbred flock of fine wool sheep at Sourhope Research Station. Similar matings were carried out in the following year and in 1991 imported semen from Saxon Merino rams was used to create Merino x Shetland crosses and to introduce new blood lines. The proportion of Merino ancestry in the Sourhope fine wool flock, which has been named the 'Bowmont', now varies from 0.5 to 0.75. No differences of consequence have been identified in the fleece weight, wool quality or apparent hardiness of crosses with these or intermediate proportions of Merino genes (Russel, Sangster, Gittus and Redden, 1994).

The principal selection criterion used in the Bowmont sheep is fleece value. This is calculated using an estimate of clean fleece weight (W)(kg) and the price-quality relationship illustrated in Figure 3, i.e.

$$\text{Value} = W(2.247 + 3190e^{-0.3383\mu})$$

Data on live weight and on fleece weight, fibre diameter and fleece value of the present Bowmont flock at shearing in 1994 are summarized in Table 2. These data indicate that the Bowmont is a small sheep, producing a heavier than average fleece for its size

	Rams		Ewes	
	Adults	Yearlings	Adults	Yearlings
Number	8	4	36	12
Live weight (kg)				
Mean	46.4	28.7	40.1	28.3
Fleece weight (kg)				
Mean	3.6	3.4	2.6	2.0
Range	2.8 - 4.9	3.0 - 4.0	2.2 - 3.3	1.4 - 2.8
Fibre diameter (µm)				
Mean	20.0	18.4	22.1	18.3
Range	18.2 - 22.8	17.8 - 20.2	17.1 - 26.1	16.9 - 20.2
***Fleece value (£)**				
Mean	14.2	20.7	7.9	13.5
Range	5.1 - 27.0	16.3 - 26.3	3.1 - 20.9	7.3 - 26.1

*based on 1987-90 world prices

Table 2. Means and ranges of live weights, fleece characteristics and wool values of Bowmont sheep (1994 shearing)

and with unequivocally fine wool. Mean fleece values, calculated on the base line used throughout this work (i.e., world prices over 1987-90), are some ten to twenty times greater than those of typical UK hill breeds. The ranges in these parameters are, perhaps, of greater interest than the mean values and indicate a potential for further substantial improvement in both fleece weight and fibre diameter, and consequently in fleece value.

SOUTH AMERICAN CAMELIDS

In recent years there has been considerable interest in the UK and elsewhere in Europe in farming some of the species of South American camelids for their fibre. Research on certain of these species was initiated in the Institute in the mid 'eighties to provide information on which their potential as an avenue for diversification could be assessed. The Institute's camelid research work was undertaken jointly with the Rowett Research Institute which was responsible for work on reproductive physiology and biotechnology while MLURI concentrated on those aspects relating to fibre and nutrition.

The major area of work in the llama has been an examination of the effects of nutrition and season on fibre growth (Russel and Redden, 1994a, 1994b). In an experiment conducted over a period of two years an approximately maintenance level of nutrition appeared at first sight to result in a greater weight of undercoat than was observed at twice maintenance. There were, however, no effects of nutrition on either fibre diameter or fibre growth rate and further investigation indicated that the effect on undercoat weight was attributable to a later initiation of fibre shedding in the animals on the lower level of feeding. This accords with the more recent observation of a similar effect in cashmere goats, as referred to above.

In contrast to the lack of effects of nutrition of fibre characteristics, the effects of season, measured as the interval from one equinox to the next, were marked (see Table 3).

These results and some general observations provide an insight into the pattern of fibre growth and shedding in the llama. Llamas do not exhibit a well defined and easily recognized moult

	January – June	July – December	Significance of difference
Patch weight (g)	0.51 ± 0.200	0.36 ± 0.018	***
Undercoat weight (g)	0.21 ± 0.011	0.27 ± 0.011	***
Guard hair weight (g)	0.15 ± 0.007	0.09 ± 0.007	***
Undercoat/fibre weight (%)	63.6 ± 1.27	69.4 ± 0.95	***
Undercoat growth (μm/d)	132 ± 13	197 ± 14	I***
Guard hair growth (μm/d)	334 ± 20	295 ± 14	NS
Undercoat fibre diameter (μm)	23.6 ± 0.27	23.6 ± 0.25	NS
SD of diameter (μm)	6.1 ± 0.19	6.7 ± 0.20	*
Medullated fibres (%)	56.4 ± 1.49	55.2 ± 1.45	NS

* p<0.05 *** p<0.001 NS not significant

Table 3. Effect of season on fibre production and undercoat characteristics in llamas (figures refer to fibre collected from 10 cm² mid-side patches). Russel and Redden, 1994b

as seen, for example, in cashmere goats in which all undercoat fibres are shed over a period of a few weeks each year. Neither do llamas grow their fibre continuously, like most breeds of sheep. If not shorn, the llama's fleece appears to attain a maximum length after two to three years. This suggests that one third to one half of the fibres are shed each year. The lower weight of fibre observed in the July to December period is consistent with the loss of fibre over this period. The greater rate of fibre growth measured over this same period is attributable to the continued growth of the fibres not shed in that year.

The results of work on the effects of nutrition on fibre production in the alpaca are in marked contrast to those obtained in the studies on llamas. As illustrated by the data in Table 4, fibre weight and growth rate in the alpaca showed substantial positive responses to a higher level of nutrition although, interestingly, fibre diameter was not affected (Russel, Redden and Kay, 1995). Alpaca fibre production is clearly highly susceptible to nutritional manipulation.

The Roles of Nutrition and Genetics

The knowledge acquired on the effects of nutrition on fibre characteristics in the llama and alpaca, when considered in relation to that in other species, allows a general hypothesis to be advanced, namely, that fibre production in single-coated species such as sheep, Angora goats, and alpacas, is sensitive to nutritional influences, whereas the fibre produced by the secondary follicles of double-coated species (the fine undercoat) is insensitive to nutritional manipulation, at least over the range of nutrition likely to be encountered in sustainable management systems.

The degree to which quantitative and qualitative fibre

Level of feeding	0.67 maintenance	2 maintenance	Significance of difference
Fibre weight (mg)	118 ±8	148 ± 11	***
Fibre growth (μm/d)	186 ± 10	223 ± 14	*
Fibre diameter (μm)	31.4 ± 1.7	32.1 ± 1.6	NS

* p<0.05 *** p<0.001 NS not significant

Table 4. Effect of nutrition on fibre production in alpacas (figures refer to fibre collected from 10 cm² mid-side patches). Russel, Redden and Kay, 1995

characteristics are amenable to nutritional manipulation has two important implications. First, with double coated-species the nutritional strategy adopted in the management system can ignore effects of nutrition on fibre weight and quality and be directed to other components of production such as reproductive efficiency and growth rate. With single-coated species, however, the nutritional strategy must be based on a clearly defined objective of maximizing either fibre weight or fibre quality, while at the same time recognizing the needs of the other components of production and of animal welfare. The decision as to whether the objective should be quantity or quality will depend on the biological relationship between these parameters in the species considered and on the economic relationship between value and quality, as discussed above in relation to Bowmont sheep.

The second implication concerns breeding strategies for improving the value of the fibre output. Again, this is more straightforward in the double-coated species where, because fibre quantity and quality are not affected by nutrition, it can reasonably be inferred that they are determined principally by genetic factors and consequently have high heritabilities. This in turn, implies that rapid improvements in either fibre weight or quality, or to a lesser extent in both at the same time, can be expected from selective breeding programmes. In the single-coated species the heritabilities of fibre characteristics are likely to be substantially lower and rates of genetic improvement consequently slower. In such species some means of quantifying and then discounting the effects of nutrition on fibre characteristics must be an essential element of any genetic improvement programme.

Application in Practice

The results from recent years' research on the various aspects of quality animal fibre confirm the view that the production of cashmere and fine wool constitute potentially viable alternative enterprises with application in the UK and probably within many EU member states. The role for camelid fibre production is, however, more doubtful.

The feasibility of producing cashmere from a wide variety of land resources, ranging from arable land to hill farms, has been amply demonstrated. At present all herds comprise breeding stock, but it is possible to envisage the development of systems based on castrates run on the poorest land resources which cannot sustain breeding female sheep or goats. Herds of castrates could also be maintained on better quality land to bring about pasture improvement for the benefit of other species or to achieve specific vegetational management objectives including the control of weed species on set-aside land.

Despite the demonstration of the technical feasibility of cashmere production, uptake by UK farmers has been poor. Unsubsidized fibre goat enterprises cannot compete with the very heavily supported sheep and beef cattle industries. This inequitable treatment does not apply in the southern EU member states which are now showing considerable interest in cashmere production and are currently reaping the benefits of the research programme carried out by the Institute.

The future of cashmere production in the UK is therefore uncertain. In the long term it may succeed through a combination of factors: increases in output per animal as a consequence of the success of the breeding programme; continued increases in cashmere prices due to the world shortage of cashmere arising from increased domestic sales in China; a reduction in the level of support for the sheep industry; and an improved price for goatmeat as a result of better marketing.

The principal role envisaged for fine wool production from the Bowmont sheep is in the poorest land resources. Sheep production in these areas is presently sustained only by the high levels of support and if this is reduced many breeding flocks will not be economically viable. The levels of lamb and ewe mortality which contribute to the poor performance of such flocks are also a cause of concern on welfare grounds. In these situations flocks of regular ages of fine wool castrate sheep could be maintained profitably in extensive low-input management systems, provided that the quality of the wool is sufficient high to command a commensurate high price. Some of the Bowmont fleece values quoted above would ensure profitability in such situations.

The reservations regarding the future for camelid fibre production in the UK or other parts of Europe stem from the fact that the fibre from llamas and alpacas cannot truly be described as fine. The fibre diameters of the llamas mentioned above are lower than average for this species but would still not command a price which would cover the cost of dehairing the fibre from their double coats, let alone the variable and fixed costs of keeping the animals. Alpaca fibre may not require to be dehaired, but world prices are similar to or less than wool from most UK sheep breeds, and again fleece values are insufficient to cover the costs of upkeep. Although producers may be able to sell the small quantities of fibre currently produced to niche handicraft markets, the long term viability of camelid fibre production enterprises must be based on world prices.

Fibre from the other two South American camelid species, the undomesticated guanaco and vicuña, is unequivocally fine; that from the guanaco is of similar diameter to cashmere and, if available in quantity, would be at least as valuable. Vicuña is arguably the ultimate in quality animal fibres, with diameters around 12μm. This species is, however, registered as endangered and trade in its fibre is currently banned, although there is prospect of some relaxation in the restrictions governing the ranching and farming of vicuña for fibre production.

The number of pure guanacos, as opposed to llama-guanaco hybrids, in Europe is small and the opportunities for increasing the size of herds through the use of superovulation and embryo transfer are limited. Importations are likely to be difficult and very expensive. The scope for economically viable guanaco fibre production in Europe is therefore also considered to be limited. There is, however, considerable potential for fibre production from guanacos and possibly vicuñas in the Andean countries of South America and collaboration with research workers in these countries to assist in the exploitation of that potential would constitute worthwhile aid to developing economies.

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LAND and ENVIRONMENTAL MANAGEMENT SYSTEMS

This project links closely with the Spatial Data Handling one. It shares the same ultimate aim of contributing to the development of decision support systems (dss) for application to land use planning and management at a range of scales. Its focus is on the analysis and synthesis of land and environmental management systems particularly through the use of conceptual, rule-based and spatial modelling but also through field systems experimentation. The research deals with the issues of resource potential, management systems options and environmental impacts and their integration within a dss framework in generic context. It is being conducted on the basis of specific applications. The foci of research are;

- **the analysis of resource potentials;**
- **the synthesis of upland management systems;**
- **the assessment of environmental impacts;**
- **the development of integrative models.**

RESOURCE POTENTIALS

Strategic research on soil water regimes underpins the development of land evaluation techniques. The ability of soils to store and transmit water has a major influence on land use and affects the soil buffering capacity, biological filtering and pollutant pathways and fluxes. Current

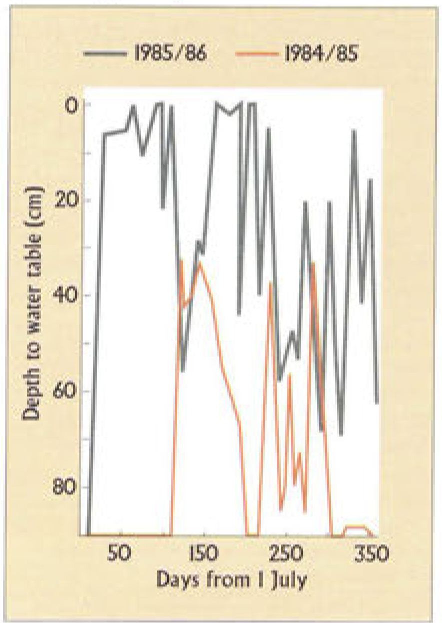


Figure 1. Variability in water table heights in two successive years.

research focuses on the need to recognize the temporal variability in soil water content (Figure 1). Data from 33 sites throughout Scotland are being analyzed. These data are being used to calibrate a soil water simulation model (SOIL) for use in dynamic land evaluation. Current results indicate that the model needs to be extended to take account of bypass flow which commonly occurs in Scottish soils. An interrogation of a limited soil hydraulic properties database has shown that there could be significant differences in retained and available water capacities from soils with similar textures and structures found in England and Wales. This could have profound implications for the development of common land evaluation systems which use interpolated parameters to predict soil hydraulic properties.

- Aspects of the above research have led to MLURI being invited to take a lead role in the development of a European soils physics database at the Winand Staring Centre in Wageningen.

UPLAND MANAGEMENT SYSTEMS

Management systems in the hills and uplands are being challenged to extensify and/or diversify. Our research approaches these challenges in two ways. The first is through modelling of upland sheep systems, particularly in relation to their nutrient budgets (which links directly and indirectly to environmental impacts); and secondly to field experimentation on alternative low-input or diversified silvopastoral systems. The modelling of upland sheep systems is being developed to take into account the effects of different genotypes of grazers. A dynamic model was developed to simulate the ammonia volatilization from grazing livestock farms (Figure 2).

- The model highlights the effect of indirect interactions between ammonia sources and of slurry management and the weather. It demonstrates that assessments of control measures may be misleading unless considered at the scale of the whole farm.

The field research on low-input upland sheep systems has, in collaboration with IGER, shown how reducing applied fertilizer nitrogen, sward height and stocking rates impact on sward composition and animal liveweight gain.

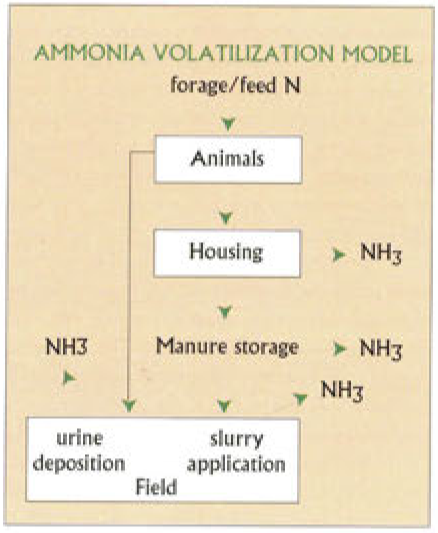


Figure 2. Farm-scale ammonia volatilization model

- The conservation benefit of such systems has been measured and it has been shown that the numbers of beetle and spider species can be maximized through a mixture of conventional and extensively grazed areas.

The field research on silvopastoral systems is part of a collaborative UK network. The MLURI experiment is run in collaboration with the Forestry Authority's Research Division. It has demonstrated that agricultural production is unaffected by the presence of trees at wide spacing during their establishment years.

- The survival and growth of trees during this phase is closely related to their planting density and appears to be a function of animal:tree ratio. The UK network has been incorporated into a European-funded project on the alternative use of agricultural land with fast-growing trees.

ENVIRONMENTAL IMPACTS

There are two specific studies on the environmental impact of land use practices. The first has looked at correlations between agricultural intensity and NO_3-N loadings in surface waters. Using satellite image-derived measures of intensity, it has been shown that nitrogen losses range from 3.4kg ha/yr^{-1} in the Western Isles to 16.1 kg ha/yr^{-1}

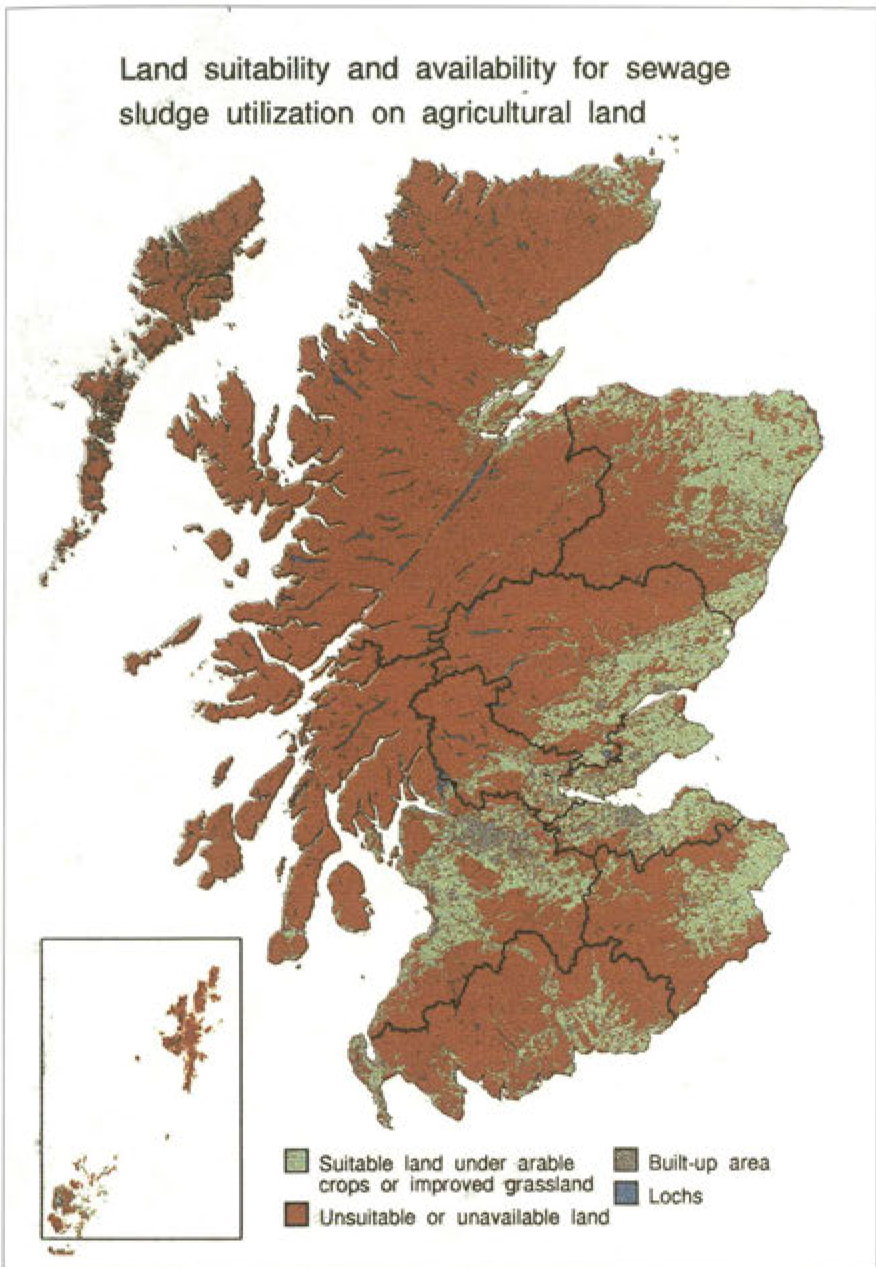


Figure 3. Land suitability and availability for sewage sludge utilization on agricultural land

in Fife. The national total is estimated at 54 (± 6.7) k tonnes/yr^{-1}, equivalent to £17M at 1993 prices.

- This research represents the first national audit of NO_3-N losses and respective regional contributions and is helping shape SOAFD policy on nitrate vulnerable zones.

The second is concerned with the land utilization of wastes (e.g. sewage sludge) as an alternative use of rural land. This has involved the development of a rule-based model for assessing risks and suitability of agricultural land for sewage sludge utilization. The model has been applied to both the National Soils Inventory and the national soils and land cover spatial databases. A national map, accompanied by area statistics, showing land which is physically suitable and available for sludge utilization has been produced (Figures 3 and 4). In addition, the availability of soil chemical data (pH, heavy metal contents) has allowed the impact of potential policy changes to be assessed.

- This objective approach has enabled all the Regional Council strategies for sewage sludge disposal to be critically reviewed, the different anomalies between Regions to be highlighted and has led to the work being incorporated into the strategies of several Regional Councils.

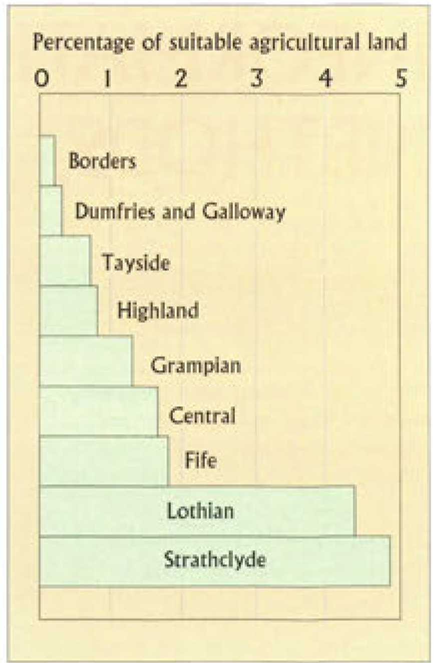


Figure 4. Percentage of suitable agricultural land required annually at a sludge application rate of 5 tds/ha

INTEGRATIVE MODELS

A new initiative on the development of decision-support systems for assessing land use options at the management unit level aims to build upon the knowledge and understanding gained in the wider MLURI programme, to provide:

- a tool for understanding patterns of change at higher levels of organization and
- to support decision-making at both management and strategic levels.

The objective is to develop an understanding of options available to land managers operating in different bio-physical and socio-economic circumstances. The system currently allows crop yield and economic returns for farm woodland, livestock and cropping enterprises, to be calculated. A conservation module is currently being written.

Contact names

Dick Birnie, Alan Sibbald, Gordon Hudson, Jacques-Eric Bergez, Nick Hutchings, Allan Lilly, Keith Matthews, Willie Towers, Matt Hare

SPATIAL DATA HANDLING and INFORMATION TECHNOLOGY METHODS

The ultimate aim of this project is to contribute to the development of decision-support systems for application to land use planning and management at a range of scales. There are strategic scientific challenges associated with the acquisition, analysis and presentation of spatial information, many of which are key to the development of decision-support systems for resource evaluation, land use modelling and environmental assessment.
The foci for current research efforts are:

- **land cover mapping and environmental resource databases;**
- **developing techniques for spatial interpolation and spatial analysis; and**
- **developing dynamic environmental impact assessment procedures, particularly in relation to water quality and landscape.**

The research makes extensive use of novel Information Technology (IT) methods and specifically aims to develop a centre of excellence at MLURI for spatial analysis and applications of Geographic Information Systems (GIS).

LAND COVER MAPPING

Monitoring change in the countryside is important to policy formulation and appraisal. There are several current initiatives that provide a monitoring system, including the Land Cover of Scotland (LCS88) conducted by MLURI on behalf of the Scottish Office, the Countryside Survey 1990 (CS90) conducted by ITE on behalf of the UK Department of the Environment, and the National Countryside Monitoring Scheme (NCMS) conducted by Scottish Natural Heritage. Each survey has its own methodology and objectives, and added value arises from their integration. We have recently completed a quantitative comparison between the LCS88 and CS90 datasets (for Scotland) on behalf of SOAFD; the results show that there are good correlations between the schemes for some of the semi-natural and woodland classes. The work has also led to the development of an integrated database for land cover for Scotland. From this it is now possible to predict the Scotland-wide or regional distribution of CS90 defined land cover and vegetation categories as well as individual plant species, and to describe the LCS88 classes in more detailed ecological terms. The database and analysis facilities have been developed within ARC/INFO GIS.

- New funding has been received from SOAFD to integrate the SOAFD June Census data and from SNH to include the NCMS data from the 1940s.

SPATIAL ANALYSIS

Unlike the LCS88, survey and data collection schemes seldom record data describing the environment for every geographic location. Most record data only at particular locations (for example, climatic conditions are recorded only at meteorological stations), and a particular challenge, therefore, is to develop methods which estimate values at places where there are no measurements. Research on spatial interpolation is developing geostatistical techniques and builds on work at Stanford University and the Centre de Géostatistique in France. We have developed a linear model of co-regionalization for estimating monthly rainfall totals which takes the need to deal with spatial correlation structure and correlation between variables into account. This model has been used to create input data describing climate, potential soil moisture deficit, machinery work days, and soil droughtiness for a national scale winter wheat suitability assessment. The suitability assessment produced is more specific (and quantitative) than the more general Land Capability assessments and deals explicitly with spatial variation in the input data. The model and input data are also being used elsewhere in MLURI.

CONSERVATION EVALUATION

The study of ecological processes over extensive geographic areas has been a comparatively neglected subject in the ecological sciences. It is, however, important to the development of appropriate wide-area and regionally-targeted conservation policies. The development and application of spatial analysis methods for developing and testing ecological theory at landscape, regional and national scales is a major theme of this project area. National and regional influences of climate, land cover, and soil on species distribution are analysed with an exploratory spatial analysis technique that generates hypotheses describing the association between the species and its environment for different geographic locations. Methods for description of uncertainty in the spatial data inputs have also been developed and incorporated into the spatial analysis technique to control error propagation into model output (Figure 1). The explanatory and predictive hypotheses provide insights into large-scale influences on species ecology and form the basis for conservation evaluation and biodiversity assessment. The significance of each of the spatial analysis techniques, the methods for description of uncertainty of spatial datasets, and incorporating error analysis into spatial analysis, is demonstrated by the international recognition they have each received.

