RESEARCH TODAY FOR LAND USE TOMORROW

THE MACAULAY INSTITUTE

ANNUAL REPORT 2000

research today for land use tomorrow

THE MACAULAY INSTITUTE

ANNUAL REPORT 2000

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DIRECTOR'S INTRODUCTION

It gives me great pleasure to introduce this report of the work of the Macaulay Institute in the year 2000, my first as Director of the Institute. The high quality and relevance of the science in this report are thus a tribute to my predecessor and my new colleagues and I would like to start by paying tribute to Professor Jeff Maxwell's role in establishing the Macaulay Land Use Research Institute and leading it to its present position. My contribution to this report is to introduce the Institute's programme of research within the context of current land use issues in Scotland and in a broader international perspective.

A change of Director is a good time to respond to changes in the external environment and this Annual Report is no exception. The scientific environment is changing very rapidly and the internet is now superseding the printed page as the most efficient means of acquiring knowledge. This Annual Report is thus a much slimmer version than those of previous years, with the bulk of the information that was presented previously now being available on our web site (www.mluri.sari.ac.uk). This printed report is designed to illustrate three themes of our work: scientific quality, the transfer of knowledge to users and examples of the relevance of our research to different end-user communities. I hope it will encourage you to read more on our web site or to write or email for specific information to the contacts whose names are given at the back of the report.

As I write this introduction, rural communities in the UK, and farmers in particular, are besieged by the onslaught of Foot and Mouth Disease. Following on the heels of BSE and the negative effects of the strong pound on the agriculture and tourism sectors, it is not surprising that there is a feeling of pessimism for the future of the countryside. What role does a land use research institute have to play at such a time? I believe that we can offer both new insights and relevant information (e.g. see www.mluri.sari.ac.uk/fmd/). For those of you unfamiliar with the Macaulay Institute's research, I will start by describing the type of information we can provide, in three categories.

I believe that we can offer both new insights and relevant information

The first category is based on the premise that environmental considerations are becoming increasingly important in relation to the management of land, particularly in a country like Scotland where the natural landscape makes such an important contribution to the attraction of visitors to our rural areas. Thus, the Macaulay Institute has a strong programme of environmental and ecological research, which asks questions about the interactions between microbes and the soil and between plants and soils, between plants within vegetation communities and the impacts of the grazing animal on these resources. Answers to these questions increase our understanding of the physiological and biochemical processes taking place in the natural world. By so doing, we will be able to provide information on the environmental consequences of different ways in which land can be used, to policy-makers, farmers, governmental and non-governmental agencies and indeed to the private sector.

Inter-disciplinary research linking economics with natural sciences

However, decisions on how to manage land both now, and in the future, are not based solely on what is best for the environment, there are also human dimensions. These range across the social and economic viability of rural communities and the effectiveness of related rural policies to the value which the wider society places on the provision of environmental goods. It is these aspects that lie at the heart of our second category of research. In it we seek to understand the links between rural development processes and land use change, drawing heavily both on economic analysis and the use of mathematical modelling and spatial techniques to provide insight into the human dimension of land use. Our approach to this research is very much a collaborative and inclusive one, in which we work closely with social scientists at the Arkleton Centre for Rural Development Research. It also includes frequent consultation with people living in rural communities as well as with those whose decisions may influence their future.

The third category of research is addressing more immediate issues that face those managing land or water catchments. This involves measuring and monitoring processes that occur in practice and the development of methods to characterise the vegetation of fields and hillsides and the exchanges between the soil and water. This research both provides evidence for the development of policies and management tools to assist resource managers and stakeholders in decision making. Inter-disciplinary research linking economics with natural sciences is a characteristic of this category of research.

We are therefore seeking to make relevant information from this programme of research available to inform the discussion on opportunities for Scottish rural communities, in the immediate aftermath of the outbreak of Foot and Mouth Disease.

The Macaulay Institute's research programme has recognised from the start that food production is not the only form of land use and in future may not even be the predominant form of land use in Scotland, but that does not mean that farmers will not have a continuing role to play. Farmers understand the land and its needs and this knowledge is vital to successful management for a broad range of objectives. In this report you will see articles on alternative types of land use, including the generation of renewable energy and the restoration of native woodlands. The final article considers the impact of different production systems on greenhouse gases, illustrating how increasingly we need to look at land management, not just in the context of Scotland, but also taking global issues into account.