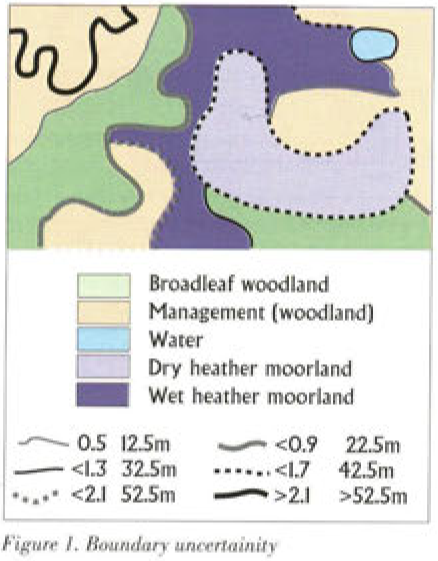


Figure 1. Boundary uncertainity

- The research has led to funding from Scottish Natural Heritage to develop a biogeographic zonation for Scotland and has formed the basis for a joint seminar at MLURI organized with the CSIRO Division of Wildlife and Ecology, on "spatial analysis for modelling wildlife distribution".

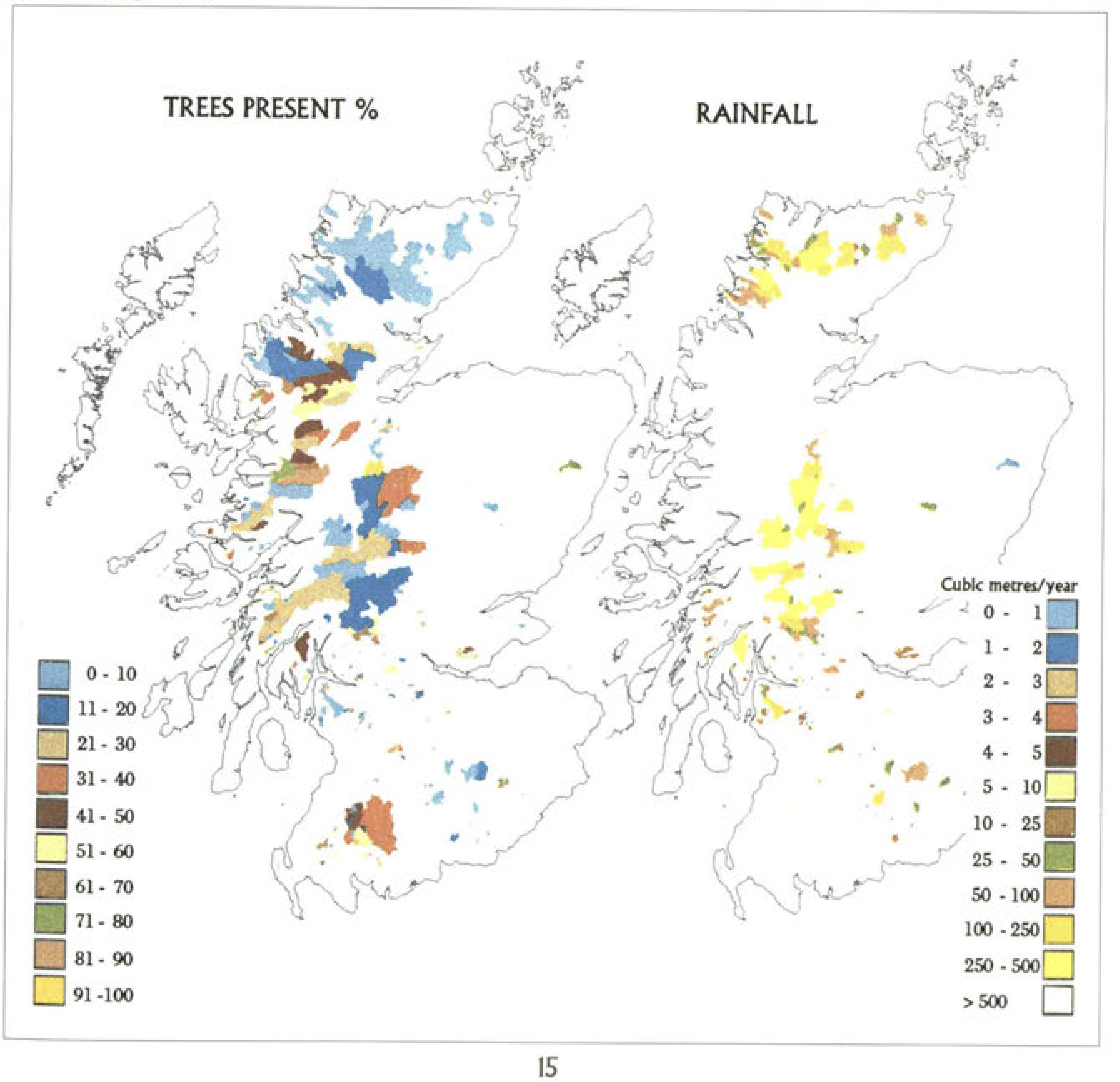
ENVIRONMENTAL IMPACT ASSESSMENT

We have designed and implemented environmental impact assessment (EIA) techniques to allow appraisal of proposals that aim to develop rural landscapes. Development of dynamic EIA techniques for identifying and quantifying the impacts of land use changes is a more recent challenge. Initial research has focused on the creation of a GIS-based environmental impact modelling facility for water quality assessment. Building on research in the MLURI Acidification Project, the water quality model MAGIC is being interfaced to a GIS database which includes river network, soils, topography, climate and land cover data (Figure 2). A flow pathway model has been developed and implemented in ARC/INFO in which the river network segments are used to weight the effects of the chemical and physical characteristics of soils and land cover on rivers. From this model, catchments have been classified according to physical and chemical characteristics. By using the topological connectivity between sub-catchments, the model can be scaled-up to look at whole catchment water quality. The implementation and output of the catchment EIA modelling tools are being used for resource and impact appraisal by a River Purification Board in Scotland.

- The approach to EIA developed in this project has also enabled MLURI, along with European partners in Finland, Sweden, and Portugal, to gain new funding under the AAIR-3 project. GIS and regional environmental models will be used to evaluate options for forest management.

Contact names:
Dick Birnie, Richard Aspinall, Alistair Law, Gary Wright, Neil Brooker, David Miller

Figure 2. Catchment characteristics. Percentage of catchment under trees and annual volume of rainfall input. Data derived from Land Cover of Scotland 1988 digital dataset.



ACIDIFICATION of SOILS and SURFACE WATERS

The objective of this project is to provide strategic information concerning the processes underlying the interactions between land use and atmospheric inputs of components that may lead to acidification of soil and water resources. In upland extensively managed land use systems catchment budgets provide important data while laboratory studies of processes such as sulphur dynamics, the decomposition of organic matter and mineral weathering provide understanding that can be integrated through modelling. The use of the critical loads concept provides information useful to planners and policy makers.

ATMOSPHERIC INPUTS

Using a series of field studies at a number of sites with different pollution loadings we have shown that inputs of soluble sulphate species to the soil environment is enhanced by:

- the ability of Sitka spruce to scavenge efficiently atmospheric pollutants and nutrients causing an increase in foliar concentrations of readily leached sulphate

SULPHUR DYNAMICS

The interaction of soluble sulphate species with soil components in both mineral and organic horizons influences greatly the mobility of sulphate from the soil environment to surface waters.

- In mineral horizons the chemistry of sulphur is dominated by adsorption processes involving specific mineral components (Figure 1).

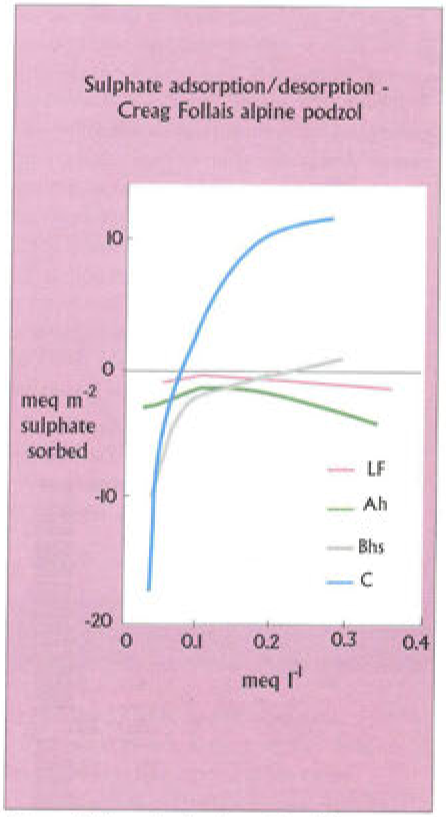


Figure 1. Adsorption isotherms for sulphate on organic and mineral horizons of a podzolic soil

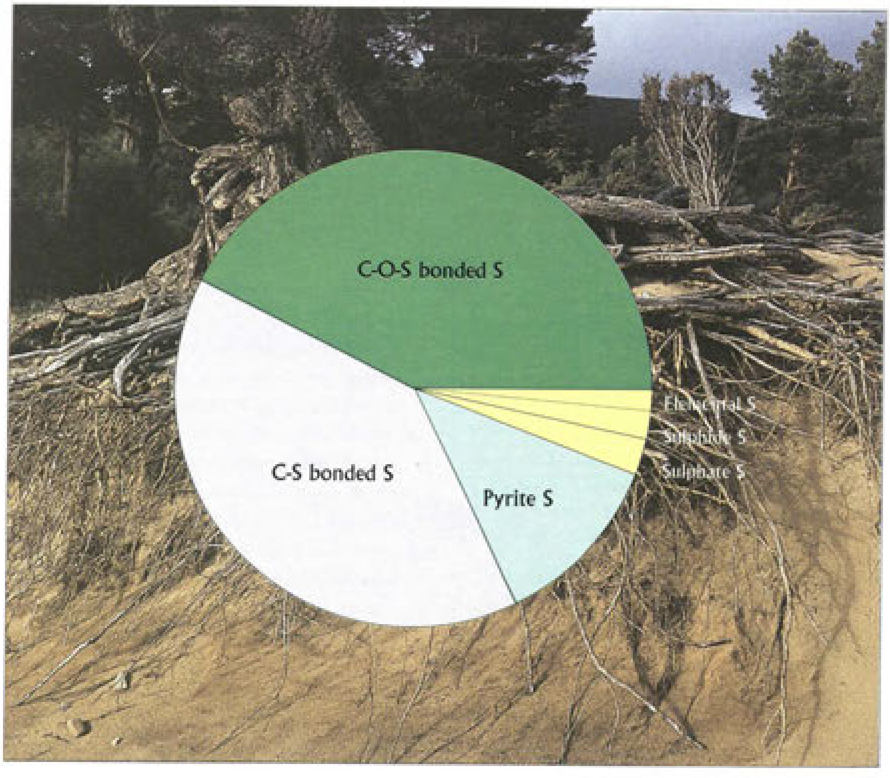
- In organic horizons, biological processes play an important role (Figure 2) and in peaty soils long-term inputs of sulphur tend to be taken up in organic forms or in reduced forms.

The ROLE of ORGANIC ACIDS

One of the principal characteristics of the soil resource affected by acidification is the presence of surface horizons in which organic matter accumulation is a dominant process and we have been able to show that:

- The acidity of many upland waters is related principally to the presence of organic acids released during the decomposition of organic matter
- Discrepancies between different methods (nuclear magnetic resonance and conventional hydrolysis) for the characterization of these materials may be due to experimental artefacts.

Figure 2. Distribution of various forms of sulphur in a peaty topsoil



MINERAL WEATHERING

Soil response to acidifying components is ultimately governed by the ability of weathering minerals to neutralize acid inputs by acting as proton acceptors and by the release of cations, such as Ca^{2+}. Studies carried out on a range of soils have demonstrated that:

- The relationship between mineral weathering rates in specific catchments are usually consistent with their acidification status.
- Strontium isotope methods may reconcile some of the anomalies that exist for specific catchments.

MODELLING APPROACHES

From the data obtained in extensive field work on well-characterized sites and the knowledge obtained from studies of the key processes in the acidification process a range of modelling approaches has been developed and applied. These include:

• wide area modelling, using the critical loads approach and the soils data held here at the Institute (Figure 3) augmented by a process-based steady state model.

• water quality modelling through our continuing involvement with the use, development and application of the MAGIC model at the catchment scale.

• linkage of water quality models with economic appraisals, in collaboration with the Institute's Environmental and Socio-economics group (Figure 4).

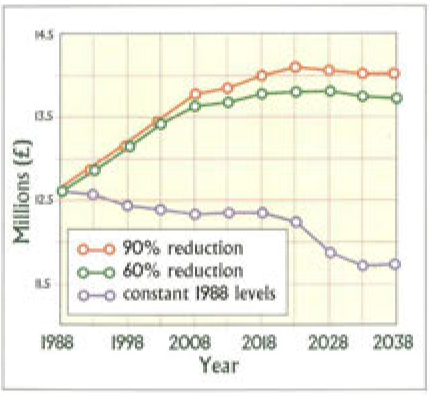


Figure 4. Economic impact of various emission scenarios on value of fishings

• thermodynamically derived models indicate that soluble aluminium-silicate complexes do not play a significant role in the chemical speciation of aluminium in acidified waters (Figure 5) and therefore cannot attenuate greatly the biological impact.

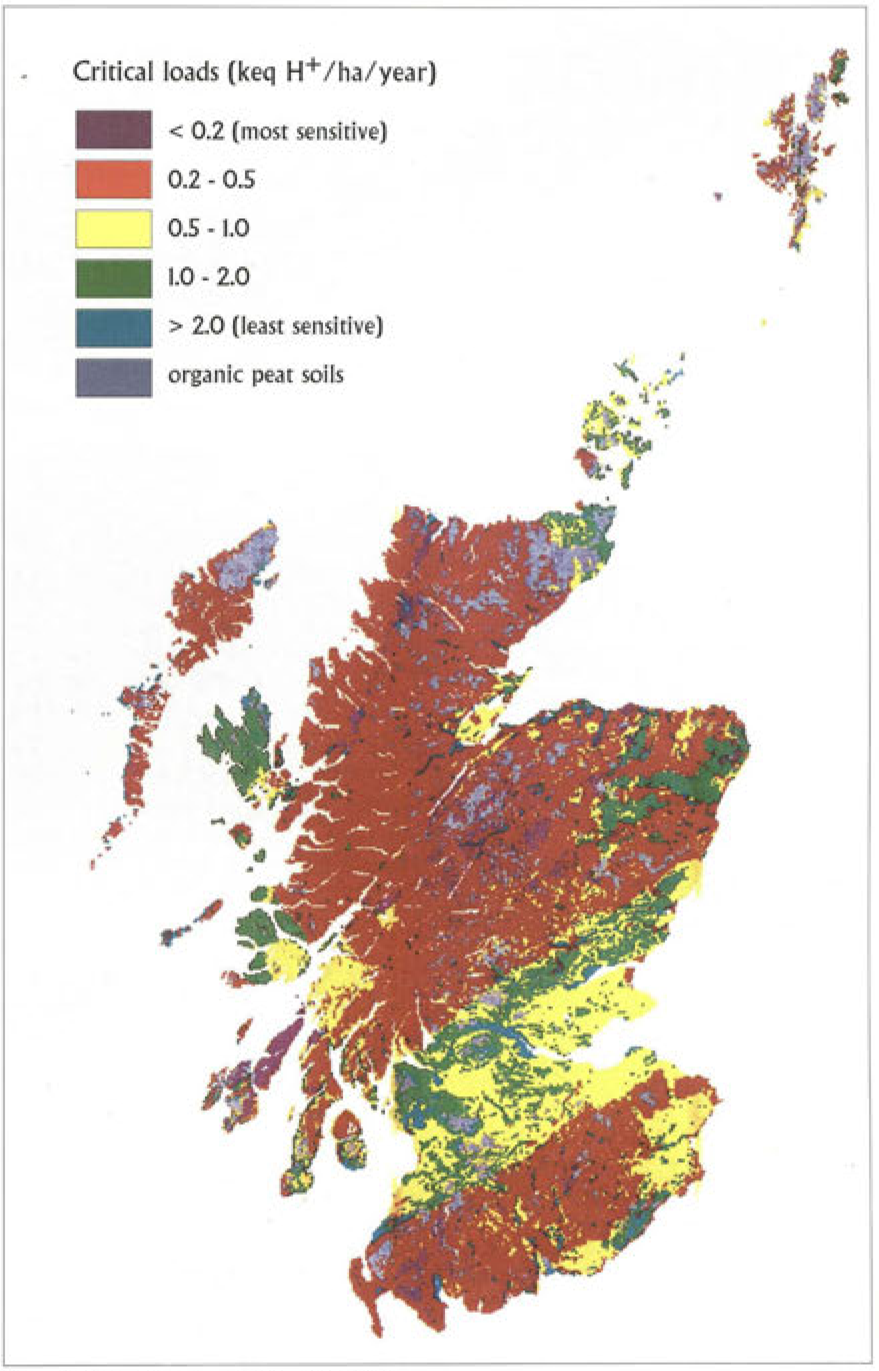


Figure 3. Critical loads of acidity for Scottish soils based on an empirical assessment

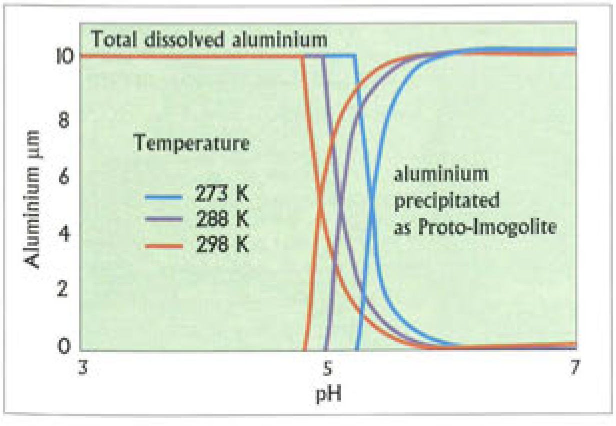


Figure 5. Influence of pH and temperature on the stability of alumino-silicate complexes in aqueous solutions

Contact names

Jeff Wilson, Hamish Anderson, Derek Bain, Martin Cheshire, Steve Chapman, Bob Ferrier, John Miller, Claire Bedrock, Simon Langan, David Lumsdon

SOIL POLLUTION

This project seeks to provide strategic information on the distribution, fate and impacts of pollutants on the soil environment. The pollutants under study include:

- **potentially toxic elements, such as lead, copper, zinc, cadmium and nickel**
- **radionuclides, such as cesium and silver**
- **organic micropollutants, such as the polychlorinated biphenyls and polyaromatic hydrocarbons.**

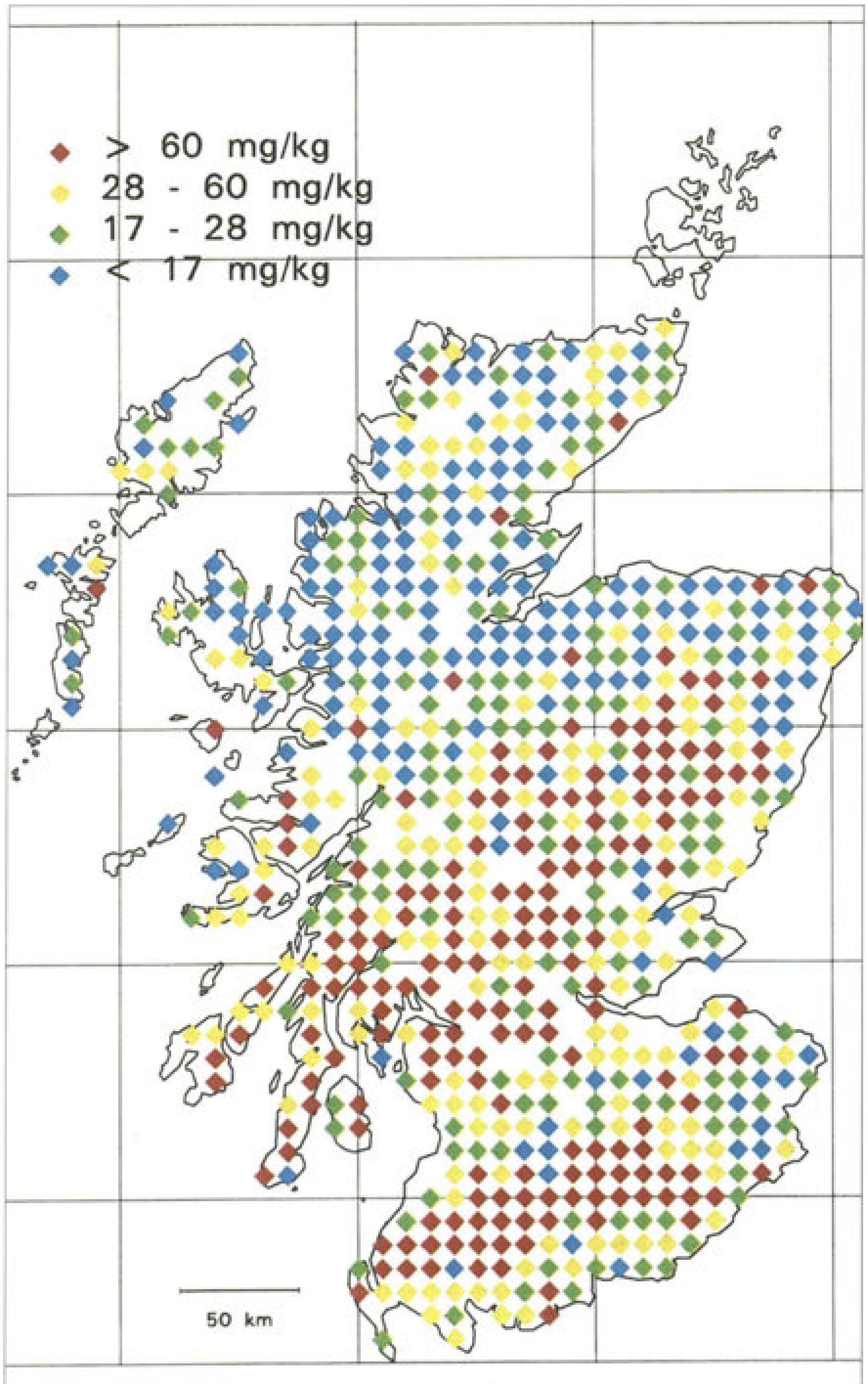


Figure 1. Distribution of aqua regia extractable lead in Scottish topsoils

POTENTIALLY TOXIC ELEMENTS

Sources of potentially toxic elements

The use of heavy-metal containing sewage sludges on agricultural soils will result in increased concentrations of potentially toxic elements (PTEs) in the soil environment and we are currently involved in the study of soils from:

- a series of collaborative field studies with ADAS and the Forestry Commission and,
- a UK network of long-term sites designed to provide a definitive resource for future studies.

It is important to recognize, however, that there are other sources of PTEs in soils and a recently completed geochemical atlas shows how heavy metal contents (Figure 1) can be influenced by:

- geological features, as expressed through the soil association concept,
- pedogenic processes, such as the accumulation of organic matter
- anthropogenic sources as seen in their spatial distribution.

Interaction with soil components

The development and use of stable isotope techniques has:

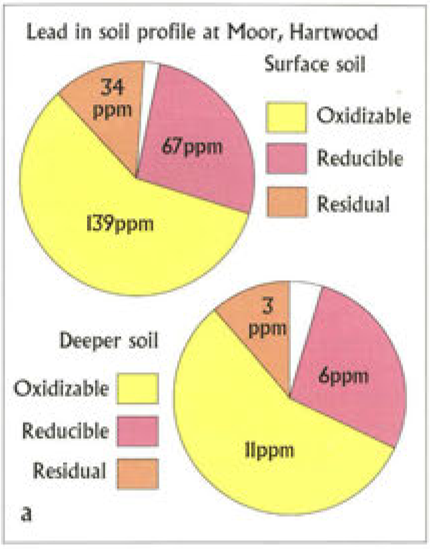
- enabled the source of anthropogenic inputs of Pb to be defined and,
- in combination with selective dissolution, provided information on the fate of heavy metals entering soils (Figure 2).

The ultimate goal must be to understand the complex range of interacting processes that influence the bioavailability of metals on a mechanistic basis but, at this stage:

- operationally defined fractionation is an important tool, particularly when combined with direct methods for the identification and analysis of the phases present in contaminated soils (Figure 3).
- surface complexation modelling, used successfully in accounting for competitive interactions between Al^{3+} and Cd^{2+}, also has a major role

Impact on soil micro-organisms

One of the most susceptible components of the soil environment to heavy metal pollution is the soil microbial biomass and in this area significant advances have been made in:



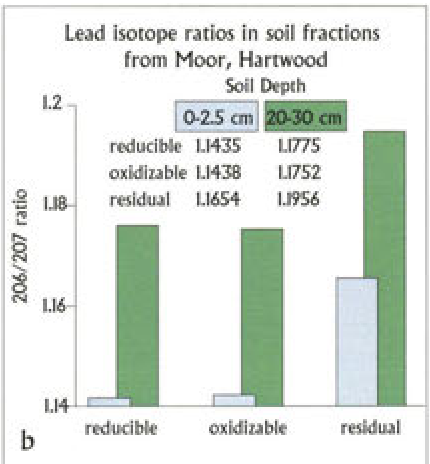
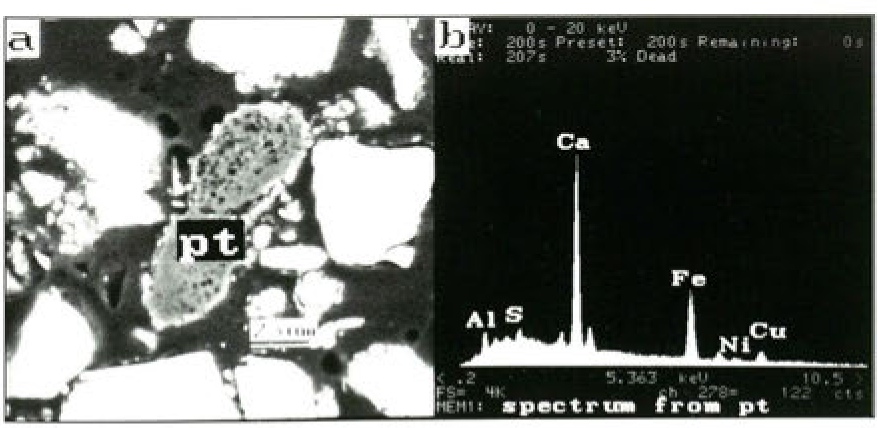


Figure 2a. Fractionation of Pb in topsoil and subsoil by selective dissolution
Figure 2b. Isotope signatures of extracted Pb from topsoil and subsoil

Figure 3(below). Backscattered electron image of contaminated soil (pt - particle of organic matter) left. Elemental analysis of 'pt' showing concentration of Cu (right)



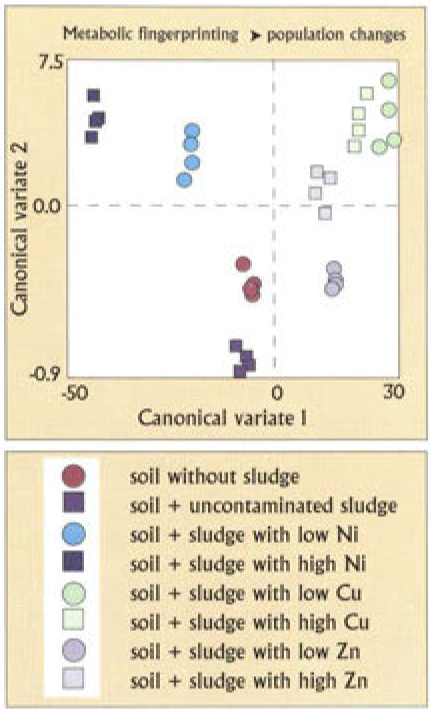


Figure 4. Canonical variate analysis showing the changes in the metabolic fingerprints of microbial populations as a result of applying sewage sludge contaminated with different heavy metals

- the use of genetically manipulated organisms implanted with the *Lux* gene as an luminescent indicator of the impact of pollution on soil micro-organisms
- the development of single carbon source utilization tests as a fingerprinting technique for soil microbial communities (Figure 4) and,
- to indicate the susceptibility of micro-organisms with specific functionality to damage.

RADIONUCLIDE POLLUTION

Work on the fate of radiocesium in organic soils has now been completed and we have shown that:

- Cesium is initially held at organic exchange sites from which it can participate in biological cycling
- It is then transported to mineral components where it is rendered inactive by ion fixation processes.
- Even in the highly aggressive environment of podzolic organic horizons mica is relatively stable in some soils.
- For the first time it has been possible to examine the ion-exchange process on particular sites using a sophisticated spectroscopic technique, X-ray photo-electron spectroscopy.

ORGANIC POLLUTANTS

Assessments have been completed of:

- the distribution of polychlorinated biphenyls (PCBs) on four transects across Scotland and,
- soils, vegetation and animals following the *Braer* tanker accident off Shetland and a study is now under way
- of the distribution of polyaromatic hydrocarbons (PAH) in the soils from the PCB transects

Contact names

Ed Paterson, Jeff Wilson, Martin Cheshire, Alistair Smith, Jeff Bacon, Colin Campbell, David Lumsdon, Steve Hillier, Hans Meeussen

SOIL NUTRIENT DYNAMICS and ENVIRONMENTAL IMPACTS

The project studies the processes governing the dynamics of nutrients in soils, their availability for uptake by plants and the environmental consequences of their loss from soils by erosion, runoff and leaching. Strategic research quantifies the dynamics of nitrogen and phosphorus (particularly in organically-complexed forms) in predominantly acid soils, covering a range of fertility.

Research on nitrogen dynamics studies the impacts of pollution by atmospheric N deposition on the nitrogen dynamics of soils, concentrating on organic fractions. This work aims at defining critical loads of nitrogen for peatlands. Study of soil phosphorus dynamics has also highlighted the quantitative importance of organic phosphorus in solutions from a range of soils under different vegetation types. Accordingly, we are determining the mechanisms by which plants utilize this resource for growth. Since organic N and P are mobile in soils and readily lost to surface waters, we are also determining the consequence of such losses for the eutrophication of rivers and estuaries.

Soil nitrogen dynamics

Deposition of inorganic nitrogen from the atmosphere can alter the carbon balance in peat bogs by stimulation of microbial activity causing increased emissions of carbon dioxide and methane. We are studying the impact of inorganic nitrogen on the microbial biomass carbon and nitrogen in the profile of an undisturbed raised bog as part of an EC funded project involving France, Finland, Switzerland Poland and Estonia. We have shown that;

• Microbial biomass varies significantly with depth in the profile of the bog (Figure 1)

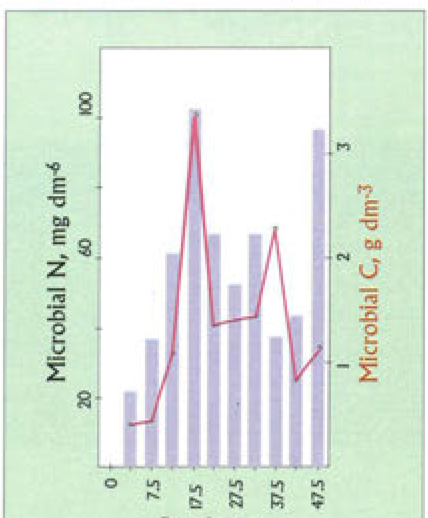


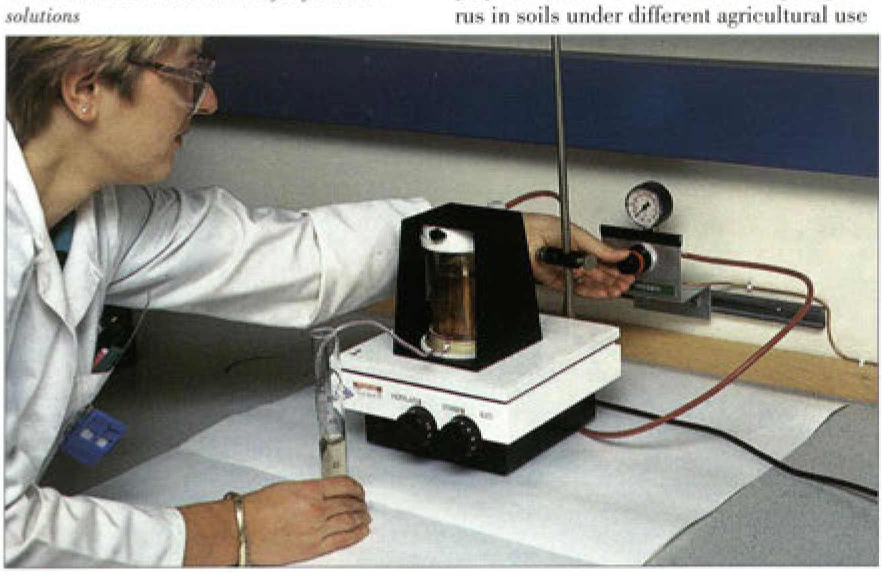
Figure 1. Microbial biomass C and N from the surface of a Sphagnum magellanicum *carpet*

• The most active zone corresponds to the aerobic layer of moss litter

• The surface moss vegetation is effective at absorbing ammonium and nitrate and in response releases dissolved organic nitrogen

• Calculations of the Critical Load of nitrogen for peaty soils and associated waters will be improved by including the dissolved organic nitrogen fraction

Figure 2. Ultrafiltration equipment used to determine the size distribution of P from soil solutions



Soil phosphorus dynamics

We are devising methods for fractionation of molybdate reactive phosphorus, dissolved organic phosphorus and dissolved condensed phosphorus in soil solutions. We have;

• Used ultrafiltration (Figure 2) to determine the size distribution of phosphorus fractions and instrumental techniques such as infra-red spectroscopy and electron microprobe analysis to determine the composition of retentates

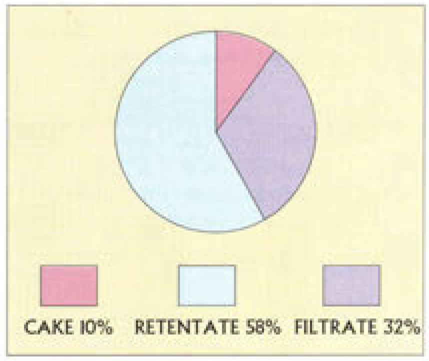


Figure 3. The recovery of molybdate reactive P (phosphate) after filtration of soil solution through a 10KD membrane

* Identified organic phosphorus as an important P component in leaching and shown a proportion of molybdate reactive P in soil solution to be associated with high molecular weight material or colloids (Figure 3)

* Established links with groups in the Netherlands and Portugal as part of an EC project to model the movement of phosphorus in soils under different agricultural use

Phosphorus uptake by plants

We are studying the mechanisms by which the roots of indigenous grasses take up organically-complexed P from soil solution. Solution culture techniques have been developed (Figure 4) to allow both synthetic compounds and soil solutions to be used as sources of P for plant growth. We have shown that;

• *Agrostis capillaris* plants can utilize P from a range of sugar, adenosine and amino phosphates when cultured under sterile conditions

Figure 4. Experiment studying uptake of organically-complexed P by Agrostis capillaris *from a solution of synthetic compounds (left) and soil solution (right)*

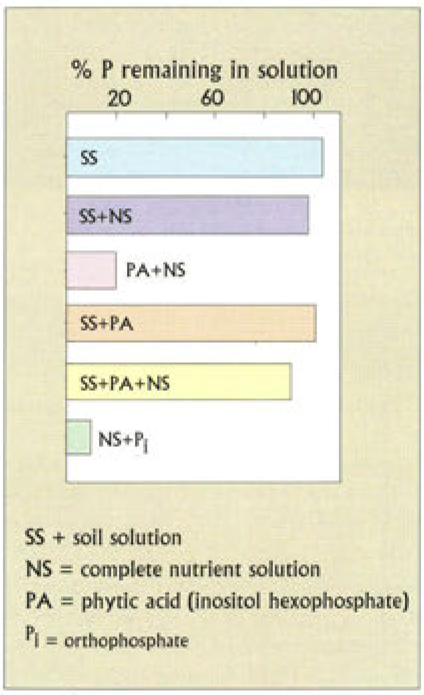


Figure 5. Uptake of phosphorus by Agrostis capillaris *seedlings from several sources over one week, measured by the amount of phosphorus remaining in solution*

• Uptake of P from phytic acid or soluble organic P in soil solutions only occurs if a nutrient solution (minus P) is provided (Figure 5)

The particular components of the nutrient solution important in allowing roots to access organic P in soil solutions are being identified.

Contact names

Pete Millard, Alan Macklon, Tony Edwards, Charlie Shand, Berwyn Williams

Nutrient losses from soils

We are quantifying the relationships between land use and the amounts and chemical forms of nitrogen and phosphorus loss to aquatic ecosystems. We have shown that;

• Soil erosion is size selective for the finer material and this component also contains a greater proportion of the total soil-P. This has been shown for a range of contrasting European soils

• Nitrate leaching is strongly influenced by land use

• Soluble organic nitrogen can make a significant contribution to total N losses, particularly for upland freshwater situations

The interactions between land management, nitrogen cycling and eutrophication of rivers and estuaries are starting to be modelled at the whole catchment scale, in collaboration with the Scottish Agricultural College, Marine Laboratory, Institute of Hydrology and North-East River Purification Board. This will provide the basis for developing a management plan for nitrate vulnerable zones.

Scientists from France, Finland, Switzerland, Poland and Estonia discussing peat bog sampling procedures as part of an EC project

ASSIMILATE PARTITIONING and INTERNAL CYCLING

With changing patterns of land use, trees are increasingly being grown in a wide range of systems, including farm woodlands, long rotation set aside and as biomass crops, in addition to natural ecosystems and plantation forestry. In such systems fertilizers are seldom applied. The majority of nutrients used for growth, therefore, come from decomposition of soil organic matter and leaf litter by soil microbes and the internal cycling of nutrients. However, these changes in land use can afford increased opportunities for managing trees as crops. This project studies the main processes regulating nutrient supply to and use by trees for growth. This will enable the consequences of different management strategies, such as choice of species and tree spacing, fertilizer inputs and weed control, thinning, rotation length and harvesting techniques to be assessed in the context of sustainable land use.

We are quantifying the impact of nutrient supply on the processes of carbon and nutrient assimilation and partitioning, and the subsequent effects of rhizosphere carbon flow and soil microbial activity. The internal cycling of nutrients is also being studied to determine the effects of management on nutrient storage and remobilization for tree growth.

ASSIMILATE PARTITIONING

We are quantifying the impact of whole-tree harvesting on long term site productivity, in collaboration with the Forestry Authority at Kielder Forest. We have shown that:

- Harvest residues aid tree establishment through increased shelter and reduced competition from weeds
- Growth responses can last more than ten years
- While whole tree harvesting can be attractive due to easier site access, long-term site productivity can be impaired

RHIZOSPHERE CARBON FLOW and SOIL MICROBIAL ACTIVITY

We are quantifying rhizosphere carbon flow from trees and its impact on soil microbial diversity and activity in relation to nutrient availability. We have shown that:

- The diversity of microbes in the rhizospheres of different tree species varies both qualitatively and quantitatively (Figure 1)
- These rhizospheres contain different levels of enzyme activity involved in carbon mineralization (Figure 2), possibly reflecting differences in carbon substrates available for microbes to utilize
- Carbon substrate utilization profiles of microbes from the rhizosphere of different tree species vary (Figure 3) due to contrasting abilities to use carboxylic acids.

A sterile growth system has been developed to enable characterization of root exudates (Figure 4). We are also developing molecular techniques, in collaboration with Aberdeen University, to enable genetic diversity (rDNA analysis), *in situ* presence (rRNA probes) and activity (molecular marking) of soil microbes to be determined.

Figure 1. Bacteria, actinomycetes (top), yeasts and fungi (bottom), isolated from the rhizosphere of hybrid larch, Sitka spruce and sycamore

Figure 2 (below). Enzyme activities in the rhizosphere of larch, spruce and sycamore

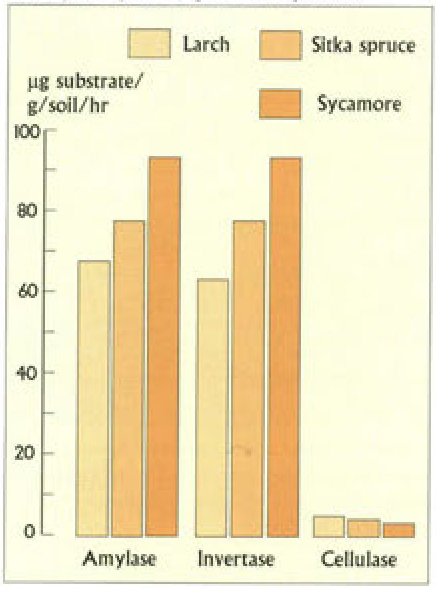
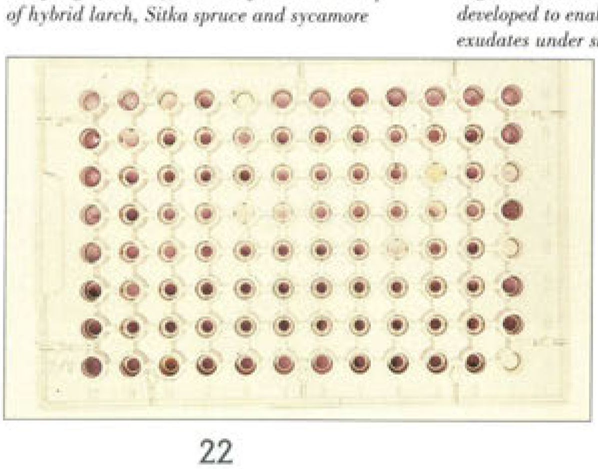


Figure 3 (below left). Biolog microplate containing 95 different carbon sources, used to metabolically fingerprint microbial communities.
Figure 4 (below right). Microcosm apparatus developed to enable characterization of root exudates under sterile conditions



One of our field sites in Kielder Forest

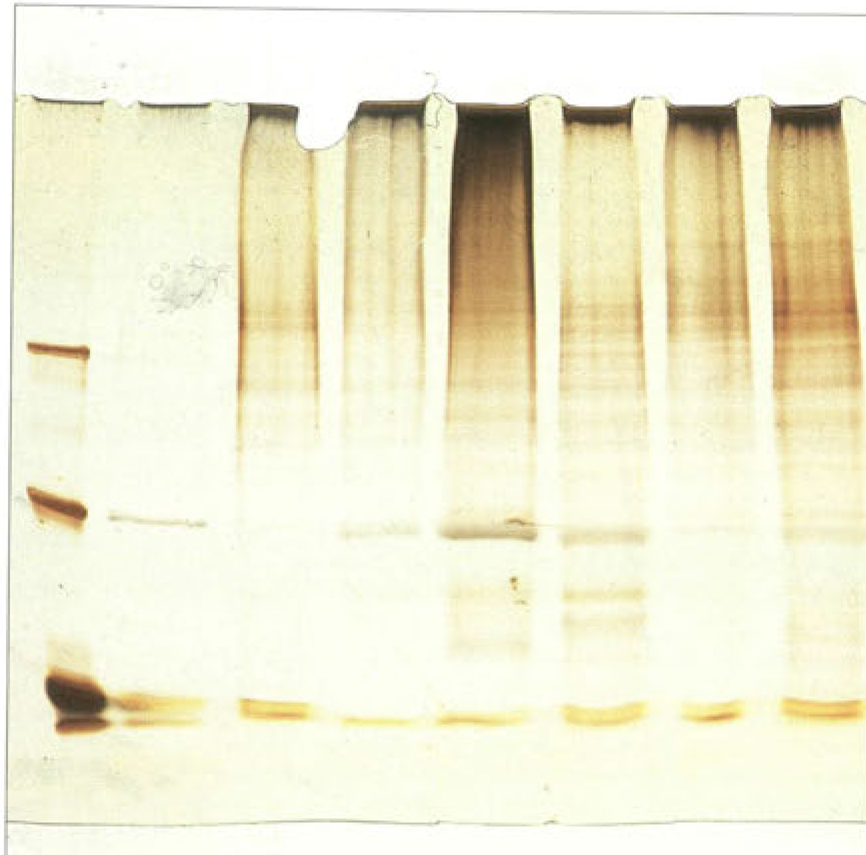


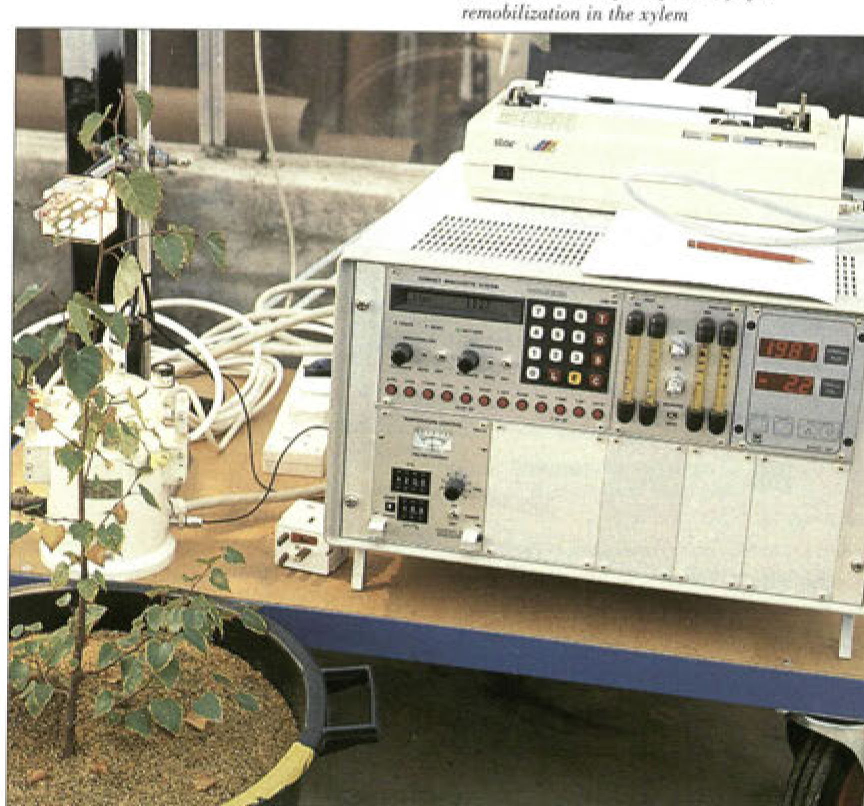
Figure 5. Storage proteins isolated by gel electrophoresis from the bark of Betula pendula

INTERNAL CYCLING

We are determining the impact of nutrient supply on nitrogen storage and remobilization for tree growth. Techniques are being developed to enable N storage to be quantified in the field without the need to harvest whole trees. We have:

- Characterized bark storage proteins by gel electrophoresis and quantified their importance for N remobilization in spring (Figure 5)
- Used ^{15}N techniques and analysis of amino acids in xylem sap exudates to quantify the duration of N remobilization in spring (Figure 6)
- Established experiments to quantify N storage in relation to seasonal growth in fertilized and irrigated apple orchards (in collaboration with Agriculture Canada)

Figure 6. Transpiration measurements on Betula pendula *leaves as part of a study of N remobilization in the xylem*



Contact names

Pete Millard, Derek Vaughan, Mike Proe, Sue Grayston, Angela Hodge

VEGETATION DYNAMICS

This project is concerned with understanding and predicting the impacts of large ruminants, such as sheep, cattle and red deer, on semi-natural vegetation and extensive grassland of the UK. Such a knowledge is required to enable government policy objectives on agriculture, wildlife conservation and landscape in the upland areas of the UK.

The approach to the research is to (a) understand the mechanisms and processes, particularly those associated with defoliation at a plant level, which influence competition between plants and hence lead to change, (b) describe and understand the outcome of different grazing pressures on the spatial and temporal changes in vegetation and (c) develop computer models to increase understanding of the underlying mechanisms and to predict the impact of grazing pressure on vegetation change. Some of the new developments in these approaches are described below.

PLANT RESPONSES to DEFOLIATION

After defoliation different plant species rely on root uptake and remobilization of N from roots and ungrazed tissue to different extents for regrowth. For example, in four commonly found pasture species experimental results have shown that there is an increasing reliance on remobilization of N in the order *Lolium perenne*, *Poa trivialis*, *Agrostis castellana* and *Festuca rubra* (Figure 1).

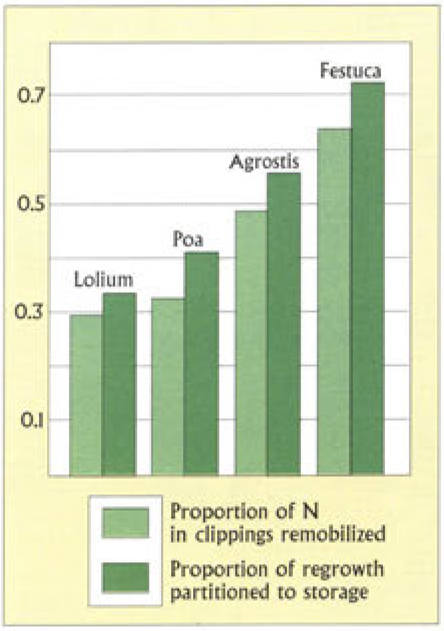


Figure 1. Comparison of remobilization of nitrogen from storage with partitioning of N to storage, predicted from a model, in four grass species after defoliation (Thornton, Millard, Duff and Buckland, 1993; C Birch and B Thornton, unpublished data)

In order to increase our understanding of the impact of defoliation on nutrient use and ultimately plant competition, a mathematical model is being developed to analyse the interactions between growth processes, nutrient partitioning and defoliation (Figure 2). The model is based on differential equations with end points defined as starting and ending at defoliation events.

The model's estimates of nitrogen partitioning to ungrazed tissue in these grass species is closely related to the patterns of remobilization observed (Figure 1).

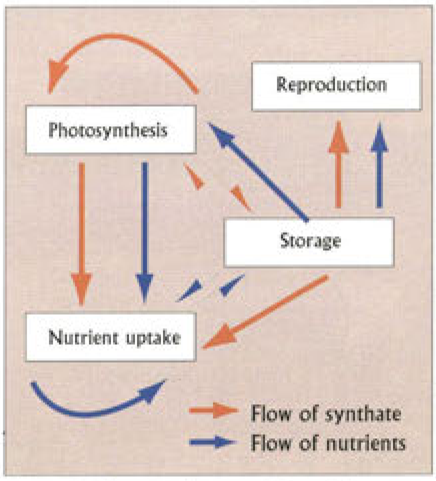


Figure 2. Schematic diagram of a model developed to explore factors affecting regrowth after defoliation.

The model is being validated by comparing the effects of different heights of defoliation on storage and remobilization as described by experimental data and predicted by the model. Ultimately the model will be developed to analyse outcomes of competition between grass species associated with grazing in extensive systems.