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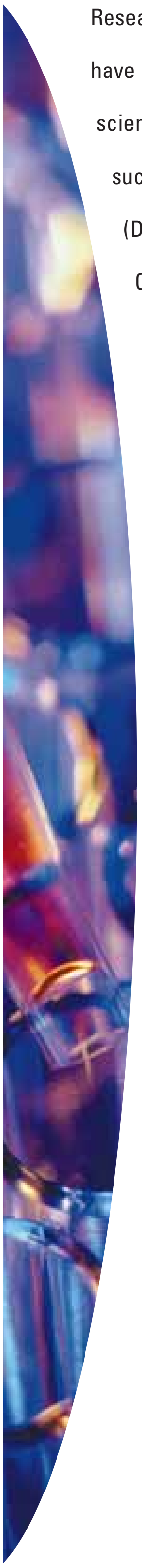
The Institute has had an international profile for some time, with



projects in Southern Africa, South America and Central Asia, but this year has seen the transfer to the Institute of the International Feed Resource Unit (led by Professor Bob Ørskov) from the Rowett Research Institute to the Macaulay Institute. As a consequence, we have been pleased to welcome an increased number of overseas scientists coming to the Institute for training. We were also successful during 2000 in winning new projects in Mongolia (Darwin Initiative funding) and Central Asia (European Commission funding) and we have welcomed visitors to the Institute from around the globe. However, notwithstanding our expanding international profile, we are still very committed to strengthening our partnerships within the UK and Europe and in the summer there was a lively community of European students at Craigiebuckler.

Closer to home, we have a number of active research units in collaboration with colleagues at the University of Aberdeen and plan to strengthen these ties in 2001. We are also seeking ways of increasing our involvement with the business community of Aberdeen as we explore new markets for our research outputs. One aspect of this is our adoption of a new image as The Macaulay Institute, which encompasses both the Macaulay Land Use Research Institute and the Macaulay Research Consultancy Services, our commercial arm.

Finally, Professor Janet Sprent will be retiring as the Chair of our Board of Governors in 2001 and I would like to take this opportunity to thank her for the enthusiasm, commitment and scientific expertise which she has brought to the role and for the contribution which she has made to the development of the Macaulay Institute.

Professor Margaret Gill

Director

June 2001

CONTENTS

RESEARCH ADVANCES

The Mission Statement of the Institute is: To be an international leader in research on the use of rural land resources for the benefit of people and the environment.

To achieve this, our programme includes ecological and environmental research at the strategic level, social science research which is both strategic and applied and applied research aimed at supporting decision making at both the management unit and catchment levels.

The following three articles give examples of our research in each of these three areas - for information on other areas, please visit our web site at www.mluri.sari.ac.uk

New Modelling Framework for Exploring Dynamic Processes in Soils

Summary

ORCHESTRA[1] is a modelling framework which allows the development of conceptual and application models that describe the physical, chemical and transport processes in soils. It is possible to apply ORCHESTRA to many areas of interest within the natural sciences, in both an applied and strategic context. In an example of the former, it has been found possible to develop models, such as ORCHESTRA-CHROMIUM, whereby the underlying processes are incorporated into a database such that the end-user only needs to deal with model inputs and outputs. The model predicts the behaviour of chromium in chromite ore processing residues at land fill sites in this application. In more strategic research ORCHESTRA can be used to implement new conceptual models within computer code and can be used in testing hypotheses in an interactive way. Finally, it has been used to facilitate the linkage of chemical and physical processes in the modelling of the transport of reactive chemicals.

designing new experimental systems to test specific aspects of fundamental processes

Context

Soils are complex materials, making it a challenge to understand how they develop, how they respond to various land management practices and, increasingly, how they interact with the wider environment. The development of predictive models of key chemical processes occurring within soils require three stages in their development. The first of these is the evolution of a conceptual model, which encapsulates the key processes. The second is the representation of these processes in the form of a mathematical model. Finally, there is implementation within computer code. The combination of these stages makes many of the current models, which tend to concentrate on a particular chemical process, relatively inflexible and difficult to extend or adapt when new models are developed. Many of these difficulties have been overcome using a new modelling framework, ORCHESTRA, which has been developed at the Institute and was described originally by Meeussen et al. (1996).