SPATIAL and TEMPORAL CHANGES

One approach to exploring temporal change is to set up experiments to study the effects of stocking density on the subtle changes which lead to transitions between heather and grass. Of particular interest in the context of the government policy of maintaining heather moorland in the UK is the rate at which degenerate heather can be encouraged to increase its cover by reducing the stocking rate of sheep. Figure 3 shows the results of an experiment undertaken on degenerate dry heather moorland in the north-east of England where a stocking rate of about 2 sheep per ha had been maintained for a number of years. It can be seen that a reduction of stocking rate to 1.4 or 0.7 sheep per ha over a 4-year period can lead to a considerable increase in cover of heather; there was also a slight benefit in terms of cover from grazing in summer rather than in winter at a stocking rate of 0.7 sheep/ha.

An alternative means of exploring spatial and temporal changes in vegetation on a large scale is by examining past changes in land cover over time. A recent

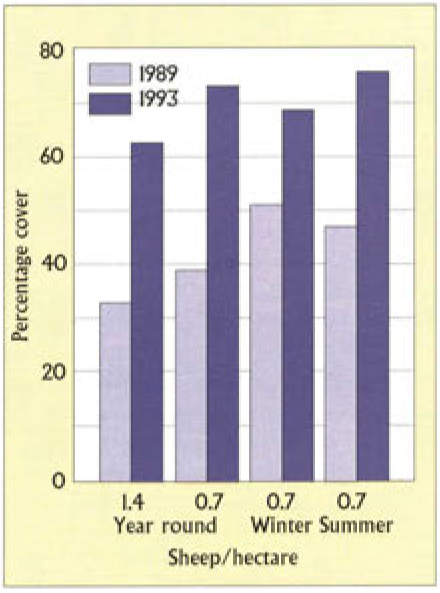


Figure 3. The effect of stocking rate of sheep and grazing management over 4 years on the increase in percentage cover of a degraded dry heather moor (Hulme, Merrill and Fisher, unpublished data)

study has examined this change between 1946 and 1988 for a 1000 km² area in the Cairngorms area of Scotland which consists mainly of upland vegetation types. The land cover data was derived from aerial photographic interpretation and the changes were

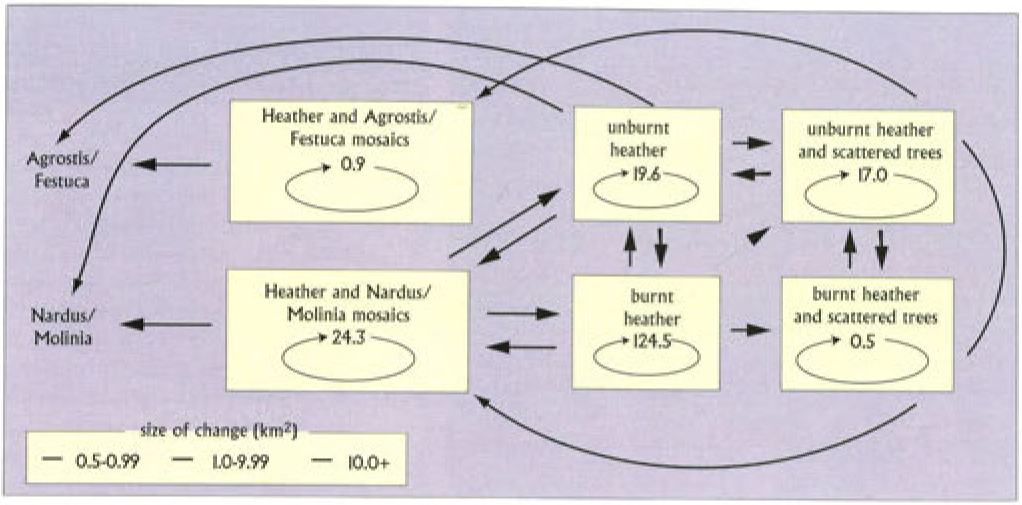
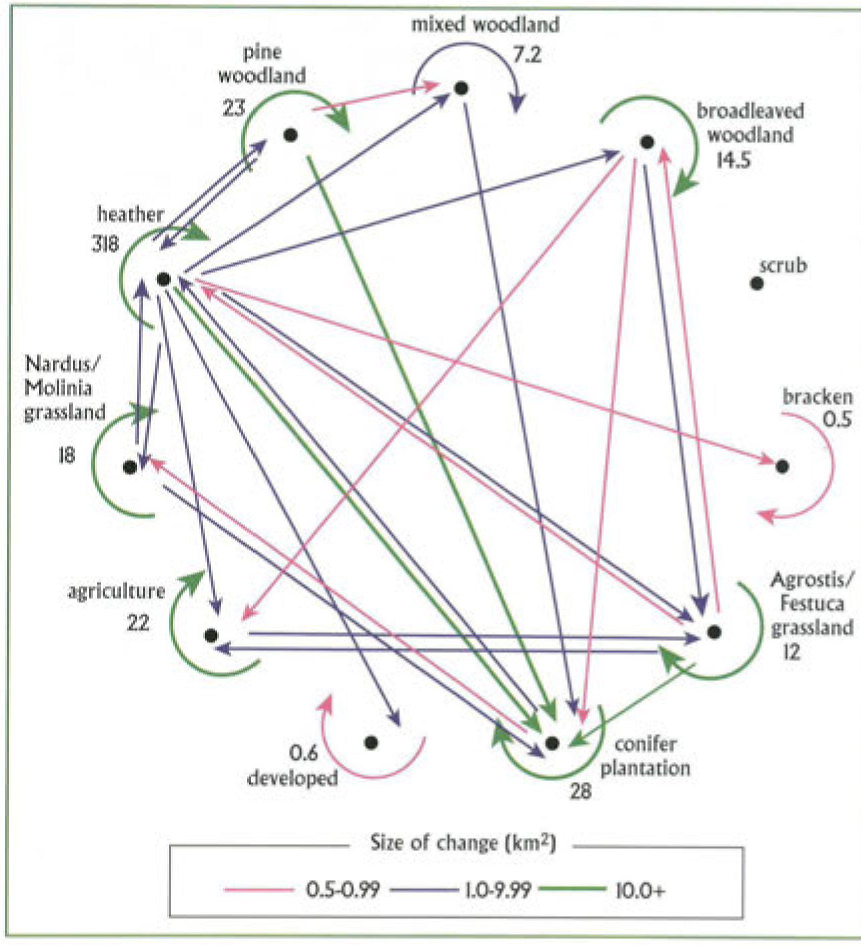


Figure 4. Transitions between heather, grass and scattered trees from 1946-1988 in an area of the Cairngorms (Hester, Miller and Towers, unpublished data)

Figure 3 (below). Main transitions between selected land cover categories from 1946-1988 in an area of the Cairngorms (Hester, Miller and Towers, unpublished data)



described using the framework of qualitative predictions of vegetation succession made by Miles (1985). The major impact on land cover change was through the planting of coniferous trees (Figure 3). Succession change in semi-natural vegetation types did occur although none of these changes were greater than 5 km². This was considered to be related to the low to moderate grazing pressure by sheep and deer over the period. Transitions between heather, grass and scattered trees are shown in Figure 4. Although the majority of transitions were between categories of burning of heather, with the greater transition being between burnt and unburned heather, there were considerable transitions between heather and grass which can be attributed to localized heavy grazing in interaction with other factors and these are currently being investigated.

COMPUTER MODELS

Predictive computer models have an important role to play in helping land managers, policy makers or policy implementers in their decision making. The Institute's Hill Grazing Management Model (HGMM) predicts the utilization rate by sheep of thirteen vegetation types and runs on most personal computers. Currently a further model is being developed which uses utilization to predict the impact of grazing on vegetation cover and plant community change. About 70 copies of the HGMM have been distributed in its first year and are being used in governmental and non-governmental agricultural and environmental agencies. The availability of such a decision-support tool has stimulated interest in expanding its capability and current research is increasing the number of plant species dealt with by the HGMM, providing a spatial component to the model and modelling the feedback of utilization rate on biomass production such that temporal change in plant communities can be predicted. In the further development of the HGMM decision-support system users are having an important part in defining the objectives of the system.

Contact names

John Milne, Pete Millard, Barry Thornton, Colin Birch, Alison Hester, Peter Hulme, David Henderson, Carol Marriott, Lorna Dawson, Andrew Nolan

HERBIVORE FORAGING

The objective of the research is to understand how domestic and other large wild herbivores forage in heterogeneous ecosystems, such as the semi-natural vegetation and permanent pastures of upland Britain. Such a knowledge is required to determine the impact of these animals on plant species and plant community change which links with research in the Vegetation Dynamics project and to provide concepts and quantitative information for the Ruminant Resource Use project.

The approach being taken is to increase our understanding through development of the ideal free distribution theory. The effects of microclimate and social behaviour as well as the distribution of vegetation, differing in its species and chemical composition, are being studied through a combination of experimental and modelling approaches.

MEASUREMENT of DIET COMPOSITION

To develop an understanding of the foraging behaviour of large herbivores, it is important to be able to measure their intake and to measure the diet that they select from a range of species and locations. The use of a natural marker system, based on the n-alkane content of the cuticular wax of all plants, developed successfully for sheep and cattle in the Institute, has been extended to other herbivores, such as goats, horses, pigs, red deer and South American Camelids. There is good agreement between known estimates of intake and estimates predicted using the n-alkane technique for these species (Figure 1).

Because the pattern of n-alkanes for each plant species is almost unique, diet composition can be predicted from a knowledge of the concentration of n-alkanes of different carbon chain length in faeces. The number of plant species that can be estimated is theoretically the same as the number of n-alkanes present. It has been shown experimentally that the approach can be successfully used to predict the composition of the diet when two species are present for a number of combinations of diet (Figure 2) and it has been used in field experiments to predict the composition of the diet for up to 5 plant species. Current research is demonstrating that other components of the cuticular wax, such as alkenes, can also be used as markers to expand the range of plant species that can be predicted from analysis of faeces samples.

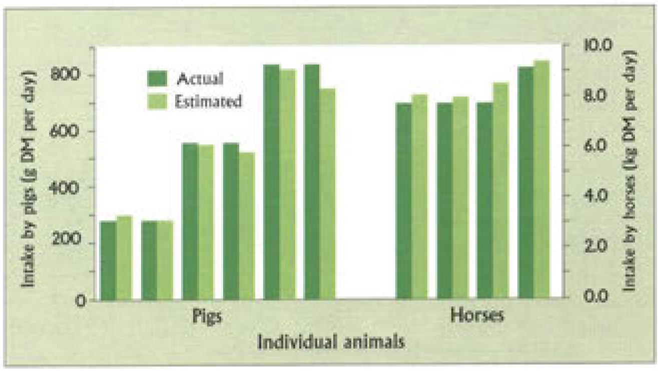


Figure 1 (above). A comparison of the actual intakes and those estimated using the n-alkane techniques for forage diets ingested by horses and pigs.

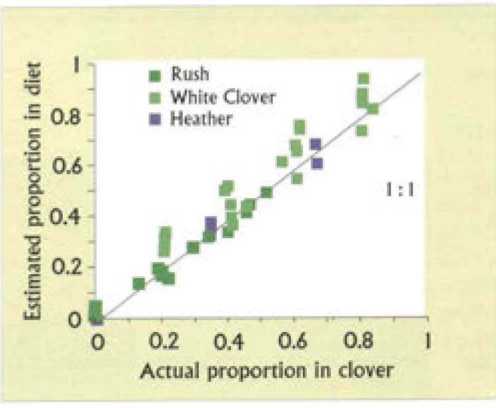


Figure 2 (left). The actual composition of the diet and that predicted by the use of n-alkanes when ruminants ingested diets containing two herbage species.

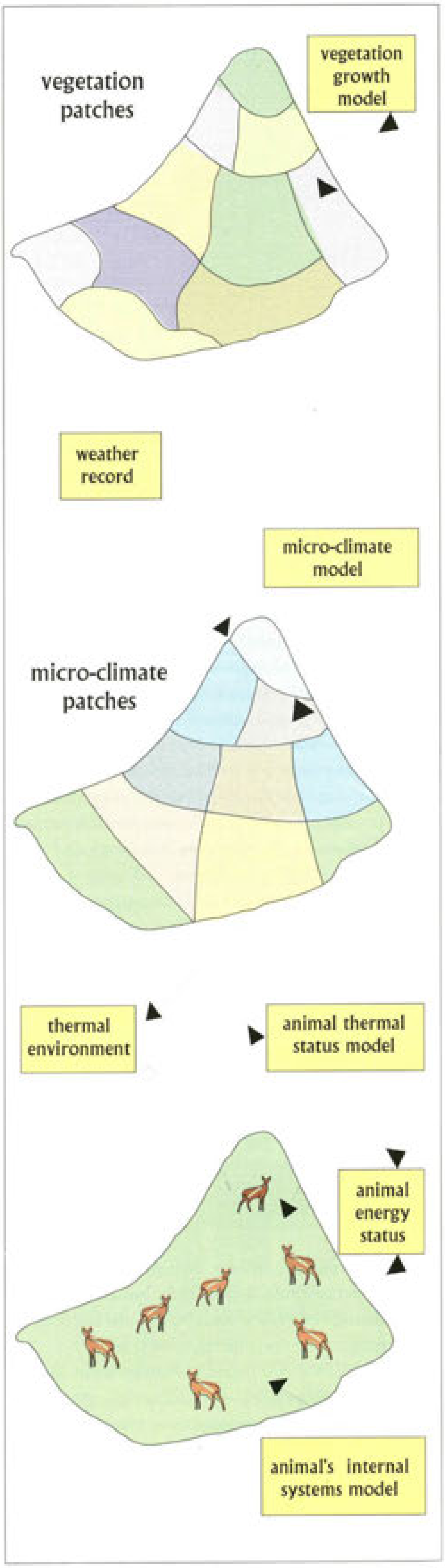


Figure 3. Diagrammatic overview of the information and the sub-models used to predict the location of large herbivores grazing heterogeneous ecosystems.

FORAGING in HETEROGENEOUS ECOSYSTEMS

Efforts to predict the impact of grazing by wild herbivores on sensitive vegetation have identified the need for predictions which take into account individual-animal behavioural differences and influences other than intake rate. To this end a model has been developed, based on ideal free distribution theory, which matches herbivore density to resource availability. This model (Figure 3) extends the ideal free distribution theory by taking explicit account of individual variation and influences of microclimate on animals' ranging behaviour. The distribution of vegetation resources and microclimate are modelled using a Geographical Information System (GIS) in which animals, modelled as individuals, interact with the environment and with each other, resulting in predictions of time spent in locations throughout the habitat. The annual variation in biomass of the vegetation, including depletion by grazing is modelled on an individual patch basis.

From the distribution of vegetation on the island of Rhum, modelled in a GIS (Figure 4), probability of presence of red deer on a one-hectare grid basis over the same surface can be predicted (Figure 5). Spatial locations are given by x-y coordinates and herbivore probability density is given by the z ordinate. Colour shows results of census counts made by the Large Animal Research Group, University of Cambridge as a comparison. There was a good first-order agreement between predicted and measured animal densities, showing the importance of vegetation in determining location. Deviations from the model predictions were identified which may reflect the importance of aspects of microclimate, other than those modelled, and the effects of social behaviour on vegetation change. Current research is exploring further the importance of microclimate and social behaviour effects and how these can be modelled.

Contact names

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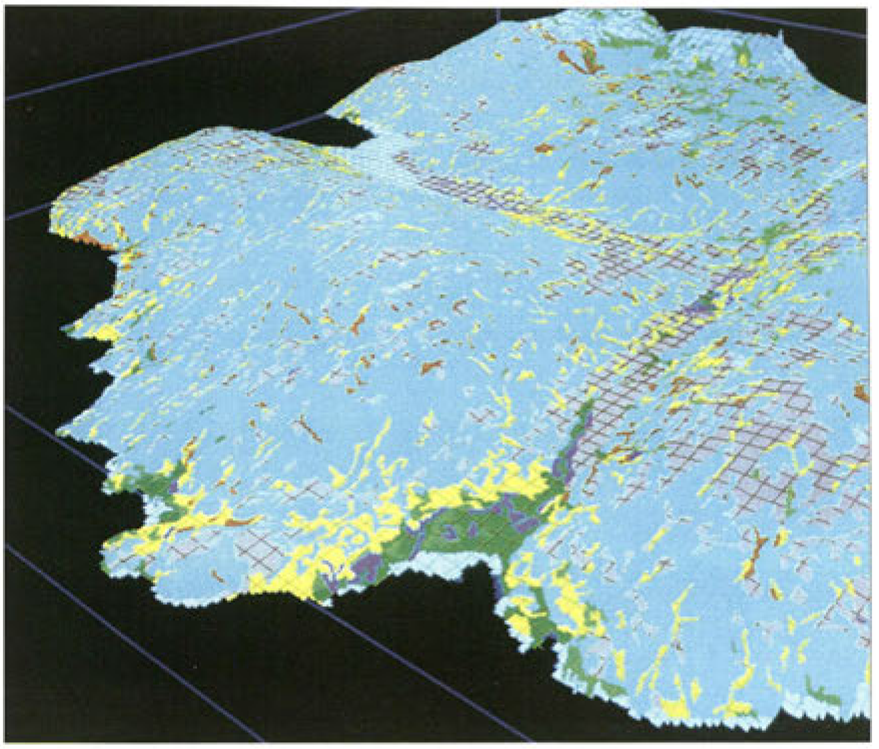

*Figure 4. Distribution of vegetation on part of the island of Rhum. The colour coding is blue: wet heath (*Calluna, Tricophorum, Molinia *spp), purple: blanket bog (*Calluna, Eriophorum *spp), yellow:* Molinia, *Green:* Agrostis-Festuca *grassland, Orange:* Nardus *grassland.*

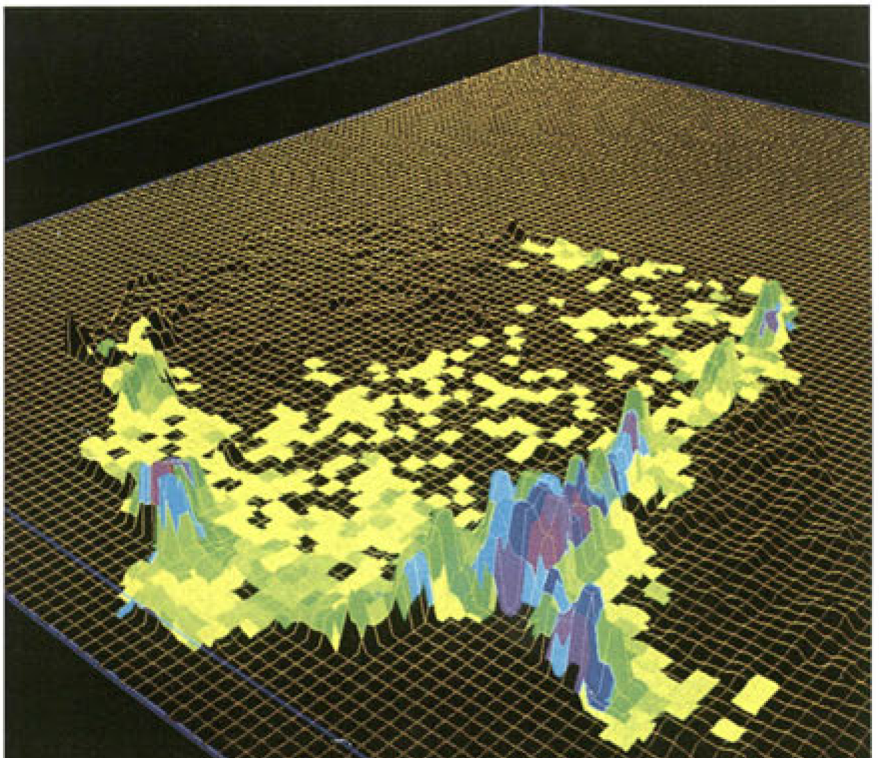

Figure 5. Comparison of red deer sightings from field observation on the island of Rhum with model prediction. Field sightings described by colour code: black -0, yellow through green, blue, purple to red 1 - 200 sightings. Predicted number of sightings is given by magnitude in z-direction.

RUMINANT RESOURCE USE

The aim of the project is to identify options for land use by ruminants and to investigate the biological properties of those systems. This is being done with respect to agricultural output and efficiency, environmental impacts and the welfare of the animals. Within the EC there are surpluses of many agricultural commodities, particularly some traditional livestock products which form the basis of output from many hill and upland areas of the UK and the rest of Europe. There is also concern about the impact of agricultural management practices on the environment and on animal welfare. In general, current EU and UK Government policies encourage the extensification of production systems and diversification of the rural economy. Within this context we are concentrating on developing principles concerning the utilization of semi-natural vegetation and permanent pasture resources by populations of traditional and alternative ruminant species. The research focuses on grazing systems, animal fibre production and animal welfare.

GRAZING SYSTEMS

Research concentrates on the interaction of characteristics of individual ruminant species with the nutritional environment on land use efficiency and on how different ruminant species may be integrated in grazing systems either in mixed or sequential systems. Recent results include:

•An EU-funded research project, with participants in Ireland, France and Spain has demonstrated that mixes of cattle and sheep result in more even utilization of vegetation and enhanced output from *Nardus stricta*-dominant semi-natural vegetation compared with single species grazing.

•Goats can be used to enhance the clover content of mixed grass/clover swards to the benefit of a subsequent species such as sheep (Table 1).

•A new model of intake of parasitic nematode larvae by grazing sheep has highlighted the sensitivity of the vertical migration of larvae on the sward to weather conditions and the micro-climate within the sward (Figure 1) and has emphasized the importance of bite depth in determining intake of larvae.

Table 1 (right). Proportion of clover in the sward and performance of weaned lambs when grazing swards previously grazed by sheep or goats.

	Previous animal species	
	Sheep	Goats
Proportion of clover in the sward (dry matter)	0.13	0.20
Proportion of clover in the diet of weaned lambs (dry matter)	0.15	0.29
Weaned lamb herbage intake (kg dry matter/day)	1.05	1.33
Weaned lamb live-weight gain (g/day)	153	207

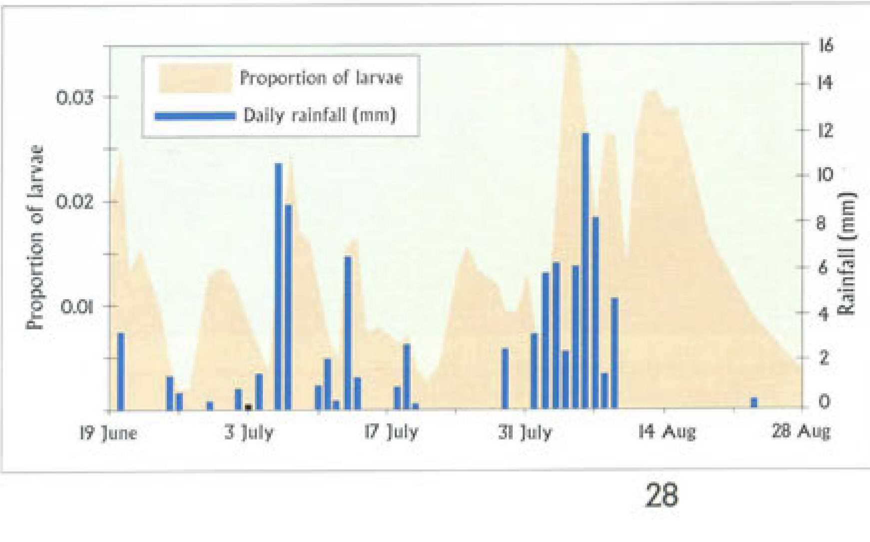

Figure 1 (below). Proportion of nematode larvae in relation to rainfall, predicted to be in the upper half of a grass sward grazed by sheep. Simulation based on weather records from Dyce, Aberdeen, 1973.

ANIMAL FIBRE

Fine fibre production offers an attractive alternative to traditional livestock enterprises in marginal areas of Europe. Our current research is concerned with the genetic and environmental factors affecting fibre quality, growth and shedding (photoperiod, temperature, nutrition and management). We are currently studying fine fibre from goats (cashmere), sheep (fine wool) and South American camelids. A full account of our research on quality animal fibre is given in the article on pages 6 to 11 of this report. Some highlights include:

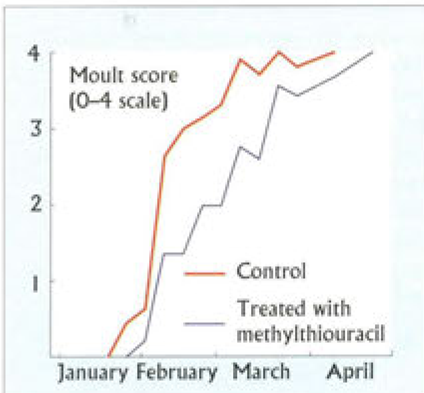

Figure 2. Treatment of cashmere goats with methylthiouracil (which blocks the conversion of T4 to T3) delays moulting.

•Thyroid hormones have been found to influence the date of shedding of the coat in cashmere goats (Figure 2).

•IGF-1 receptors have been found in hair follicles of cashmere goats.

Weaned lamb grazing grass/clover pasture previously grazed by goats.

•Development of the Bowmont sheep from the Shetland and Saxon Merino breeds. The top quality animals produce fleeces worth over £25 each.

•MLURI has been involved in establishing cashmere herds in Spain, Italy and Norway, and is coordinating an EU-funded research project in Spain, Italy, Germany and the UK. MLURI also runs the EU-funded European Fine Fibre Network.

The fleece of the new Bowmont sheep is worth up to £25.

ANIMAL WELFARE

It is often assumed that animal welfare problems are a feature of intensive agriculture only. This may not be the case. The farming of novel species and the keeping of animals in extensive systems of management raise their own welfare issues. The aims of our research in this area are to identify behavioural and physiological indices of stress which can be used to characterise stress in extensively managed ruminants and to assess the degree of stress caused by different management systems and procedures. We have:

•Developed new automatic blood sampling equipment to allow blood samples to be collected without the necessity of handling animals.

•Shown that repeated mixing of red deer causes an increase in agonistic behaviour and depresses cell-mediated immunity (Figure 3).

•Identified that the optimum group size for housed red deer calves to maximize performance and welfare is 15 to 20 (Table 2).

	Group size		
	10	18	28
Proportion of time			
lying	0.55	0.45	0.49
ruminating	0.11	0.21	0.08
Live-weight gain (g/day)	252	271	248

Table 2. The effect of group size on the behaviour and live-weight gain of housed weaned red deer calves

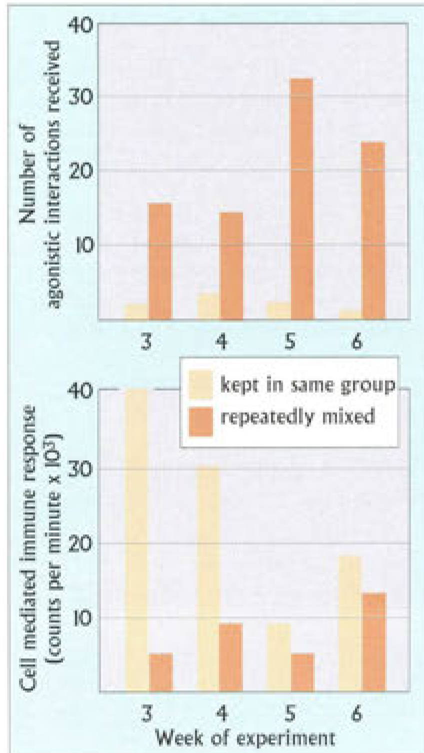

Figure 3. Agonistic interactions received and cell-mediated immune response in red deer yearlings kept in the same group or repeatedly mixed.

Contact names

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ENVIRONMENTAL and SOCIO-ECONOMICS

Rural land use is facing new pressures: the reform of the Common Agricultural Policy (CAP) substitutes direct payments to farmers for market support; new agri-environmental policies are being implemented, and greater incentives have been provided for commercial forestry. A key objective in our research has been to identify how farmers respond to new environmental measures and to measure benefits that environmental services can produce for the public. We have been developing and applying valuation methods which seek to place a monetary value on the benefits from improved landscapes, wildlife habitats and countryside facilities. One aspect of this research currently underway is an assessment of the benefits to the public from payments in two Environmentally Sensitive Areas of Scotland (Perthshire and the Western Isles). We have also researched the benefits from improved public access to the countryside using a case study in Grampian Region to determine what types of new facilities residents are willing to pay for in the Region. Finally, much conservation investment is being directed towards restoring valued ecosystems which have degenerated or are under threat. We are supporting the development of new policies by identifying the value ascribed by the public to different ecosystem designs, and mechanisms which will encourage landowners to re-create habitats and landscapes.

The landscape as it appears today (left) and as the new Caledonian Forest might appear 100 years from now (right)

FARMERS in the UPLANDS - Situation and response to environmental measures

Although agri-environmental policies represent only a small part of the agricultural support system, they symbolize a major change in the direction of government policy. Consequently, the move from supporting farmers for food production to supporting them for looking after the environment, involves a significant change in the culture of farming. This research project focused on the way farmers gave meaning to the changes occurring in agriculture, and to the growing importance of conservation issues. The study was done in southern Scotland, where farmers' perceptions of changing agriculture, in the light of the designation of the Southern Uplands Environmentally Sensitive Area (ESA) scheme, were examined. Tape recorded interviews with farmers were the main source of data.

Analysis of the interviews revealed that uncertainty was a very important concern of farmers. Changes in the CAP and the fear that support for farmers could not be maintained, influenced this. Additionally, many farmers felt they were increasingly dependent on, and controlled by governments because of the importance of subsidies in their income. The changing role of farmers in society was of interest; farmers were having to come to terms with new ideas about what it meant to be a farmer. Many felt that the status of farmers had declined: previously the public relied on farmers for food, now farmers found they were dependent on public support. Farmers' ideas about conservation, their views of nature, and the meanings they attached to conservation activities, were examined. It was apparent that farmers believed in 'looking after' their land, but they did this in different ways to conservationists. Many believed that the land and the natural environment should be productive, and that it was good for the land to be farmed. The differences between farmers and conservationists, in their interpretations of how best to conserve the countryside, are very significant, and explain many of the conflicts which arise between the two groups. It was also found that farmers had many ways of accommodating the changes in agricultural policy and the move to agri-environmental schemes, but that their main goal was to preserve their way of farming.

Deeper understanding of how farmers interpret what is happening to agricultural markets and policies, and the position of farmers in society is helpful in explaining some of farmers' reactions to the growing importance of agri-environmental schemes. Additionally by exploring the meaning that 'looking after the environment' has for farmers, their involvement in conservation can be better understood. This is critical at a time when environmental considerations are gaining priority.

ECONOMICS of ECOSYSTEM REGENERATION - Native Pinewoods

The Caledonian pinewoods, which once covered three-quarters of the Scottish Highlands have been reduced by timber felling, burning and grazing to less than 1% of their former distribution. Expansion of native Caledonian pinewoods is now encouraged and the government has established a target of 5000 new hectares of new pinewoods within the next four years. In addition to revenue from timber and stalking, new native pinewoods can generate a wide range of non-market benefits such as recreation and biodiversity enhancement. A recent study at MLURI has attempted to estimate the non-market value of a potential large new pinewood in Strathspey using the Contingent Valuation (CV) method. The approach relies on direct questioning of the general public about their willingness to pay for a specific

environmental change which is described using both textual and visual information.

A survey of visitors to Strathspey revealed that the annual willingness-to-pay (WTP) for creating the Strathspey Forest ranged between £0 and £250 per household with an average payment of £31. Over 80% of all visitors interviewed were in favour of the plan to create the forest, with only 8% actually preferring the landscape as it is now. The next stage in this research programme will be to extend the CV approach to the general population, including non-users, in order to estimate an aggregate WTP figure.

Valuation issues regarding the opportunity cost of the habitat which the pinewoods will replace, the re-introduction of extinct flora and fauna, and the appropriate location and scale of pinewood schemes will also be investigated. The insights gained through this research into the preferences and values held by our society towards pinewood restoration, are likely to be of considerable significance to the development and implementation of future policy.

ECONOMIC EVALUATION of the BENEFITS of COUNTRYSIDE ACCESS

The countryside access debate has been very prominent over the past few years and has seen significant steps forward towards improving arrangements for open-air recreation. These advances have been highlighted by the recent launch of the Scottish Natural Heritage document *Enjoying the Outdoors: a Programme for Action* which represents the culmination of a major review of access. MLURI has been a contributor to this review with a study which evaluated the costs of countryside access to landowners. MLURI is presently continuing this line of research with a post-graduate study which is evaluating the benefits gained by society from improving facilities for open-air recreation.

The first stage of the research involved the use of focus groups to identify the types of countryside improvements which are of importance to the public. The improvements identified included countryside path maintenance, path creation and the provision of countryside facilities.

The next stage involved the evaluation of the benefits gained from these improvements. This was achieved by using a Contingent Valuation Method survey. In this type of survey, respondents were given a description of the countryside improvements and then asked to state how much they would be prepared to contribute towards that improvement. Results from the main study are not yet available. However, findings from the pilot study show that households in Grampian were willing to pay an average of £30 per year for access improvements. The greatest concern was the maintenance of existing paths, rather than their upgrading or an extension of the path network (see Table).

The main study will allow a more detailed analysis of the benefits of countryside improvements. Such analysis is important for policy makers to enable efficient targeting of resources to maximize the benefits from expenditure on recreation.

Contact names

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Countryside improvement					
Path maintenance	Path upgrade	Creation of short paths	Creation of long paths	Provision of basic facilities	Provision of user-friendly facilities
£25.00	£7.90	£8.50	£9.95	£11.60	£6.70

Annual willingness of residents to pay for countryside improvements in Grampian (£)

THE HEALTH PROSPECTS OF HOMO SAPIENS EXAMINED WITHIN AN ECOLOGICAL FRAMEWORK

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The 18th Macaulay Lecture, November 24, 1994

Introduction

In this lecture the rapidly emerging complex problem of forecasting the impacts of global environmental change upon human health is examined. This will illustrate the general problems for science of addressing the consequences of perturbing complex natural systems - which, of course, includes managed agroecosystems. There are five issues which will be addressed.

1. Epidemiology as a way of determining the causes of human disease - and the limitations of the prevailing reductionist approach

2. An historical review of the interplay between human ecology, local environments and disease profiles over the lifespan of *Homo sapiens*

3. The current emergence of systemic global hazards to human health, with special attention to the likely impacts of climate change

4. The problems for science in attempting to predict these future impacts

5. Possible health impacts of other forms of planetary overload, including the sustainability of world food production

I. Epidemiology as a way of determining the nature and causes of human disease

First then, epidemiology. Epidemiologists are an infrequent breed among biomedical scientists. Since many people think that epidemiologists are specialists in epidermal diseases or that they only study epidemic outbreaks, epidemiology requires definition.

Epidemiology is the basic quantitative science of public health. It seeks understanding of the causes of disease and disability within populations, and ways of improving population health. As a 'quantitative science', it measures disease frequency, and compares health risks between categories of persons. It is predominantly an observational science. (After all, one simply cannot do an experiment, on humans, to see if ionising radiation causes leukaemia.) It picks up the real-world chips as, or after, they fall, and sifts through them in order to identify meaningful, perhaps 'causal', relationships.

Epidemiological research thus tells us that smokers have a seven-times higher risk of lung cancer than lifelong non-smokers. It tells us that HIV and cancer of the cervix are infectious diseases associated with particular behaviours; and in collaboration with laboratory science it identifies the causal agents of these infections. Epidemiology tells us that alcohol consumption increases the risk of road fatality and liver disease - but (better news here) it reduces the risk of heart disease and gallstone disease.

This thumbnail sketch of epidemiology reminds us that its basic research strategy is essentially reductionist. In this it conforms with the centuries-old legacy of mainstream Western science. That is: to understand the working of the whole, one studies, in detail, the working of selected isolated parts.

Beyond Reductionism, to Complexity

With this Newtonian reductionist approach we have notched up very many scientific advances. Today, however, we are beginning to sense the limitations of such a disaggregating type of science, as we are confronted by an array of larger-scale problems that arise from the inherent complexity of the world in which we live. The mathematically and logically precise world of Newton and

Descartes, disturbed early this century by the uncertainties of Einstein, Planck and Heisenberg, is now under siege by chaos, strange attractors, and complexity theory.

This word 'complexity' is rapidly entering the lexicon of contemporary science. Paul Davies and John Gribble (1991), two well-known popular science authors, have recently written: 'The paradigm shift that we are living through is a shift away from reductionism and towards holism; it is as profound a paradigm shift as any in the history of science.'

An important part of this planet's complexity is represented by the processes and the internal relationships of its wonderful ecosystems. Those systems are the fundamental milieu, the essential context, within which the limits to human population health are set. Accordingly, the health sciences now must find a way of dealing with the complexity - and with the inherent scientific uncertainties - of assessing how today's incipient global environmental changes might affect human health. From what I have learnt of the Macaulay Land Use Research Institute I sense that there are some similar ideas and strategies developing here, now that land use is seen to depend on understanding the nature and long-term needs of complex ecosystems - and can no longer be approached in a more mechanistic, utilitarian and often exploitative fashion. Land use science is thus becoming an integrative science, spanning many disciplines.

In one sense, the wheel may thus be coming full circle for epidemiology. Early last century - which represented the real dawn of formal epidemiology - early European epidemiologists examined the broad disparities in health between rich and poor, between urban and rural, between factory worker, merchant and aristocrat. Occasional notions of specific disease causation were overshadowed by notions of systemic insult and deprivation. Later, as the idea of specific contagion and the Germ Theory evolved, epidemiologists identified particular causes of infectious disease.

This century, epidemiologists have supplemented their earlier focus on infectious disease with increasing attention to nutritional deficiencies, then occupational diseases, then the social-behavioural sources of chronic diseases such as heart disease and diabetes, and, more recently, environmental health hazards. Most of this research has postulated the existence of specific exogenous causal factors - for example, vitamin deficiency, asbestos exposure, cigarette smoking, and particular urban air pollutants. Today, however, epidemiologists sense that maybe most of disease causation is not of that simple kind; that, mostly, there is a complex causal web.

Of course, epidemiologists have long understood that, in the causation of infectious diseases, there are interactions between infectious agent, aspects of environment, and characteristics of the human host. Or that genetic predisposition influences one's vulnerability to the heart-endangering effects of high fat diets. But this is not the same thing as understanding complex systems - that is, systems with feedback, with critical thresholds, and with assorted non-linearities. Yet it is human-induced disruptions of complex natural systems, at the global level, that is now casting a shadow over the sustainability of human health.

2. An historical review of the interplay between human ecology, local environments and disease profiles over the lifespan of Homo sapiens

We are a big-brained species, and we therefore have the distinctive capacity of being able to imagine the distant future. Nevertheless, it is, as yet, quite uncertain that we have the capacity to act on behalf of that more distant future. First, however, we should look back in time, to appreciate within an ecological framework the broad sweep of health and disease in the history of *Homo sapiens*.

Humans, alone among species, have been able to substantially loosen the bonds of the natural world's constraints - constraints that otherwise limit the size and activity of populations of species. Cultural-technological advances over the past 10,000 years - especially the harnessing of extra-somatic (that is, non-food) energy and the cultivation of food - have led to a sequence of population surges (Boyden, 1987). Compared to our estimated five million ancestors at the onset of agriculture, today's human population uses extra-somatic energy at a total global rate that is approximately one million times greater (Boyden, 1987). *Homo sapiens* now accounts for approximately 40% of the total terrestrial photosynthetic product (actual or potential): by growing plants for food, by clearing land and forest, by degrading land (both arable and pastoral), and by building or paving over the land (Vitousek *et al.*, 1986). If human numbers double, then, on this arithmetic, we would not leave much for other species - whose numbers are already declining at an accelerating rate largely because of human impact on natural habitat (Wilson, 1989; Soulé, 1991). Indeed, we are apparently living through the sixth, and fastest-ever, global extinction of vertebrate species - and it is largely one of our own making.

In this and other ways, we are now encroaching on a set of limits that have never before applied to human populations at the global level.

Cultural evolution: the shifting ecological equilibria

Overall, these deviations from the biologically-defined 'natural order' have conferred survival benefits on human populations. Hence the increases in human numbers and in life expectancy (Boyden, 1987; Powles, 1992). But it has not been all plain sailing.

In particular, a distinctive profile of infectious diseases has been evident at each stage of human cultural evolution. Microbes, with their brief generation time and potentially rapid genetic evolution, tend to fill newly available niches quickly. The recent rise of HIV is evidence of this - as is the recent emergence of various unfamiliar haemorrhagic fever viruses affecting human populations living in disrupted local tropical environments (Johnson, 1993; Levins *et al.*, 1994).

The long historical saga of human infectious disease can facilitate our thinking about human health within a broad ecological framework. Since the approximate time when *Homo sapiens* evolved from *Homo erectus* (around a quarter-million years ago), there has been a series of realignments in the ecological relationships between humans and their environment, including infectious disease agents. With some over-simplification, six phases can be identified:

Phase 1: 250,000-100,000 years before present (BP)

Early *Homo sapiens* lived at low density in tropical Africa (most probably) (Kingdon, 1993). Population growth was limited by three main things: by the need to find food; by predators; and by vector-borne infections. For infectious microbes that were spread between mammals by mosquitoes, ticks, flies or other 'vector' – for example, malaria or plague – the sparse human populations were thin pickings. Early humans may have thus provided incidental hosts, alongside other more numerous animal species as hosts. On the dietary front, some recent palaeontological evidence suggests that, seasonally, as early humans clustered around shorelines and rivers, they ate rather more fish than we have previously imagined (Stewart, 1994). This could account for the recent evidence of surprisingly wide-ranging health benefits from the consumption of fish oils.

Phase 2: 100,000 - 10,000 years BP

Humans migrated out of Africa, mostly to more temperate climates (for example, Europe, eastern Asia, and Australasia). This migration began over 100,000 years ago (Kingdon, 1993), and generally entailed moving away from tropical situations of high-density vector-borne infections.

Migration continued throughout the approximately 80,000 year-long last ice-age, including via land-bridges as oceans subsided by more than 100 metres. The forces of natural selection during those slow, unplanned, migrations through unfamiliar dietary terrain imbued different racial groups with some distinctive metabolic profiles (Ritenbaugh and Goodby, 1989). Thus, the predisposition of today's American Indian and Polynesian populations to diabetes mellitus, or the relative immunity of the Japanese to bladder cancer, are distant echoes of our human evolutionary past.

By 15-12,000 years ago, humans occupied all (non-Antarctic) continents. At that time, late palaeolithic humans may have contributed to the widespread extinction of large edible mammals (Diamond, 1991; Kingdon, 1993). Emergence of early agriculture and pastoral herding ensured sufficient food, at a time when the world climate was changing markedly. Larger and denser populations started to 'settle'.

Phase 3: 10,000 - 200 years BP

Since the slow beginnings of the agricultural revolution, probably in today's Turkey-Syria-Jordan region, settlement in villages and towns occurred. This allowed various person-to-person 'crowd' infectious diseases to emerge, most probably by transfer from a newly-constituted source - herded animals (McNeill, 1976). Population size, while increasing, was constrained by these contagious infections, and by the limits of agriculture and the attendant nutritional deficiencies. Comparison of ancient human skeletons (Eaton and Konner, 1985) indicates a stunting of around 4-6 inches in average adult body height relative to pre-agrarian body size.

As villages became towns, and towns became cities, the glories and the might of urban life unfolded. Great civilizations came and went, often largely in response to the exhaustion of local agricultural systems - as seemed to be the case, for example, with the 2,000-year success story that once was Mesopotomia. Its overworked, over-irrigated farmland finally succumbed to silt and salt. Infectious disease epidemics occurred most notably at times of great social upheaval - as with the plague pandemics at the end of the Roman Empire and as European feudalism crumbled in the fourteenth century (Epstein, 1992).

During these ten millenia, the great bulk of humanity lived and laboured in rural settings. For the masses, diets were monotonous and barely adequate; famines occurred sporadically.

Phase 4: Rapid changes in lifestyle, 19th-20th centuries

The advent of mechanized agriculture in the 18th and 19th centuries, along with sea-freight and refrigeration, increased the food supplies to Western countries. Europe's population expanded and spilled over to the Americas, southern Africa and Australasia (Crosby, 1993). Industrialization and imperialism brought material wealth and social modernization to Europe - especially sanitation, housing, food safety, personal hygiene and literacy. These, in turn, led to control of infection. Later, immunization and antibiosis consolidated a new era of human supremacy over infectious diseases.

This century, the emergence of modern 'affluent' living - especially diet, smoking, and physical inactivity - led to increases in chronic degenerative diseases of later adulthood (Boyden, 1987; Riggs, 1993). Meanwhile, the introduction of life-saving public health and medical technology to Third World (ex-colonial) countries has reduced infant/child infectious disease mortality. This has so far only been partially offset by a subsequent fall in fertility. A rapid population increase therefore began in those countries around the middle of this century (King, 1990). Ninety percent of today's population surge is now occurring in the world's non-Western countries.

Phase 5: (microbes emerging and re-emerging): late 20th century

Late this century, antibiotic-resistant strains of microbes and pesticide-resistant strains of vectors, such as malarial mosquitos, have emerged (Cohen, 1992; Levins *et al.*, 1994). There has been a resurgence of malaria, tuberculosis, sexually transmitted diseases, and cholera. New infectious agents - for example, Legionnaires' disease and HIV - have appeared in response to changes in human demography and behaviour (Levins *et al.*, 1994). The extension of irrigated agriculture and of long-distance transport have potentiated the spread of various mosquito-borne viral haemorrhagic fevers (Morse, 1993).

Epidemiologists may thus have spoken prematurely and uncritically of the inevitability of the 'epidemiological transition', which has long been assumed to be a virtually automatic concomitant of economic development. This transition entails the replacement of age-old infectious diseases, particularly in childhood, with the chronic degenerative diseases of later life that are amplified by aspects of affluent living. We have imagined that, with modern science, technology and public administration, infectious disease agents would be held at bay. Now we can see that this is an ecologically naive view, and that serious infectious disease will be with humankind for the indefinite future. We have thus over-looked, or mis-read, the meaning of the great cycles of disease in human history. We have underestimated the evolutionary capacity, and speed, of bacteria and their ilk.

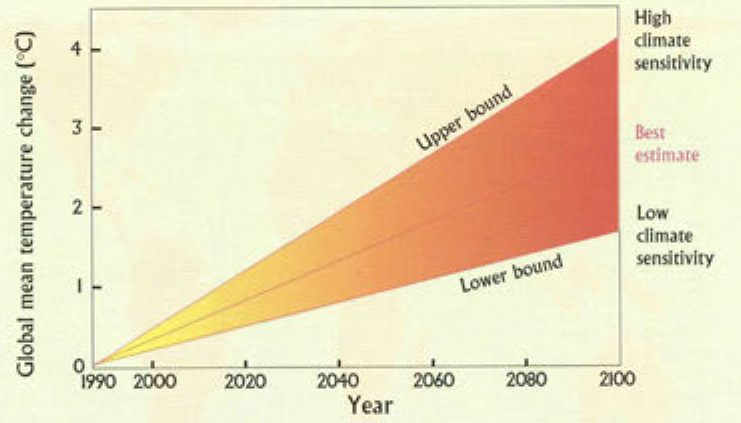
Phase 6: (advent of global-scale disequilibrium): from now

In this, the current phase, the aggregate impact of the human population size and economic activity upon various of the world's biophysical systems has begun to exceed the regenerative and repair capacities of those systems. Such overload has never before occurred globally. Its manifestations include: greenhouse gas accumulation in the lower atmosphere, depletion of stratospheric ozone, loss of productive agricultural and pastoral land, the exhaustion of many ocean fisheries, and the loss of biodiversity. These environmental changes pose a new type and scale of risk to human health (McMichael, 1993a; Last, 1993a).

Western populations have become familiar with local chemical pollutants as an environmental health problem. The risks to health - while usually small (and often difficult to detect in epidemiological studies) - are, in general, easily understood. This understanding comes from direct observation of their effects, or by reasonably extrapolating risks observed at higher, occupationally-induced, exposure levels. They typically entail linear relationships; and occur by direct insult to organs or metabolic pathways.

However, a different type and scale of health hazard is posed by the disruption of Earth's natural systems. These are the life-support systems that stabilize, produce and regenerate – and which therefore underpin the long-term health and survival of all species (WHO, 1990; McMichael, 1993b).

We easily overlook the fundamental fact that the sustaining of our good health is irretrievably tied to maintaining the biosphere's biological support systems. The basic equation is simple: disruption of natural systems impairs 'life-support'. The sustaining of good health requires a sustained supply of clean air, safe water, adequate food, tolerable temperature, stable climate, dynamically stable relationships with other health-affecting species, protection from solar ultraviolet radiation, and the existence of diverse species (and their genetic resources). But how on earth can we bring formal science to bear on the assessment of those health impacts?



Intergovernmental Panel on Climate Change estimate of global warming

Anticipatory Epidemiology

Note that this is an 'If-Then' problem for science. Thus, it is a very different research proposition from the comforting conventional exercise of gathering empirical data, looking at it, and deciding what the patterns mean.

The anticipated risks to population health would, in general, differ qualitatively from the more familiar environmental problems caused by direct-acting toxicity of local pollutants. Instead, they would mostly arise via indirect pathways, reflecting the disruption of ecosystems and of other natural geochemical systems. They must therefore be addressed within a complex ecological framework. Hence, their formal assessment will require a new capacity for systems-based thinking, predictive modelling, and dealing with uncertainty. Epidemiologists will thus have to embrace both the concept of complexity and the task of forecasting, within a penumbra of uncertainty, the health impacts of probable future scenarios.

3. The current emergence of systemic global hazards to human health, with special attention to the likely impacts of climate change

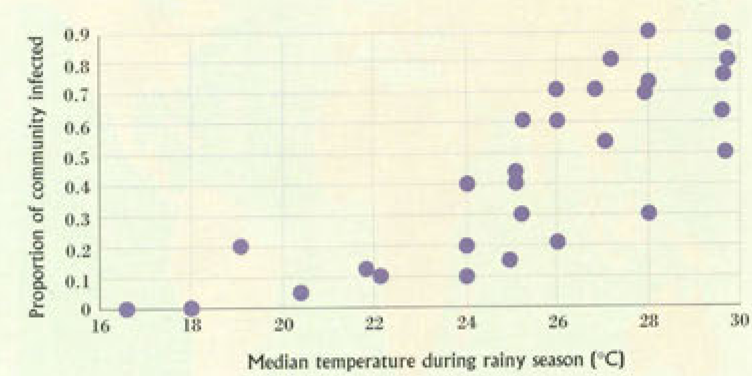
The various potential impacts of global climate change upon human health illustrate the complexity of the processes (WHO, 1990). The UN's Intergovernmental Panel on Climate Change (IPCC) foresees an increase in average world temperature of around 3°C over the coming century (IPCC, 1993). The predicted consequences for human health are mostly adverse when they are aggregated globally. They include direct thermal effects due to an increased frequency of heatwaves, and more frequent natural disasters due to increased weather instability. Climate scientists estimate that a 2-3°C increase in average world temperature would cause an approximate doubling in the frequency of heatwaves - and this would cause extra deaths and illnesses, particularly among the sick, the frail, the very old and the very young. There is already some evidence of an increase in weather instability. The international insurance industry is starting to retreat from insuring natural disasters, in the light of an approximate 20-fold increase in payouts over the past thirty years, at least part of which appears to reflect a true increase in the incidence of events.