ORCHESTRA

The modelling framework, constructed using an object-oriented approach, describes the conceptual models and their formal representation as user-defined objects. These are then used by the central calculation core of the programme which deals with the matrix algebra and other mathematical operations required to solve the equations involved. The ORCHESTRA framework is generic in the sense that the model has basic building blocks, "primary objects" which are used in a hierarchical way to represent various processes. For example, one of the primary objects is the phase

[1] ORCHESTRA stands for Object Representation of CHEmical Speciation and TRAnsport Models

object which is used to define compartments within a model system that are separated by a distinct interface called the phase boundary. In a soil the defined phases could be the dissolved, solid and gas phases. Phase boundaries are necessary for modelling dynamic systems where there is a need to distinguish between the mobile and

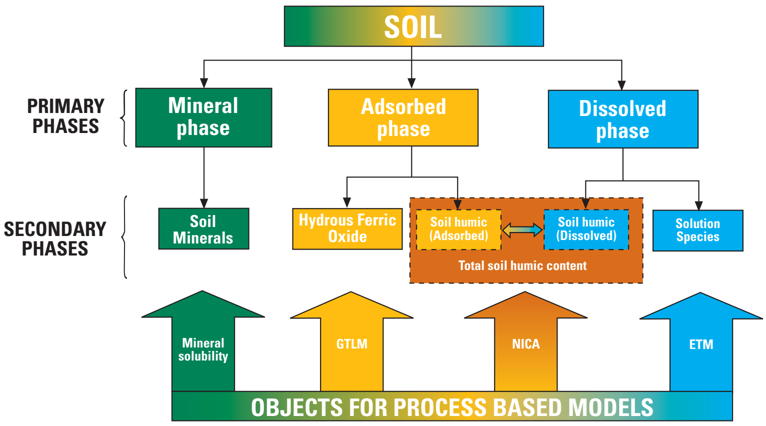


Figure 1. Representation of soil chemical processes within ORCHESTRA. GTLM (Generalized-two-layer-model) for adsorption on mineral surfaces, NICA (Non-ideal-competitive adsorption) for reactions with organic matter and ETM (Equilibrium thermodynamic model) for soil solution species.

non-mobile phases, for example, in modelling the leaching of soil chemicals. In addition the phase object functions as an internal accounting system within the model. It keeps track of the transfers of elements/matter/chemicals from one phase to the other, thus allowing convenient model output. An illustration of a phase object structure used for an ion adsorption model is shown in Figure 1, and is described in more detail in the section below. Other objects include the representation of chemical reactions as both equilibrium and kinetic processes as well as physical processes that transfer matter according to the laws of diffusion and convection. ORCHESTRA allows the modelling of key processes that are important in soils and sediments. Thus, reactions involving mineral dissolution, precipitation, mobilisation of dissolved organic matter and ion-exchange and specific adsorption can be modelled. In addition, these chemical processes can be combined with physical ones, such as diffusion and convection, to model the reactions that are involved, for example, in plant uptake of nutrients and leaching of contaminants from soil to water. Examples are given below of some of the applications of ORCHESTRA to address specific issues.

Modelling Mineral Dissolution and Precipitation in Complex Materials

Over 2.5 million tonnes of chromite ore processing residues (COPR) have been used in and around Glasgow as landfill material (Figure 2). However, these deposits are now known to contain large amounts of toxic, mobile Cr(VI) which is leaching into surface- and ground-waters (Farmer et al., 1999). In a collaborative project with the Environmental Chemistry Unit at Edinburgh University and the environmental consultants, Dames and Moore, ORCHESTRA has been used to predict the behaviour of chromium (Cr) in chromite ore processing residues.

Within the ORCHESTRA-CHROMIUM model (Geelhoed et al., 2001), various reactions are represented, including the aqueous speciation of all the major elements and the precipitation/dissolution reactions of a series of mineral phases. Mineralogical techniques, such as X-

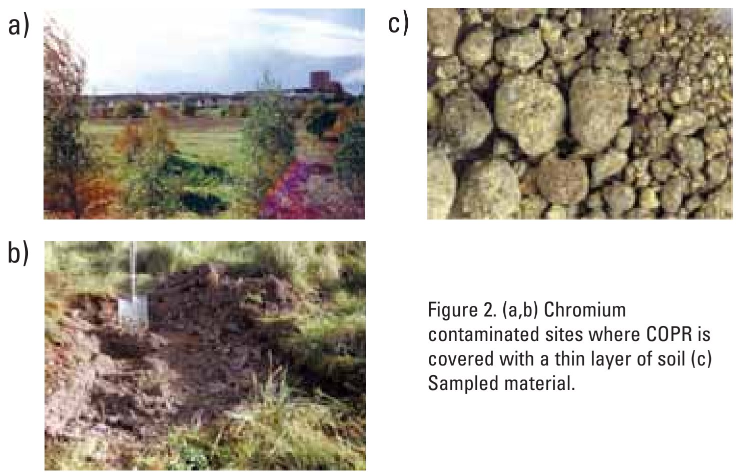


Figure 2. (a,b) Chromium contaminated sites where COPR is covered with a thin layer of soil (c) Sampled material.

ray diffraction, scanning electron microscopy and energy dispersive microanalysis, have been used to provide a qualitative assessment of the mineral phases present.

Thermodynamic data for these minerals have been retrieved from the literature and used to define mineral "objects" within the model. Inputs to the model include pH, the chemical composition of the chromite ore processing residues, obtained by aqua regia digestion, and the proportion of Cr(VI) to total Cr.

Mineral	Modelled content, %	Measured content, %
Hydrocalumite	6.6	5.8
Hydrogarnet	19.8	20.5
Brownmillerite	12.3	13.7
Chromite	2.0	5.0
Calcite	5.1	5.5
Periclase/Brucite	27.4	15.0
Ca-Si glass	5.3	Not determined
Mg-Na-Al-Si glass	Not included in model	Not determined
Total glass	Not included in model	34.5

Figure 3. Modelled and measured mineralogical composition of COPR.

One application of ORCHESTRA is the prediction of the mineralogical composition which can be compared with a quantitative determination obtained by X-ray diffraction (Figure 3). It is clear from Figure 3 that the predicted and measured values generally agree well. The modelled and measured contents for the majority of minerals agree well although the results for the magnesium oxide/hydroxide species, periclase and brucite, show some discrepancies between the modelled and measured outputs. This may be due to the fact that some of the magnesium is associated with the amorphous glass components found in the residues, which was not included in the model. Despite underestimating the amount of chromite, the model provides a reliable prediction of the mineral species present. These data have subsequently been used to model particular aspects of the behaviour of the residues, which are of importance in environmental risk assessment and in remediation treatments. One of these is the buffering behaviour at high pH values of this highly alkaline material. This is predicted very well over the range 11.5 to 9.5, where the reactions controlling the changes in pH are due to the dissolution of the series of calcium aluminate minerals (Figure 4). This was confirmed by direct observation of the residues at various stages of acidification.

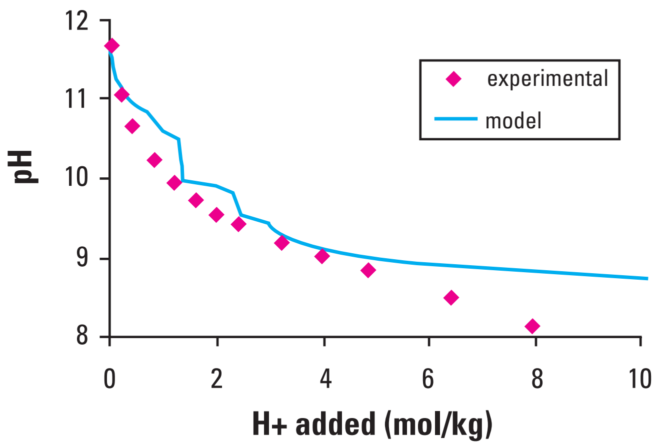


Figure 4. Experimentally measured and modelled buffering curves for COPR.