There would probably be early indirect effects due to changes in the distribution of insects and other vectors that spread infectious diseases. It is worth exploring further this impact on infectious diseases, since it indicates just how sensitive the response of ecosystems can be to small changes in background climate. Many of the factors that influence the probability of infection with vector-borne pathogens depend on temperature and humidity. Temperature is especially important for parasites that develop in cold-blooded hosts (for example, mosquitoes), or which have free-living stages (for example, the schistosomal larvae excreted into water by infected humans).

These complex relations between vector, pathogen and human host cannot be reduced to a simple linear relation between temperature and disease rate. Sometimes, the vector may spread without any consequent increase in disease. Increases have occurred in mosquito numbers along Australia's River Murray in some flood years, but have not been accompanied by outbreaks of clinical Australian Encephalitis (Liehne, 1988). Sometimes, however, a small increase in temperature may produce a marked increase in infections. In Mexico, for example, increases in temperature have been associated with increased transmission of mosquito-borne dengue (Koopman *et al.*, 1991). In Rwanda, an unusually hot and wet year, 1987, was associated with a several-fold increase in the incidence of malaria (Loevinsohn, 1994).

Malaria: a case study

Let us consider malaria further. Changes in temperature and rainfall affect mosquito reproduction. At higher temperatures their biting rates increase, but their lifespan shortens. Meanwhile, the malarial parasite will not mature in the mosquito at temperatures below a certain critical temperature. Above that temperature, this maturation period shortens with increasing temperature, which facilitates the transmission of infection - up to an upper temperature threshold.



Dengue and climate, in Central America
(Adapted from Koopman, American Journal of Epidemiology, 1991)

An integrated model, to improve the quantitative prediction of climate-related changes in the potential distribution of malaria, has recently been developed by Dutch scientists (Martens *et al.*, 1994). Although this model does not take account of all the above mentioned determinants of transmission potential, it does take account of how climate change affects the mosquito population directly – i.e., mosquito development, feeding-frequency and longevity of the mosquito – and how it affects the maturation period of the malarial parasite inside the mosquito.

The model's predictions refer only to the potential for alterations in the geographic range of transmission. Therefore, their significance must be interpreted in relation to local conditions and public health control measures.

This particular model predicts a worldwide increase in the mosquito's habitat and "vectorial capacity" next century – that is, an extension of areas of potential malaria transmission. A global mean temperature increase of approximately 3°C by the year 2100 would increase the epidemic potential of the mosquito population in tropical regions twice – and more than ten times in temperate climates. In the subtropics, in highly endemic areas, malaria prevalence may increase, whereas in areas of lower endemicity it is far more sensitive to climate changes. Worldwide, the model predicts a climate-induced increase in malaria cases of around 80 million in the year 2100 – that is, around a one-third increase in total numbers.

But this is very inexact and uncertain science! Obviously, uncertainties in the outcomes of climate change models and in the biological responses of mosquito and parasite influence the uncertainties in the assessment of the transmission potential of the mosquito population.

Climate, food and health: another case-study

Another potentially great impact of global climate change upon human health could occur via altered food production, especially cereal crop production (Parry & Rosenzweig, 1993; Leemans & Solomon, 1993). Cereal grains, as this audience knows well, account for around two-thirds of all food energy consumed by humans. Climate change impacts would occur via the effects of temperature and moisture upon germination, growth, and photosynthesis, as well as via indirect effects upon plant diseases, predator-pest relationships, and supplies of irrigation water. There is much scientific uncertainty about the global impacts of climate change upon agriculture, and about their time-course (Chen & Kates, 1994). However, it is certain that there would be major regional variations in impact. Tropical countries are likely to be the most adversely affected, and, in those increasingly populous countries, small percentage losses in agricultural productivity next century could have significant population health consequences. There would be compensatory productivity gains at higher latitudes

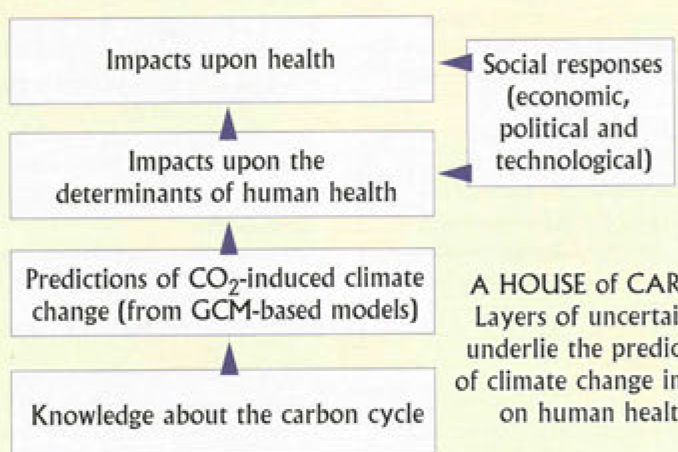
It has been predicted recently by Parry and Rosenzweig (1993) that the impact of climate change upon cereal grain production would cause an additional several hundred million hungry people by around 2060. The essential modelling task is to predict the climatic changes that a prescribed change in atmospheric composition would cause; to predict how that climate change would influence agricultural productivity; and then to predict how, within various social-political frameworks, that would translate into worldwide patterns of food availability. In this particular example, Parry and Rosenzweig (1993) took into account the likely time-trends in economic, trade and demographic factors. Their model did not allow for other possible ecological influences, such as a continuation of widespread land degradation, or the various effects of ecosystem weakening (for instance, loss of insect predators) and climatic changes upon crop pests and infectious organisms.

Finally, climate change may also cause a variety of delayed and variably indirect effects via a rise in sea levels. The IPCC estimates that a rise of up to half a metre is likely by 2100. Even more diffuse, but potentially dramatic, impacts on public health would ensue from the social-demographic impact of ecological refugees, especially from floods or famine, and from competition and conflict over increasingly scarce resources (Last, 1993b).

4. The problems for science in attempting to predict these future impacts

It is clear that there are two basic difficulties confronting scientists who attempt to predict future health impacts. First, the prediction is predicated on a multi-layered infrastructure of uncertainty from other disciplines: climatology, oceanography, atmospheric chemistry, agricultural science, ecology, and so on. Second, we have little directly relevant empirical evidence about the impact of many of these predicted environmental changes upon human health. A 2-3°C increase in average global temperature within a century would fall outside the range of human experience since the onset of agriculture and human settlement. The impact of such a change in background climate upon human health is therefore not directly deducible by generalizing from previously documented health effects of short-term temperature fluctuations around the stable-state mean temperature.

We must therefore rely on extrapolation, modelling and scientific theory, and must explicitly incorporate information about the substantial penumbra of uncertainty (McMichael and Martens, in press). The modelling required is mathematical, not statistical; that is, it seeks to represent a simplified abstraction of the real world - not to describe (via statistical equation-fitting) a set of empirical data. Mathematical modelling is used often enough by epidemiologists - for example, to understand the observed dynamics of infectious disease epidemics, or to predict the future timetrends in diseases (such as HIV/AIDS or heart disease). On the global environmental change front, however, there has so far been relatively little development of formal mathematical modelling.



A HOUSE of CARDS? Layers of uncertainty underlie the prediction of climate change impact on human health

It is salutary to remember, nevertheless, that prediction is intrinsically conservative. It presumes that the future is essentially like the past. We can predict with some confidence the next cycle of 'flu - but we cannot predict the emergence of a newcomer like HIV. This presumption that future unkowns are like present knowns is what makes predictive modelling, indeed all of science, possible. But it is the troubling possibility that unknowns are also not like the knowns that makes science necessary. We should therefore expect surprises - that is, events that fall outside the boundaries of prediction that is based on prior experience and theory.

Nor is it easy to bring together disparate pieces, from fragmented scientific research, to form an integrated predictive model. The fact that DDT will kill a mosquito in a jar (a toxicological fact, from reductionist science) may suggest that DDT spraying will achieve mosquito control at large (an ecological expectation). Yet, in the longer term, this may not be so. For our model to have predicted this 'surprise', it would have had to incorporate knowledge of the impact of spraying on the mosquito's competitors, on its natural predators, and on the genetic evolution of DDT resistance in the mosquito and other species. Knowledge of the dynamic interactions between changing population sizes and behaviours would also be needed. Clearly, our predictive models are unlikely to have certain validity very far beyond the boundaries of what science already 'knows'.

5. Possible health impacts of other forms of planetary overload, including the sustainability of world food production

Depletion of stratospheric ozone

Earth's mantle of stratospheric ozone accumulated slowly as a byproduct of early photosynthetic life on Earth. By about half a billion years ago, its concentration was such that the teeming aquatic life-forms could begin to radiate out on to dry land, relatively well protected from solar ultraviolet radiation. Today, just one terrestrial species is beginning to deplete that protective mantle.

The most certain direct effect of increased exposure to ultraviolet will be an increase in non-melanoma skin cancers: basal cell carcinoma and squamous cell carcinoma (Lloyd, 1993). A recent estimate, made by scientists advising the UN Environment Programme, is that, if the ozone losses of the 1979-92 period persist for several more decades, then basal cell carcinoma incidence would increase by 1-2% at low latitude (5°), by 5-10% at mid-latitude, and, at 55-65° (which includes Aberdeen), by up to 15% in the northern hemisphere and up to 30% in the south. The percentage increases for the less common squamous cell carcinoma would be approximately double those for basal cell carcinoma (Madronich & de Gruijl, 1993; UNEP, 1994).

Increased exposure to UVR would probably increase the incidence of various disorders of the eye, particularly cataract (UNEP, 1994). Cataract currently accounts for half of the world's blindness. Less certainly, some suppression of the immune system (both local and systemic) may occur (Jeevan and Kripke, 1993). This would reduce protection against infectious and fungal diseases, and could reduce vaccination efficacy in populations that are already immunologically compromised (for example, undernourished and chronically infected) (Kripke, 1991; Jeevan and Kripke, 1993).

A potentially more important, although much more indirect, health detriment could arise from ultraviolet-induced impairment of photosynthesis on land (terrestrial plants) and at sea (phytoplankton) (Worrest and Grant, 1989; Smith *et al.*, 1992; Holm-Hansen *et al.*, 1993). While such an effect could reduce the world's food production, few quantitative data are yet available. The marine phytoplankton, as the 'grass of the ocean', is the base of the entire marine food chain. Recent studies of UV impact on phytoplankton have yielded inconsistent results - some showing significant adverse effects; others showing little change.

Land degradation

Land degradation is another "overload" problem. During the 1980s, the combination of erosion, dessication and nutrient exhaustion, plus irrigation-induced water-logging and salination, rendered unproductive an estimated one-fifteenth of the world's readily arable farmland (World Resources Institute, 1992). Much other intensively-farmed land is showing stress. The world's per-person production of cereals appears to have faltered since the mid-1980s (Brown, 1993) - although several explanations are possible.

The 'Green Revolution', which fed much of the expanding human population during the 1960s to the 1980s, depended on laboratory-bred high-yield cereal grains, fertilizers, groundwater and arable soils. With hindsight, it appears that much of those productivity gains may have come from exhaustible ecological 'capital'. Today, as we seek to feed ever-more people, the absolute numbers of malnourished persons, especially children, are still growing (World Resources Institute, 1992; Parry and Rosenzweig, 1993).

Perhaps genetic engineering will yet boost agricultural productivity via biological enhancement of food-crop species. But it would be folly to depend wholly on an unguaranteed succession of further technical breakthroughs. Rather, as part of a widespread social and economic restructuring, we should do three things that are no doubt very familiar ideas here:

(1) Move beyond labour-intensive and energy-intensive agriculture to knowledge-intensive, low-impact, agriculture.

(2) Achieve a managed heterogenity of land-use patterns – a land-use 'mosaic' that confers buffering, diversity, pest control, and fertility.

(3) Use flexible scales of production.

But the sobering reality is that the world's urgent population pressures, coupled with the dominant 'orthodox' international model of agriculture, may impede such a redirection of world agricultural practice.

Meanwhile, at sea, many of the great ocean fisheries are on the brink of being over-exploited (Glantz, 1992). The Food and Agricultural Organization estimates that we have neared the sustainable fish-catch limit. A majority of the thirteen main fisheries are now in decline. One, the Grand Banks fishery of NE America, has apparently collapsed, with no evident recovery since its dramatic contraction in 1991.

Loss of biodiversity

In the background, looms the problem of loss of biodiversity (Wilson, 1989). We are losing a rich repertoire of genetic and phenotypic material. Our major cultivated 'food' plants are selectively-enhanced descendants of wild strains. To maintain their hybrid vigour and environmental resilience, a diversity of wild plants needs to be preserved as a source of genetic additives. Similarly, a substantial proportion of modern medicinal drugs in western medicine has natural origins, and some defy synthesis by our laboratory chemists (Farnsworth and Soejarto, 1985). Scientists continue to test tens of thousands of novel chemicals from nature each year, in the quest for new life-saving drugs. Perhaps more important, the loss of key species can weaken and destabilize ecosystems. This process may have contributed to the recent spread and emergence of various infectious diseases (Levins *et al.*, 1994).

Accelerating urbanization

Finally, the problem of accelerating urbanization. Today, approximately 40% of the world's population lives in cities, compared to around 5% early last century. Huge cities are a recent, unplanned, and increasingly precarious experiment in human social organization, they often entail massive pressures on local ecosystems and, in tropical countries, new contacts between human populations and parasitic organisms at the urban-wilderness interface (McMichael, 1993b).

Conclusion

So, how well do we humans rate on the basic evolutionary criterion of 'fitness'? In terms of reproductive success, we are indisputably a success story. Yet, because of this numerical success, allied to our cultural-technical evolution, we are now reducing the vitality, resilience and sustainability of many of the world's ecosystems?

Homo sapiens may have achieved an illusory 'fitness' that is ultimately unsustainable - because it depends on high levels of consumption and degradation of natural resources. Yet there is cause for hope. We humans, with our cerebral awareness, can imagine the future (Gott, 1992; Ramel, 1992). For us, then, the definition of success must surely include sustaining the world's life-support systems for future generations.

The bad news is that human health is now, for the first time at a global level, falling under the shadow of disrupted natural systems. The good news is that an awareness of this ought to advance the public debate on these issues. Pessimists argue that our evolutionary inheritance through the struggle for short-term survival binds us to a fixation on the present tense. Optimists argue that we could now use our abundant brainpower to find ecologically enlightened ways of sustaining the long-term health and survival of *Homo sapiens.*

This is a tall order - but evolution is all about meeting new challenges. It is now becoming clear that the dominant mode of social and economic development in today's world can, for previously unanticipated reasons of ecological complexity and constraint, be no more than a transitional stage. We must move on.

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Measurement of stable isotopes of inorganic and organic elements by mass spectrometry

Fine wool sheep at Sourhope Research Station

Macaulay Research and Consultancy Services (MRCS) was established on 1 December 1994 to further the marketing of the research and consultancy expertise of the Institute.

MRCS will continue to serve the needs of its existing customers who include local and national governments, non-governmental organizations, international funding agencies and commercial organizations and actively seeks to expand the range of customers it serves.

RESEARCH SERVICES DIVISION

Contract research is undertaken for a wide range of clients on specific topics from across the entire research programme of the Institute. Multidisciplinary teams of scientists can also be assembled to focus on a particular research issue or to develop effective programmes of environmental management.

The following are a few examples from MRCS' portfolio of research expertise:

- impact assessment of large domestic and wild ruminants on grassland and rangeland vegetation (Contact: Dr John Milne)
- development of decision support systems to aid management of these resources (Contact: Dr John Milne)
- spatial data handling and geographic information systems (Contact: Dr Richard Aspinall)
- impact of land use on the potential for river eutrophication (Contact: Dr Tony Edwards)
- management protocols for growth of trees in a range of soils (Contact: Dr Pete Millard)
- assessment of critical loads of acidification of soils and surface waters (Contact: Dr Simon Langan)

In addition, MRCS has considerable expertise in the following areas:

Pasture contaminated by diesel spillage

Contaminated land and waste recycling

Contact: Dr Jeff Wilson or Ed Paterson

- impact assessment of utilization of wastes (sewage sludge, paper, distillery) on surface and ground water quality
- land suitability assessments for strategic waste management planning
- site remediation research and consultancy
- microbiological studies on the effects of pollutants on soil fertility
- research on the behaviour and effects of heavy metals and organic compounds in soils
- characterization of wastes (value as a fertilizer; concentration of potentially toxic compounds) and of pollutants (heavy metals, radionuclides, toxic organic compounds) in contaminated soils
- modelling the effects of land management on soil and water resources

Economics research and consultancy

Contact: Dr Bob Crabtree

The Economics Group at the Institute offer considerable expertise in:

- economic appraisal of alternative land uses
- policy analysis and evaluation
- analysis of attitudes and responses of farmers and landowners to policy initiatives
- economic valuation of environmental and recreational effects

Consultancy services have been provided across a wide range of private and public sector organizations including local authorities, countryside and nature conservation agencies and government departments.

Animal fibre testing, research and consultancy

Contact: Miss Hilary Redden or Dr Angus Russel

The Institute houses a suite of specially designed laboratories dedicated to the measurement of animal fibre (wool, hair, cashmere) to international standards. The services available include measurements of:

- fibre diameter (mean and distribution)
- yield
- staple length and drawn length
- histological assessment of fibre follicles

& CONSULTANCY SERVICES

Farm services

Contact: Dr Iain Wright

The Institute has extensive farm and livestock resources and skilled and experienced staff who can undertake research on a range of topics from animal feeding and nutrition to metabolism. Research can be conducted on beef cattle, sheep, red deer and goats at pasture, on indoor feeding trials or in the metabolism unit.

ANALYTICAL SERVICES

Contact: Dr Alistair Smith

Comprehensive analytical services backed by the highest standard of data integrity and specialist staff dedicated to a multi-disciplinary approach to data analysis and interpretation are available to meet the exacting demands of the environmental sector.

Examples of analyses carried out include:

- environmental risk assessments of pollution by inorganic/organic compounds from industrial and agricultural sources
- long term studies of changes in water quality and chemistry
- petrological, metallurgical and investigative analysis of rocks, metals and other materials
- mineralogical analysis of reservoir rocks, shales, soils and fine-grained materials including corrosion products
- monitoring of food and other products for radiation levels
- chemical and physical characterisation of soil and soil types
- assessment of soil fertility

CONSULTANCY SERVICES DIVISION

Contact: Dr Jim Gauld, Head of Consultancy Services

This Division of MRCS comprises the staff of the former Resource Consultancy Unit and is particularly concerned with utilising the comprehensive soil and environmental datasets held at the Institute in consultancy work relevant to the study and management of land resources.

Services available include:

Survey work

- soil surveys to describe, classify and map soils at a variety of map scales
- peat and vegetation surveys to characterize the resource at selected map scale.

Resource datasets

Contact: Data Leasing Officer

- 1:63 360 and 1:50 000 Soil and Land Capability for Agriculture maps of the arable lands within Scotland.
- 1:250 000 scale soils of Scotland

This is the digital version of the soil maps. Data for any number of 50 km x 50 km tiles may be leased on an annual basis.

- Hydrology of Soil Types (HOST)

The 1:250 000 scale soils dataset has been reclassified according to hydrological response. Data for any number of 50 km x 50 km tiles may be leased on an annual basis.

- Land Cover of Scotland 1988

The first true census of the land cover of Scotland has been captured from 1:24 000 scale aerial photography, most of which was flown in 1988. Data for any number of 10 km x 10 km tiles may be leased on an annual basis.

- Soil database

Contains site descriptions, soil profile descriptions and analytical data for a large number of profiles of the soils found throughout Scotland. Data for any number of attributes at any number of sites may be leased on an annual basis.

- Satellite images

The Institute is the Scottish Regional Remote Sensing Centre and holds an archive of good quality Scottish LANDSAT MSS, LANDSAT TM, AVHRR, ERS-1 and SPOT satellite images. Data may be purchased either in its raw form or after processing in various ways.

Interpretative services

- interpretation maps, at a variety of scales, to assess land quality prior to and after development and for rent tribunal work.
- land capability for agriculture and forestry maps for planning purposes.

Specialist expertise on land use issues

- Environmental risk assessment, for example, flooding or pollution risk
- Determination of land cover change based on air photograph interpretation
- Habitat assessment — impact of land use or land cover change
- Integrated catchment studies — impact of afforestation or other land use change on water quality.

The MRCS stand at the Envirotec Exhibition at SEC, Glasgow

MACAULAY MRCS RESEARCH & CONSULTANCY SERVICES

Scottish Agricultural Statistics Service

The Scottish Agricultural Statistics Service (SASS) is a collection of 30 statisticians and mathematicians, with units based in Aberdeen (Rowett Research Institute and MLURI), Ayr (Hannah Research Institute), Dundee (Scottish Crop Research Institute) and with headquarters in the University of Edinburgh. It is responsible for the provision of statistical consultancy and training at the Scottish Agricultural Research Institutes and also at the Scottish Agricultural College. Training is provided, formally, through computer-based short courses in Statistics and Mathematical Modelling, most of which utilize Genstat or Minitab, and also, informally, through individual and small-group discussion.

SASS has particular expertise in the areas of Environmental Modelling, Mathematical and Systems Modelling, Image Analysis, Molecular Biology, Plant Breeding and Variety Testing, Food and Nutrition, Expert Systems and Artificial Neural Networks; major projects in these areas can call on the services of the relevant SASS specialists.

The Aberdeen group of SASS comprises eight staff, four of whom are based in the Environmental Modelling Unit at MLURI. The primary duties of the unit are:

- to provide a consultancy service to MLURI scientists;
- to engage in collaborative research with scientists from MLURI and elsewhere;
- to develop programmes of applied statistical research.

The consultancy service is operated through a well publicized open door policy, whereby a member of staff is available each afternoon of the week. The four staff involved each take responsibility for one of the MLURI divisions. The consultancy service was very well used in 1994 with well over 100 scientists, visiting workers or research students seeking advice on statistical and mathematical issues covering a wide range of topics.

Consultancy work is often the first stage in building stronger collaborative links with MLURI scientists. In the past year existing links have been strengthened and new collaborations begun. In particular: work involving David Hirst (SASS RRI) on the analysis of stream chemistry data with the Soils Division has been completed and submitted for publication and further work is under way; collaborative work with the environmental economics group has been extended on aspects of statistical design, modelling and analysis in contingent valuation studies; new work has begun on statistical analysis of data on fibre production with scientists in the Animals and Grazing Ecology division; good progress has been achieved on the problem of adjusting regression coefficients when a predictive model is fitted using data at one spatial resolution but used to make predictions with data of a different resolution, with the Land Use Division.

The research work of the unit also involves collaboration with other institutions, namely: the Institute of Terrestrial Ecology, the departments of Statistics at the universities of St. Andrews and Glasgow, the Institute of Aquaculture, the Centre of Cognitive and Computational Neuroscience and the departments of Economics and Business Studies at the University of Stirling.

Good progress on methodological issues has been achieved during the year on a variety of topics including: work on the reference distribution for fixed effects in REML, smoothing using penalized likelihood methods, the development of a nonparametric approach to causality testing in econometrics, the development of new kinds of artificial neural networks for unsupervised learning. The unit achieved a good publication rate during the year with 18 articles being published or currently in press.

About one-fifth of the income of the unit comes from external sources, mostly for work on environmental issues but also involving the design and analysis of medical studies. This includes work on the monitoring and valuation of environmentally sensitive areas, jointly with MLURI, ITE and AOC (Scotland), funded by SOAFD and work with ITE involving the study of metapopulations.

INSTITUTE STAFF

1 January 1995

DIRECTOR'S GROUP

Director,
Professor T Jeff Maxwell, B.Sc., Ph.D.
Deputy Director,
John A Milne, BA, B.Sc., Ph.D.
Assistant to the Director,
Claire L Howard, B.Sc., Ph.D.
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 secretaries,
Lucy M Burnett
Carol A Smith (Environmental & Socio-Economics)

Other staff,
Richard J Morgan, B.Sc., M.Sc.

1. Land and environmental management systems

Project leader,
Alan R Sibbald

Research objective leaders,
Gordon Hudson, B.Sc., GAeostat. (ENSMP Dipl.)
Jacques-Eric Bergez, B.Sc., Agron. eng (ENSAR Dipl.), Ph.D.
Nick J Hutchings, B.Sc., Ph.D.
Allan Lilly, B.Sc., M.Sc.
Keith B Matthews, MA, M.Sc.
William Towers, B.Sc.
Matthew P Hare, BA

Other staff,
Robert D M Agnew, L.I. Biol.
Andrew J I Dalziel, B.Sc.

Staff undertaking doctorates,
Matthew Hare, BA
Allan Lilly, B.Sc., M.Sc.
Keith B Matthews, MA, M.Sc.

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

2. Spatial Data Handling

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.
Neil A Brooker, BA, M.Sc.
David R Miller, B.Sc., Ph.D., RICS

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

Staff undertaking doctorate,
Diane M Pearson, B.Sc., M.Sc.

Postgraduate students, (Ph.D.),
Cameron Campbell, MA, Robert Gordon University
Mario Cuetano, B.Sc., MS (USA), University of Lisbon
Alessandro Gimono, B.Sc., M.Sc., University of Aberdeen
Rachel Harvey, B.Sc., Heriot-Watt University
Ann Humble, B.Sc., University of Aberdeen
Jason Matthiopoulos, University of Aberdeen
Charles H K Muchoki, University of Aberdeen

3. Information technology methodologies
Alistair N R Law, MA, M.Sc., Ph.D., C.Phys., M.Inst.P.

Postgraduate student, (Ph.D.),
Chris Skelsey, B.Sc., 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)
Alison P Brown, LLB, B.Sc.
Craig H Bullock, BA, M.Sc.

Other staff,
Neil Chalmers, B.Sc. (Consultant)

Staff undertaking doctorates,
Douglas C Macmillan, B.Sc., MS (USA)
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
Matthew G Wells, B.Sc., M.Sc., Ph.D.
Helen L McHenry, B.Agr.Sc.

SOILS & SOIL MICROBIOLOGY DIVISION

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

Divisional secretary,
Aileen Stewart

1. Acidification of Soils and Surface Waters

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

Research objective leaders,
Hamish A Anderson, B.Sc., Ph.D.
Derek C Bain, 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.
John D Miller, LRSC
Claire N Bedrock, B.Sc., Ph.D.
Simon J Langan, B.Sc., Ph.D.
David G Lumsdon, B.Sc., Ph.D.

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

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

2. Soil Pollution

Project leader,
Edward Paterson, B.Sc., C.Chem, FRSC (from 1 March, 1995)

Research objective leaders,
Martin V Cheshire, B.Sc., Ph.D.
Jeffrey R Bacon, B.Sc., Ph.D.
Colin D Campbell, B.Sc., Ph.D.
Stephen J Hillier, B.Sc., Ph.D.
David G Lumsdon, B.Sc., Ph.D.
Johannes C L Meeussen, IR, Ph.D.

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

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

Visiting Workers
Zhao Bingzi, Institute of Soil Science, Nanjing, People's Republic of China
Nikola Kostic, University of Belgrade, Serbia

Staff who have left Soils & Soil Microbiology Division since last the Annual Report
Jillian Mellanby, B.Sc.

PLANTS DIVISION

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

Divisional Secretary,
Iona M Shand

1. Soil Nutrient Dynamics and Environmental Impacts

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

Research objective leaders,
Alan E S Macklon, B.Sc., Ph.D.
Tony C Edwards, B.Sc., Ph.D.
Charles A Shand, B.Sc., Ph.D.
Berwyn L Williams, B.Sc., Ph.D.

Other staff,
Pippa Chapman, B.Sc., Ph.D.
Petronella Domburg, M.Sc., Ph.D.
James A M Ross, NDS, SDA, SDDH
Allan Sim, LRSC
Deborah J Silcock, B.Sc., Ph.D.
Yvonne E M Cook, HNC
Grace Coutts, HNC
Denise R Donald, LRSC, MPhil
Eileen Fisher, B.Sc., M.Sc.
Shona Smith, LRSC
Miriam E Young, HNC
Karen Clements, HNC
David W Nelson

Staff undertaking doctorates,
Eileen Fisher, B.Sc., M.Sc.

Staff undertaking MPhil,
Shona Smith, LRSC

Postgraduate students, (PhD),
Helmut Ernstberger, University of Aberdeen
Fiona MacLeod, Robert Gordon University

2. Assimilate Partitioning and Internal Cycling

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

Research objective leaders,
Peter Millard, B.Sc., Ph.D.
David Jones, B.Sc., M.Sc., Ph.D., MIBiol, FRMS
Derek Vaughan, B.Sc., Ph.D.
Mike F Proe, B.Sc., Ph.D.
Sue Grayston, B.Sc., Ph.D.
Angela Hodge, B.Sc., Ph.D.

Other staff,
Jess H Griffiths, B.Sc., MPhil (H)
Brian G Ord, HNC
Renate E Wendler, Dipl Biol, Ph.D.
Sandra Galloway, HNC
Eileen J Reid, HNC
Julie Sutherland, HNC
Ruth MacDougall
Mandy Whyte

Postgraduate students, (PhD),
Charles Russell, B.Sc., University of Aberdeen

3. Vegetation Dynamics

Project leaders,
Peter Millard, B.Sc., Ph.D.
John A Milne, BA, B.Sc., Ph.D.

Research objective leaders,
Carol Marriott, B.Sc.
Lorna Dawson, B.Sc., Ph.D.
Barry Thornton, B.Sc., Ph.D.

Other staff,
Geoff Bolton, B.Sc. (H)
Julia Fisher, HNC
David Hamilton, B.Sc., PGD
Shona Pratt, B.Sc.
Kenny Hood
Mary Tyler

Staff undertaking MPhil,
Shona Pratt, B.Sc.

Visiting Workers,
Meng Xian Min, Changchun Institute of Geography, People's Republic of China
Shenqiang Wang, Institute of Soil Science, Academia Sinica, People's Republic of China
Alex MacDonald, NE River Purification Board

ANIMALS & GRAZING ECOLOGY DIVISION

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

Divisional secretary,
Margaret W Forsyth

PUI4 Manager,
John A Milne, BA, B.Sc., Ph.D.

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

1. Vegetation dynamics

Project leaders,
John A Milne, BA, B.Sc., Ph.D.
Peter Millard, B.Sc., Ph.D.

Research objective leaders,
David J Henderson, B.Sc.
Peter D Hulme, B.Sc., Ph.D., M.I.Biol.
Carol A Marriott, B.Sc.

Colin P D Birch, BA, Ph.D.
Alison J Hester, B.Sc., M.Sc., Ph.D.
Andrew J Nolan, B.Sc.

Other staff,

G Titus Barthram, B.Sc. (H)
David E Suckling, JP, HNC, C.Biol., M.Biol. (H)
Lynne Torvell, B.Sc.
Gordon J Baillie, HNC

Postgraduate students, (Ph.D.),

Amanda Cook, B.Sc., University of Aberdeen
Fiona Stewart, B.Sc., University of Aberdeen

2. Herbivore foraging

Project leader,

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

Research objective leaders,

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

Other staff,

T Gordon Common, HNC (S)
C Stuart Lamb, B.Sc. (Agric)
Nicholas Outram
Ewen Robertson, B.Sc.
David A Sim, HNC
Grant C Davidson, B.Sc.
Anna H Murray, B.Sc., M.Phil (H)
Alison J Smith, HNC (H)
Patricia J Wilson, B.Sc.
Elaine Foreman
James L Small (S)
Iain L Thomson
Sheila A Young, HNC

Postgraduate students, (Ph.D.),

Jane Cooper, B.Sc., University of Aberdeen
John Hadjigeorgiou, B.Sc., University of Aberdeen

Staff undertaking doctorate,

Angela M Sibbald, MA

Visiting workers,

Paloma Cuartas, Instituto Pirenaico de Ecologia (Yaca), Spain
Juan Muñoz, University of Zaragosa, Spain
Jesus Royo, University of Zaragosa, Spain

PUI5 Manager,

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

Ruminant resource use

Project leader,

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

Research objective leaders,

Stewart M Rhind, B.Sc., Ph.D.
Angus J F Russel, B.Sc., M.Sc., Ph.D. (H)
Peter J Goddard, B.Vet.Med., Ph.D., MRCVS
William J Hamilton, BA, NDA, NDD, C.Biol., M.Biol. (G)
Jonathan A Beecham, BA
Pamela Dicks, B.Sc., Ph.D.
Philip N Grigor, B.Sc., M.Sc., Ph.D.
Alison J Hanlon, B.Sc., M.Sc.
Margaret Merchant, B.Sc., Ph.D.

Other staff,

Patricia M Colgrove, HND (H)
Alastair J Macdonald, SDA, NDA
Stuart R McMillen, HNC
Hilary L Redden, B.Sc.
Thomas K Whyte, HNC, SDA
Carol A Littlewood, HND (G)
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Brenda Copland
Audrey R Stephen

Postgraduate students, (Ph.D.),

Susan Borwick, B.Sc., University of Aberdeen

Staff undertaking doctorate,

Alison J Hanlon, B.Sc., M.Sc.

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

Claire L Howard, B.Sc., Ph.D. (transferred to Administration)
Michael S Lonergan, BA

ANALYTICAL DIVISION

Head of Division,

Alistair Smith, B.Sc., Ph.D., C.Chem., FRSC

Divisional secretary,

Lynda M Keddie

I. Inorganic element analysis

Alistair G Inglis, B.Sc.
Alison M Stewart, HNC
Lesley J Sinclair
Doris M McCombie
Thelma Robertson

2. Mass spectrometry

Andrew J Midwood, B.Sc., Ph.D.
Jennifer J Harthill, HNC
Kathleen H Davidson

3. Soil analyses

Jason Owen, B.Sc., M.Sc.
Keely P Taylor
June B McAdam

4. Electron microscopy

Bill J McHardy, B.Sc., Ph.D.
Evelyn M McMurray, HNC

5. Radiochemistry

Terry Atkinson, LRSC (Consultant)

6. Colourimetric analyses and chromatography

Pat E Moberly, B.Sc.
Susan M McIntyre, HNC
Arlene M Murray, HNC
Gillian L Sim, B.Sc.
Anna L Hendry
Gillian Martin
Donna MacDonald
Dawn Morley

7. Technical services

Bert W Stuart, HNC
James S Anderson
Gordon J Ewen, HNC
Graham J Gaskin, HNC
Allan I A Wilson, HNC
Jim A Steinson
David W Clark, HNC
Gordon W Stott

Staff who have left Analytical Division since the last Annual Report

Albert C Birnie, M.Sc., C.Chem., MRSC
Basil F L Smith, B.Sc., M.Sc., C.Chem., MRSC
Harry Shepherd, LRSC
Susan Bradberry, B.Sc.
Corina Mavrodin
Jim Normington

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)
Tony H Sunman, HND (systems manager)
Alexander D Moir (spatial data manager)
Jane D Stebbings, B.Sc., M.Sc.
Susan MacLeay, B.Sc.
Ruth A Morrison
Ann M Teale

Staff who have left Computing & Information Services Division since the last Annual Report
Jacqueline Thorpe

MACAULAY RESEARCH AND CONSULTANCY SERVICES

Head of Consultancy Division,
James H Gauld, B.Sc., Ph.D.

Secretary,
Nicola G Paterson

Staff,
Frank T Dry, B.Sc. (H)
John S Bell, B.Sc.
Andrew G Richman, B.Sc., M.Sc.
Ann Malcolm, B.Sc., DMS
Julia Miller, B.Sc.

Staff who have left Resource Consultancy Unit since the last Annual Report
Margaret J Still, B.Sc., Ph.D.
Sarah Madden, B.Sc., M.Sc.

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)
John W Black (Jnr.) (tractorman)
James Scott (shepherd)
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.
Andrew G Brown
Craig A MacEachern

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)

SOURHOPE

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

Staff,
Geoffrey D Gittus NDA (Deputy OIC)
John L Wallace (head shepherd)
Patricia Gentry (recording officer)
James C Pringle (stockman/tractorman)
T Gavin Rogerson, Dip.FBOM (goats)
Pamela Tapson (shepherd)
Matthew Wilson (shepherd)
Dorothy H Wallace (cleaner)

Staff who have left Research Stations Division since the last Annual Report
Irene J Black
Judith M A Leonard (cleaner)
Charles M Grant (shepherd)
John A R McGlen (shepherd)

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
Janice M Laing
Jacqueline S Wales
Jim Price, B.Sc.

Secretaries/typists,
Lucy M Burnett
Margaret W Forsyth
Iona M Shand
Aileen Stewart
Julie McKenzie
Nicola G Paterson
Carol A Smith

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
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Patricia R Carnegie
Caroline C Milne
David J Riley

Cleaners,
Jill Evans
Margaret Kindness

INSTITUTE STAFF

Agnes M Rennie
Margaret A Walker

Outdoor staff,

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

Security staff

David Burgess
John R Ewen
William L W Ross
Allan E J Rhynas
Wilfred F Wallace

Others

James Robertson
Graham Thomson

Staff who have left Administration Division since the last Annual Report

Donald W Futty, B.Sc.
Elaine T Watson

Susan King
Jacqueline Argo
Irene Hillcoat
Sheila W M Angus
Kathleen I McPherson
Hazel A Mutch
Ruth Penny
John Guyan

SASS staff based at MLURI

Head,

Jim Kay, B.Sc., B.D., Ph.D.

Other staff,

David A Elston, BA, M.Sc., C.Stat.
Gayathree Jayasinghe, Grad.IS, M.Sc.
Elizabeth I Duff, B.Sc.

Staff who have left SASS since the last Annual Report

Susan Ahmadi, B.Sc.
Verena M Trenkel, Dip.Biol., M.Sc.

Honorary Fellows

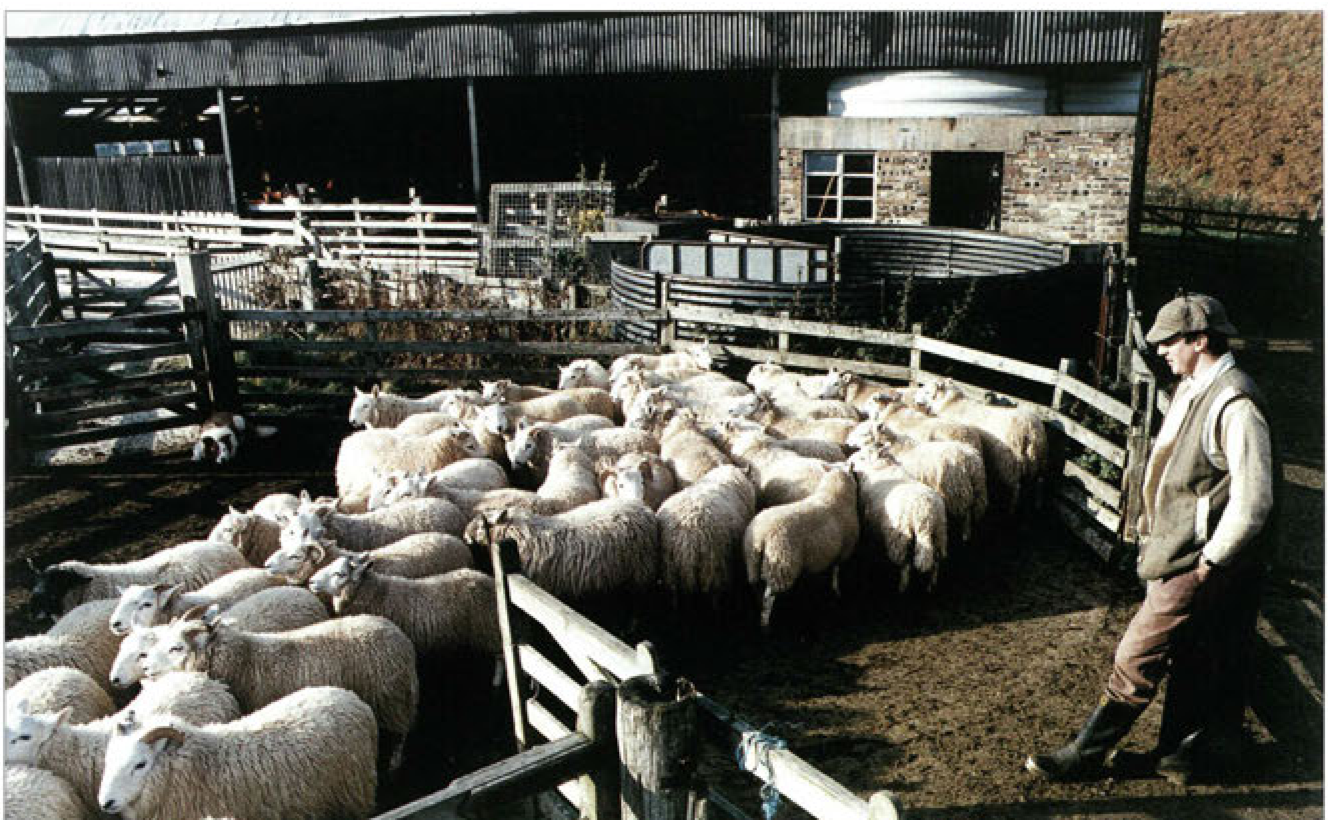
G Anderson, B.Sc., Ph.D.
Miss E J Dey, MBE
J Eadie, B.Sc.
P Newbould, B.Sc, B.Agr., D.Phil.
Miss E A Piggott, OBE
T S West, CBE, FRS
E G Williams, B.Sc., Ph.D.

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.)



Fine wool sheep at Sourhope Research Station, Roxburghshire

VISITING WORKERS and RESEARCH STUDENTS

VISITING WORKERS

Land Use Division

Antonio Leone, Irrigation Institute, Naples, Italy
Dr Brian Lees, Australian National University, Canberra, Australia
Henrik Mantufel, Warsaw Agricultural University, Poland
Professor Pere Riera, Universitat Atònoma de Barcelona, Spain
Dr Paul Walker, CSIRO Division of Wildlife and Ecology, Australia

Soils & Soil Microbiology Division

Paola Adamo, University of Naples, Italy
Astrid Berg, University of Munster, Germany
Dr J Cosby, University of Virginia, Charlottesville, USA
Professor S J Kim, Department of Geological Sciences, Seoul National University, Korea
Dr Nikola Kostic, University of Belgrade, Serbia
Jeannine Lherminier, INRA, Station de Recherches sur les Mycoplasmas et les Arbovirus des Plantes, Dijon, France
Dr Irina Solntseva, All Russia Institute for Agricultural Microbiology, Russia
Bingzi Zhao, Institute of Soil Science, Nanjing, People's Republic of China

Plants Division

Antonio Delgarno, University of Córdoba, Spain
Saman Dharmakeerthi, Rubber Research Institute, Sri Lanka
Janet Dutch, Forestry Authority, Edinburgh
Jerome Faveeuw, University of Lille, France
Professor Haque, Bangladesh Agricultural University, Bangladesh
Alex MacDonald, NE River Purification Board
Professor Meng Xian Min, Changchun Institute of Geography, People's Republic of China
Riccardo Scalenghe, Univeristy of Turin, Italy
Ricos Thanopoulos, Greek Ministry of Agriculture, Ioannina, Greece
Dr Shenqiang Wang, Institute of Soil Science, Academia Sinica, China

Animals & Grazing Ecology Division

Dr Paloma Cuartas, Instituto Pirenaico de Ecologia (Yaca), Spain
Dominique Feist, Ecole Supérieure D'Agriculture, Angers, France
Eric Force, Cite de L'Ensam, Montpellier, France
Dr Javier Giraldez Garcia, University of Leon, Spain
Hal Müller, Texas A&M University, USA
Juan Muñoz, University of Zaragoza, Spain
Jesus Royo, University of Zaragoza, Spain
Paola Sabbitini, University of Perugia, Italy
Dr Dale Whittaker, Texas A&M University, USA

POSTGRADUATE RESEARCH STUDENTS

(with University and funding source), current students, 1 January 1995 are shown thus *

Land Use Division

Ph.D.

* Rebecca Badger, University of Aberdeen, MAFF CASE Studentship
* Cameron Campbell, The Robert Gordon University
* Mario Cuetano, University of Lisbon, CEC
* Rachel Harvey, Heriot-Watt University, MLURI
* Ann Humble, University of Aberdeen, SERC CASE Studentship
* Mike Christie, University of Aberdeen, Aberdeen Research Consortium
* Allessandro Gimono, University of Aberdeen, MLURI

Robert MacFarlane, University of Aberdeen, ESRC
* Jason Matthiopoulos, University of Aberdeen, Aberdeen Research Consortium

Charles Muchoki, University of Aberdeen, Rockefeller Foundation
* Leonard Nwaigbo, University of Aberdeen, Commonwealth Scholarship
* Chris Skelsey, University of Aberdeen, Aberdeen Research Consortium
* Xuan Zhu, University of Edinburgh

M.Sc.

Stephen Emo, University of Aberdeen
Tekwe Charles Fon, University of Aberdeen, FAO/British Council
* Pierre Laviolette, University of Aberdeen, CEC ERASMUS programme

Daniel Reitz, University of Aberdeen
Trevor Rotzein, University of Edinburgh, self-financed

Soils & Soil Microbiology Division

Ph.D.

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 Scholarship
* Graeme Paton, University of Aberdeen, Aberdeen Research Consortium

Simon Peacock, University of Aberdeen, EC
* Maureen Young, The Robert Gordon University, Historic Scotland

M.Sc.

Angela Schoen, University of Aberdeen, self-financed

Plants Division

Ph.D.

* Helmut Ernstberger, University of Aberdeen, Aberdeen Research Consortium

Loufty Ibrahim, University of Aberdeen, self-financed
* Fiona McLeod, The Robert Gordon University
* Charles Russell, University of Aberdeen, BBSRC

M.Phil.

* Shona Pratt, University of Aberdeen, MLURI
* Shona Smith, University of Aberdeen, MLURI

M.Sc.

Adrian Crew, University of Aberdeen
Liz Ebbs, University of Bournemouth
Charles Smith, University of Aberdeen

Animals & Grazing Ecology Division

Ph.D.

* Susan Borwick, University of Aberdeen, SERC CASE Studentship
* Amanda Cook, University of Aberdeen, MLURI
* Jane Cooper, University of Aberdeen, Aberdeen Research Consortium

Marieca Fraser, University of Edinburgh, SOAFD
* John Hadjigeorgiou, University of Aberdeen, Greek Government

Manuel del Pozo Ramos, University of Edinburgh, INIA,Spain/British Council
* Fiona Stewart, University of Aberdeen, NERC CASE Studentship

M.Phil.

Anna Murray, University of Aberdeen, SOAFD

M.Sc.

Josephine Edwards, University of Edinburgh
George Fulford, University of Aberdeen
Ian Onaga, University of Aberdeen, Government of Papua New Guinea
Andemariam Paulos, University of Aberdeen, Ministry of Agriculture, Ethiopia
Suzanne Rennie, University of Edinburgh
Gareth Thomas, University of Edinburgh, British Veterinary Association Animal Welfare Foundation Scholarship
Aberash Wolansa, University of Aberdeen, Ministry of Agriculture, Ethiopia

CONFERENCES and VISITS ABROAD

UK Conferences at which papers were presented during 1994

Land Use Division

ASPINALL, R J. Climate Change - From Impact to Interaction, Wrest Park Conference Centre, Dundee, 5-7 January 1994

ASPINALL, R J. GIS Research UK 1994, Leicester University, Leicester, 11-13 April 1994

ASPINALL, R J. Environmental GIS and Remote Sensing, Cardiff, 20 July 1994

ASPINALL, R J. Spatial Data Handling, Edinburgh, 5-9 September 1994

CRABTREE, J R. Access in the Countryside, Nottingham, 21-22 September 1994

HUDSON, G. Climate sensitivity: economic & social impact of climate variability, Stirling University, Stirling, 1-3 September 1994 (paid by Association of British Climatologists)

HUTCHINGS, N J. Potential for Abatement of Ammonia Emissions, Culham, 31 October-2 November 1994

McHENRY, H L. Rural Realities, 35th EAAE Seminar, Hosted by ARC, Aberdeen, 27-29 June 1994

McHENRY, H L. New Directions in Rural Land Use, Cheltenham, 14-16 September 1994

MACMILLAN, D C. Agricultural Economics Society Conference, Exeter University, Exeter, 8-11 April 1994

MACMILLAN, D C. Acid Rain Damages, London (RSA), 9-11 May 1994

MACMILLAN, D C. Native Pinewoods, Culloden, 20-22 October 1994

MILLER, D R. Tompsom Symposium of the Photogrammetric Society, University of York, York, 8-10 April 1994

MILLER, D R. GIS Research UK 1994, Leicester University, Leicester, 11-13 April 1994

MILLER, D R. Spatial Data Handling, Edinburgh, 5-8 September 1994

MILLER, D R. Association for Geographic Information, Birmingham, 15-17 November 1994

PEARSON, D M. GIS Research UK 1994, Leicester, 11-13 April 1994

SIBBALD, A R. Livestock Farming Systems, MLURI, 1-2 September 1994

Soils Division

MITCHELL, D. European Conference on Sludge and Organic Wastes, University of Leeds, Leeds, 12-15 April 1994

HILLIER, S J. Laterites, Queens University of Belfast, Belfast, 29 August-4 September 1994

HILLIER, S J. Clays and Isotopes, University of Reading, Reading, 17-18 November 1994

PATERSON, E. Climate Change - From Impact to Interaction, Wrest Park Conference Centre, Dundee, 5-7 January 1994

PATERSON, E. Soils, Sustainability and the Natural Heritage Programme, University of Paisley, Paisley, 24-26 August 1994

Plants Division

EDWARDS, A C. BS^3 Annual Meeting, Silsoe, 11-3 April 1994

PROE, M F. Climate Change - From Impact to Interaction, Wrest Park Conference Centre, Dundee, 5-7 January 1994

SILCOCK, D J. Ecosystem Manipulation, Bowness on Windermere, 16-21 October 1994 (EC funded)

WILLIAMS, B L. Ecosystem Manipulation, Bowness on Windermere, 16-21 October 1994

Animals and Grazing Ecology Division

BEECHAM, J A. 45th Annual Meeting of the European Association of Animal Production, Edinburgh, 5-8 September 1994

BEECHAM, J A. Pasture Ecology, MLURI, 14-16 September 1994 (EC funded)

BIRCH, C P D. British Ecological Society Meeting, Stirling University, 5-7 January 1994

BIRCH, C P D. The 6th International Congress of Ecology, Manchester Conference Centre, Manchester, 21-26 August 1994

COOPER, J. British Society for Parasitology, University of Bath, Bath, 5-8 April 1994

DENNIS, P. Fragmentation in agricultural landscapes, Myerscourgh College, Preston, 13-14 September 1994

DICKS, P. Skin Biology, Glasgow University, Glasgow, 21 April 1994

GODDARD, P J. The 3rd International Congress on the Biology of Deer, Heriot Watt University, Edinburgh, 29 August-2 September 1994

HANLON, A J. The 3rd International Congress on the Biology of Deer, Heriot Watt University, Edinburgh, 28 August-2 September 1994

HANLON, A J. Animal Management and Health, Edinburgh, 5-8 September 1994

IASON, G R. British Ecological Society, Stirling, 5-7 January 1994

IASON, G R. The role of individual variability in populations, Newburgh, 10-11 September 1994

RUSSEL, A J F. European Association of Animal Production, Edinburgh, 5-8 September, 1994

WRIGHT, I A. European Association of Animal Production, Edinburgh, 5-8 September 1994

CONFERENCES and VISITS ABROAD

CONFERENCES ABROAD at which papers were presented during 1994

MAXWELL, T J. Strategies for Land Use in Agriculture, Buenos Aires, Argentina, 17-24 October 1994 (funded by Argentinian Government)

Land Use Division

ASPINALL, R J. GIS '94, Paris, 30 March-1 April 1994

BIRNIE, R V. Remote Sensing in Landscape Ecological Mapping, Leuven, Belgium, 17-19 March 1994 (paid for by JRC - Ispra)

BROOKER, N A. Eighth Annual Symposium on Geographical Information Systems, Vancouver, Canada, 21-24 February 1994

MATTHEWS, K B. Chaos theory in biology and the life sciences, Baltimore, USA, 24-29 June 1994

MILLER, D R. Decision Support 2001, Toronto, Canada, 12-16 September 1994

SIBBALD, A R. Systems oriented research in agricultural and rural development, Montpellier, France, 21-25 November 1994

Soils Division

MEEUSSEN, J C L. 6th Conference of the Netherlands Integrated Soil Research Programme, Lunteren, The Netherlands, 6-7 December 1994

Plants Division

GRAYSTON, S J. International Mycological Congress, Vancouver, Canada, 14-21 August 1994

DOMBURG, P. 6th Conference of the Netherlands Integrated Soil Research Programme, Lunteren, The Netherlands, 6-7 December 1994

Animals and Grazing Ecology Division

GODDARD, P J. Deer - veterinary/ welfare/management, Queenstown, New Zealand, 20-24 June 1994

VISITS ABROAD during 1994

Land Use Division

ASPINALL, R J. GIS/LIS '94, Phoenix Arizona and Santa Barbara, USA, November 1994

BADGER, R J. European Environmental Economics Conference, Dublin, Ireland, 22-25 June 1994

BERGEZ, J E. EC Agroforestry Project, ISSA, Arezzo, Italy, 22-26 February 1994 (EC funded)

BERGEZ, J E. Bio-economic and Bio-physical modelling in Agroforestry, INRA-France, 18-27 May 1994 (EC funded)

BERGEZ, J E. Biophysical Modelling Group, INRA, Avignon, France, 14-15 November 1994 (EC funded)

BULLOCK, C H. European Environmental Economics Conference, Dublin, Ireland, 22-24 June 1994

CHRISTIE, M. European Environmental Economics Conference, Dublin, Ireland, 22-24 June 1994

CRABTREE, J R. British Council Project, CIDA Granada, Spain (funded by British Council)

CRABTREE, J R. Meeting on Agricultural Reform, Madrid, Spain, October 17-20 1994 (Travel funded by OECD)

HUDSON, G. Applications of spatial and temporal statistics, Wageningen, 28 August-1 September 1994 (funded by NATO)

MILLER, D R. Collaboration with Sweden, Umeå, Sweden, 19-24 June 1994 (paid for by British Council and University of Umeå and Luleå)

PEARSON, D M. GIS '94, Paris, 30 March-1 April 1994 (Self-funded)

SIBBALD, A R. EC Agroforestry Project, ISSA, Arezzo, Italy, 22-26 February 1994 (EC funded)

SIBBALD, A R. INRA HQ, Paris, 20-22 April 1994

TOWERS, W. Eurowaste '94, Gent, Belgium, 23-25 November 1994

Soils Division

BACON, J R. Discussion of results of BCR Certification Contract, Brussels, 2-3 June 1994

JONES, D. Histologie, ultrastructure and Cytologie Moleculaire des Interactions Plantes - Microorganisms, Montpellier, France, 30 November-2 December 1994 (accommodation self funded)

WILSON, M J. Phosphate losses from over-fertilized soils, Institut für Bodenkunde, Germany, 15-18 January 1994 (EC funded)

WILSON, M J. Eureka Brokerage Event, Warsaw, Poland, 25-26 May 1994 (funded by SARIC)

Plants Division

EDWARDS, A C. EC coordination meeting, Torino, Italy, 2-11 September 1994 (EC funded)

GRAYSTON, S J. INRA, Nancy, France, 21-26 June 1994

PROE, M F. CIFOR, Indonesia, 22-25 February 1994 (Travel funded by ETSU)

PROE, M F. Effects of different tree species on soil properties, Lincoln University, Canterbury, New Zealand, 28 February-2 March 1994 (part ETSU funded)

PROE, M F. Understanding plant nutrient uptake and supply - opportunities for managing site productivity, FRI, New Zealand, 3-12 March 1994 (ETSU funded)

PROE, M F. Modelling Workshop, Swiss Federal Institute Forests, 9-10 May 1994

SILCOCK, D J. Second Coordination Meeting of EC funded project, Clermont-Ferrand, France and Neuchatel, Switzerland, 6-13 March 1994 (EC funded)

SILCOCK, D J. Eighth Nitrogen Workshop, Gent, Belgium, 5-8 September 1994 (EC funded)

WILLIAMS, B L. Second Coordination Meeting of EC funded project, Clermont-Ferrand, France and Neuchatel, Switzerland, 6-13 March 1994 (EC funded)

WILLIAMS, B L. International Symposium on Ecology and Management of Northern Forested Wetlands, Ontario, Canada, 23 August-7 September 1994 (travel and meeting costs met by Natural Resources, Canada)

Animals and Grazing Ecology Division

CUARTAS, P. International Symposium of wild and domestic ruminants, Berlin, Germany, 3-4 October 1994

DICKS, P. European Hair Research Society, Seville, Spain, 13-14 October 1994 (travel and subsistence funded by European Fine Fibre Network)

GORDON, I J. Exploitation of Marginal Mediterranean Areas and FAO Workshops on Systems of Production and Sheep and Goat Production, Thessalonika, Greece, 18-22 June 1994 (Travel and Subsistence funded by EC)

LAKER, J P. Wool and its potential for rural development, Chantmarle, France, 3-5 December 1994

PARTRIDGE, L W. Decision Support Systems, Delta Chelsea Inn, Toronto, Canada, 12-16 September 1994

Administration Division

DICKIE, A H W. Library Networking in Europe, Brussels, Belgium, 12-14 October 1994

Glen Clova, Angus. Words & Pictures, Aberdeen

PROGRAMME OF RESEARCH

January 1994 to December 1994
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 1993

011151 Modelling and field testing of silvo-pastoral systems (A R Sibbald)

011153 Decision-support models for assessing land use options at the farm level (K B Matthews)

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)

011343 Data architectural development (R V Birnie) (non-commissioned research)

Current research projects

011013 Field testing of low input upland sheep systems (A R Sibbald) (non-commissioned research)

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

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

011152 Modelling upland sheep systems (N J Hutchings)

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)

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) (non-commissioned research)

011339 An approach to modelling wildlife dynamics in hill grazing systems using grouse as a model (A R Sibbald)

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

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)

011371 Decision-support system for assessing land use options at the management unit level (K B Matthews)

011372 Assessment and impact of potential conflicts between re-cycled organic wastes from different sources (W Towers)

011373 Application of remote sensing and GIS for predicting nutrition of voles (R V Birnie) (non-commissioned research)

011374 Strategic planning issues associated with windfarm location in the Scottish hills and uplands: a feasibility study (C H Osman)

011376 Multiple-benefit upland silvopastoral systems: modelling and experimentation (A R Sibbald)

011401 Integration of land cover and agricultural information from the agricultural and horticultural census of SOAFD with the Land Cover of Scotland 1988 (LCS88) to provide an enhanced, co-ordinated and multi-temporal land cover database for Scotland. (N A Brooker) (SOAFD Flexible Fund)

011418 Decision making tool kit - a short term research review (R V Birnie / J A Milne) (SOAFD Flexible Fund)

PROGRAMME UNIT 12

SOIL AND THE ENVIRONMENT

Research projects completed since December 1993

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

012172 Assessment of acid sensitive waters in Scotland 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)

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)

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)

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 mobilization of aluminium and other toxic metals in soils and waters (D G Lumsdon)

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

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

012175 Characterize 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 soil microbial activity, including mycorrhizas, in agricultural and forest soils (C D Campbell)

012327 Use of the Isotope Hydrograph Separation technique to determine hydrological pathways (H A Anderson)

012328 Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility (J R Bacon)

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

012378 Water resource modelling: the effect of land use, atmospheric deposition and climate change on soils and waters (R C Ferrier)

012379 Interaction between the biosphere and the atmosphere in wetlands (S J Chapman)

012380 Influence of competitive interactions on the impact and fate of heavy metals in sewage sludge-treated soils (E Paterson)

012381 Cycling and bioavailability of radioisotopes in upland soils, particularly organic-rich soils (M V Cheshire)

012382 Role of fine-grained and colloidal particulate material in transporting pollutants in the environment (M J Wilson / S J Hillier)

012385 Critical loads to natural and semi-natural ecosystems with particular reference to nitrogen (S J Langan)

012386 Modelling chemical behaviour and transport of reactive contaminants in soils (J C L Meeussen)

012392 The use of *LUX* modified soil bacteria as an assay for soil heavy metal toxicity (C D Campbell) (non-commissioned research)

012414 Effects of heavy metals on frequency of aromatic catabolism in soil microorganisms (C D Campbell) (non-commissioned research)

PROGRAMME UNIT 13

PLANT SOIL RELATIONS

Research projects completed since December 1993

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

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)

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 capillaris* and *Lolium perenne* (A E S Macklon)

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

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)

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

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

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

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 Microbial diversity and activity in the mycorrhizosphere of trees (S J Grayston)

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

013349 Characterization of nutrient flows in upland grassland ecosystems using stable isotope signatures (C A Marriott) (SOAFD Flexible Fund)

013362 Biomass and nutrient allocation in species associations in relation to defoliation and nutrient supply (C A Marriott)

013363 Remobilization of nitrogen in grasses in relation to defoliation and nutrient supply (B Thornton)

013364 Fractionation of phosphorus in soil solution in relation to bioavailability and leaching (C A Shand)

013365 Availability of soluble and insoluble organic and condensed P sources in soil to *Agrostis capillaris* plants (A E S Macklon)

013395 Predictive modelling of eutrophication with the river Ythan catchment and the development of an integrated management plan (A C Edwards) (SOAFD Flexible Fund)

013398 Development and application of molecular biological techniques in studies of the interactions between microbes, nutrient cycling and vegetation among a range of agriculturally important pastures, to enable scaling from microcosm to field (S J Grayston) (SOAFD Flexible Fund)

PROGRAMME UNIT 14

PLANT-ANIMAL RELATIONS

Research projects completed since December 1993

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

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)

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

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)

014208 Changes in floristic composition, diet selection and soil nutrients of grazed 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)

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)

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) (non-commissioned research)

014347 Development of a decision support system for managing the impact of red deer on vegetation dynamics and habitat diversity (L Partridge) (SOAFD Flexible Fund)

014366 Antioxidant efficacy of dietary polyphenolics in relation to diet choice in sheep (D B McPhail)

014390 Effects of extensive grazing management on soil physical properties and botanical composition of upland mixed sown swards (J A Milne) (non-commissioned research)

014391 The effects of deer browsing on upland woodland dynamics (A J Hester) (non-commissioned research)

014396 Representations of time trends and the spatial nature of plant communities on utilization rate in the Hill Grazing Management Model (J A Milne) (SOAFD Flexible Fund)

014400 Develop a Geographic Object-Oriented Simulation Environment for individual based ecological modelling using GIS data (K D Farnsworth / N Outram) (SOAFD Flexible Fund)

PROGRAMME UNIT 15

RUMINANT RESOURCE USE

Research projects completed since December 1993

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

015231 Modelling the influence of animal attributes on efficiency of resource use by ruminants (N J Hutchings)

015259 Behavioural stress and immunocompetence in farmed deer (A Hanlon) (SOAFD Flexible Fund)

015298 Modelling helminth larval intake in grazing ruminants (J A Beecham) (SOAFD Flexible Fund)

015334 Development of automatic blood samplers (P J Goddard) (non-commissioned research)

Current research projects

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

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)

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)

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)

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)

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

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

015361 Mechanisms of early life nutritional effects on lifetime reproductive performance in sheep (S M Rhind) (non-commissioned research)

015367 Effect of rearing environment, management and genotype on the stress susceptibility of sheep in extensive systems (P J Goddard)

015368 Relationship between behaviour, hormonal and immune responses to stress in sheep (S M Rhind)

015369 Hormonal and metabolic mediators of seasonal changes in appetite in ruminants (S M Rhind)

015370 Modelling interaction of genotype and nutritional environment in sheep (N J Hutchings)

015389 Immunocompetence as an index of stress in weaned lambs (A J Hanlon) (non-commissioned research)

015397 Effects of pre-natal nutrition, colostral, immunodulators and lamb growth factors on aspects of innate and adaptive immunity in lambs (S M Rhind) (SOAFD Flexible Fund)

015399 Testing models of nematode larval intake by ruminants (J Beecham) (SOAFD Flexible Fund)

015402 Object oriented modelling of mixed grazing systems (J Beecham) (SOAFD Flexible Fund)

PROGRAMME UNIT 16

LAND USE OPTIONS and IMPACT: ENVIRONMENTAL and SOCIO-ECONOMICS

Research projects completed since December 1993

016277 Uptake of rural development and environmental initiatives - socio-cultural attitudes and determinants (H L McHenry) (non-commissioned research)

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)

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)

016383 Social factors in environment and development: determining private and public interests in land use change (A Brown)

016384 Economic analysis of habitat and ecosystem restoration (D C Macmillan)

016393 Provision and economic impact of access-related recreation in upland Scotland (J R Crabtree) (non-commissioned research)

PROGRAMME UNIT 09

EXTERNAL CONTRACTS with source of funding

LAND USE DIVISION / Resource consultancy Unit

Contracts completed since December 1993

090351 Feasibility study of a systems approach to modelling agriculture and land use in Scotland (A R Sibbald/ R J Aspinall) [SOAFD]

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

090394 Review of modelling work for policy analysis (R V Birnie) [MAFF]

090410 The integration of Land Cover Data from NCMS with LCS88 MLURI data (N A Brooker) [SNH]

090413 Biogeographical zones - smoothing the boundaries of existing zones (R J Aspinall) [SNH]

Current contracts

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)

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]

090375 Land use miscellaneous contracts (R V Birnie)

090404 Valuation of the conservation benefits of Scottish ESAs by the general public (D C Macmillan) [SOAFD]

090408 Review of Land Use Research in the UK (R V Birnie) [SOAFD]

090412 Silvicultural strategies for predicting damage to forests from wind, fire and snow: integrating tree, site and stand properties with Geographic Information Systems and regional environmental models to evaluate options for forest management (D R Miller/ANR Law/ RJ Aspinall) [EC]

090269 RCU Commercial contracts - [Miscellaneous] (J H Gauld)

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

090406 Fire management of western vegetation: survey (J H Gauld (RCU)) [SNH]

090407 Survey of footpath provision in lowland areas of the Cairngorms (F T Dry (RCU)) [SNH]

090415 Monitoring of Environmentally Sensitive Areas in Scotland (J H Gauld (RCU)) [SOAFD]

090416 IACS field parcel identification (R V Birnie) [SOAFD Casual Contract]

SOILS and SOIL MICROBIOLOGY DIVISION

Contracts completed since December 1993

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

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

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

090377 Calcareous loam soil, domestic sewage sludge and mainly industrial sewage sludge reference materials (J R Bacon) [EC]

Current contracts

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)

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

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

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

090303 Immobilization of soil nitrogen by decomposing plant residues and the potential of the forms of immobilized nitrogen for remineralization (M V Cheshire) [EC]

090304 Phosphate release potential for overfertilized 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]

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

090359 Characterization, management and utilization of red soil resources of southern China (M J Wilson) [EC]

090403 Critical evaluation of weathering rates in relation to critical loads determination (S J Langan) [National Power]

090409 Pollutant pathways in soils (J R Bacon) [ICI]

PLANTS DIVISION

Contracts completed since December 1993

090388 Sulphur balance in paddy soils and fertilizer strategies (A C Edwards) [EC]

090411 Environmental impact of phosphorus from the agricultural disposal of sewage sludge (A C Edwards) [ADAS]

Current contracts

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

090270 Commercial contracts [Misc.]

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

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

090387 Soil borne organic phosphorus as affected by different agricultural regimes and climate: leaching and potential contribution to eutrophication (C A Shand/ A C Edwards) [EC]

090417 Immobilization of faecal enzymes by clay minerals (P Millard / M J Wilson) (Johnson and Johnson)

ANIMALS and GRAZING ECOLOGY DIVISION

Contracts completed since December 1993

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

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) [EC]

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

090276 Identification of 'hot spots' in restricted areas (R W Mayes) [ITE]

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

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

Current contracts

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

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

090243 N-alkane determinations (R W Mayes) [Miscellaneous]

090271 Commercial contracts [Misc]

090300 The welfare of sheep before, during and after transport (P J Goddard / P N Grigor) [Edinburgh University]

090301 Transfer of radionuclides in animal production systems (R W Mayes) [CEC]

090305 Coordination 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]

090310 Development of rapid techniques to assess the availability to food animals of radionuclides in or on feed (R W Mayes) [ITE]

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

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

090348 Ben Lawers grazings - baseline survey (I J Gordon) [NTS]

090405 Research on the production of high quality cashmere from goats and its potential for agricultural diversification (A J F Russel / P Lynch) [EC]

ANALYTICAL DIVISION

Current contracts

090272 Commercial contracts [Misc.] (A Smith)

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A variety of land use near Auchleven in the Insch Valley, Aberdeenshire. Words & Pictures, Aberdeen

FINANCIAL STATEMENT

ANNUAL FINANCIAL STATEMENT for the YEAR ENDING 31 MARCH 1994

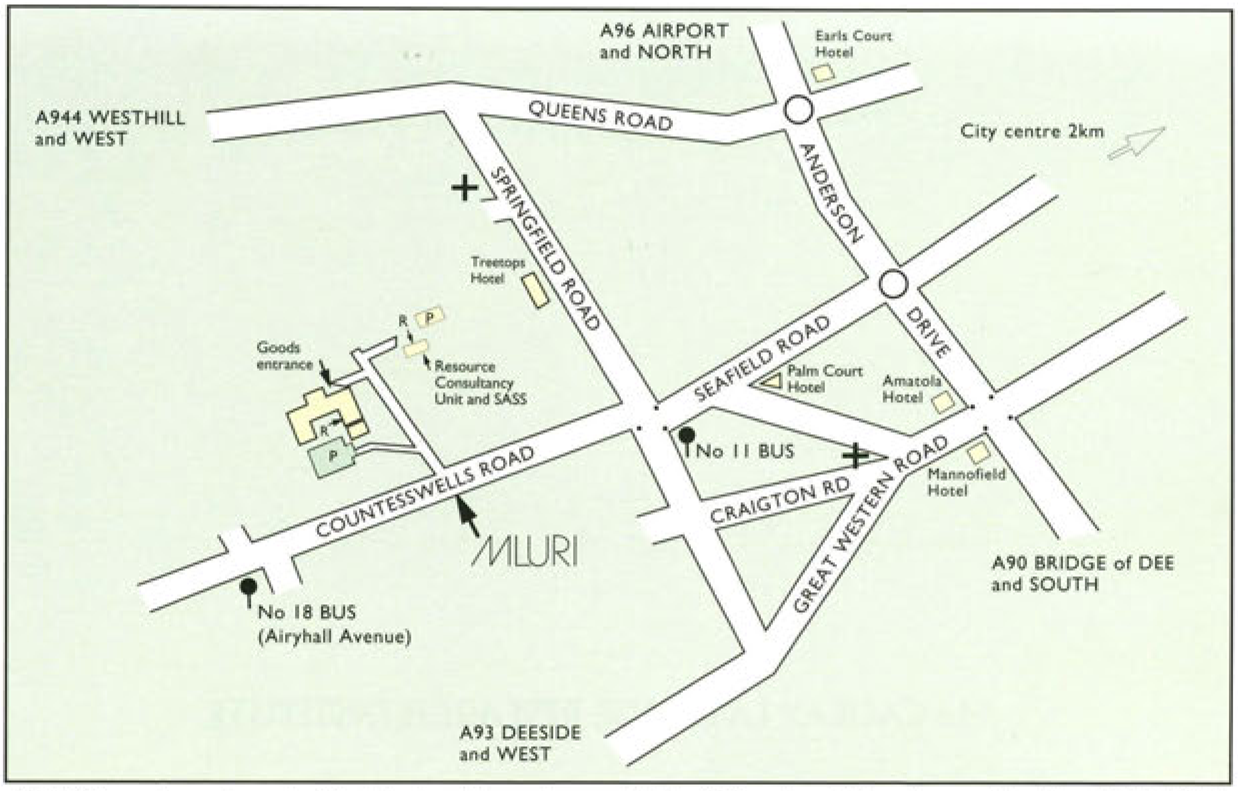
Income	£k
Scottish Office Agriculture and Fisheries Department (SOAFD)	6010
SOAFD Flexible Research Funding and other SOAFD contracts	479
European Union research contracts	543
Funding from other Government Departments, Public Bodies and Agencies	204
Private research and consultancy contracts	171
Other income	304
	7711
Less Equipment purchased from revenue grants	-107
Total income	7604

Expenditure	£k
Staff costs	4483
Research expenditure including Research Station costs	1648
Other operating costs	1201
	7332
Surplus (deficit)	272

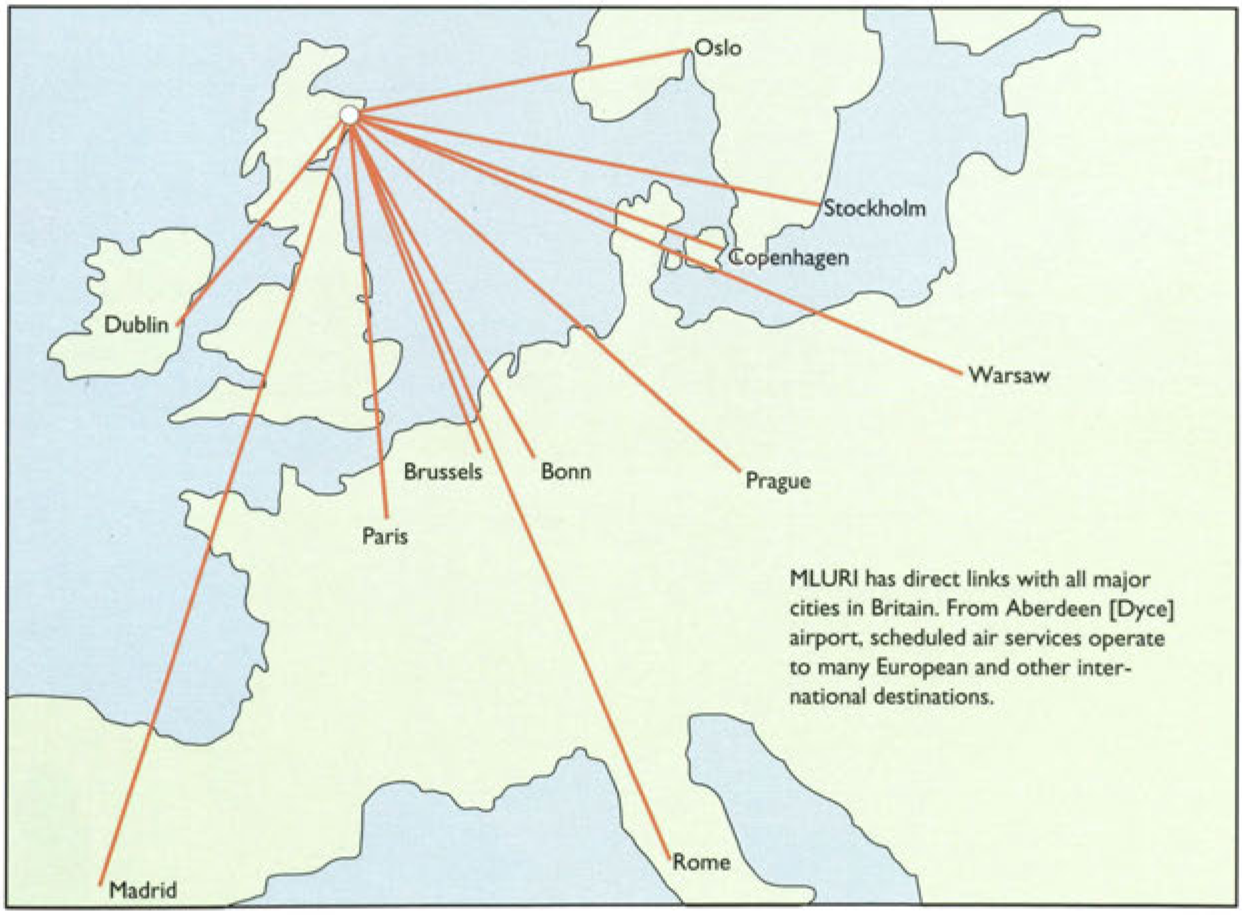
The capital funds received from SOAFD totalled £708,207 of which £477,067 was for capital works.

During the year the turnover of the Resource Consultancy Unit was £194,092

MLURI CONNECTIONS



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



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.

MACAULAY LAND USE RESEARCH INSTITUTE

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