Modelling Ion Adsorption and Dissolved Organic Matter in Soils

Soil organic matter content features in almost every set of soil quality indicators that have been proposed. This reflects its importance in a range of processes including C sequestration, nutrient cycling and the maintenance of soil structure. In addition, the organic acid functional groups associated with organic matter buffer soil pH and are very effective at binding metals (e.g. aluminium, cadmium) and other organic molecules such as pesticides and poly-aromatic hydrocarbons. Thus, the solubilisation of soil organic matter can enhance the leaching of chemicals from soils, and should be included in any soil chemical model.

A model for dissolved organic matter has been implemented as part of a soil ion adsorption model, in which adsorption processes on minerals and soil organic matter are included. It is recognised that the organic matter on which ions can be adsorbed can become soluble and thereby increase the mobility and leaching of ions associated with the dissolved organic matter (e.g. the movement of lead as dissolved organic complexes in organic soils).

For the first stage of the soil model implementation, the soil phase

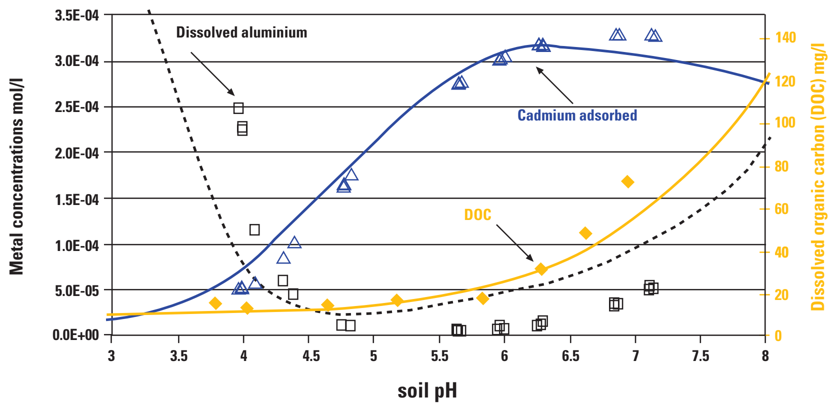


Figure 5. Experimental data (symbols) and model calculated (lines), for soil adsorbed cadmium, dissolved organic carbon and dissolved aluminium as a function of soil pH.

was divided into three primary phases - the dissolved, mineral and adsorbed phases (Figure 1). The dissolved phase contained the dissolved chemical species found in the soil solution and the mineral phase was used for minerals that may precipitate or dissolve in the soil environment (e.g. gibbsite, calcite and phosphates). The adsorbed phase contained two secondary phases, a hydrous ferric oxide reactive surface and reactive humic substances (soil organic matter) represented by the newly developed NICA model (Kinniburgh et al., 1999). The next stage was to build into the model the solubility of the organic matter and include this within the phase hierarchy.

The solubility of humic substances depends upon the surface charge of the humic molecules and their hydrophobicity (Tipping & Woof, 1991). Within the ORCHESTRA modelling framework it was possible to calculate the charge on the humic molecule as a function of soil solution composition (pH, ionic strength, calcium and aluminium concentrations etc) using the NICA model, and hence estimate the amount of dissolved humic material. To include this within the phase structure of ORCHESTRA, total soil organic matter was divided into two phases. One was organic matter in the solid phase, which was a part of the adsorbed phase, and dissolved humic which was part of the dissolved phase. This is shown schematically in Figure 1.

The model was applied to describe dissolved organic carbon and aluminium and adsorbed cadmium in soils of varied mineral and organic matter contents for a wide range of pH (Figure 5).

potential applications include the biological arena where root or microbiological processes could be included in models of soil processes.

Transport Processes in Heterogeneous Soils

Transport modelling is an essential tool to predict the movement of solutes in, and from, soils. Different models have been developed by hydrologists to describe water movement through soils ranging from simple models describing homogeneous flow through a soil to more complex models which attempt to take into account flow heterogeneity and varying hydraulic conductivity in different sizes of pores. A simple but effective approach is the two-region model that divides the soil solution into a mobile and an immobile region. In this model, mass transport takes place by convection in the mobile region and by diffusion in the immobile region. However, for substances that interact with the solid matrix of the soil, as is the case for some nutrients and many contaminants, transport is also strongly affected by chemical processes, such as ion-exchange and/or specific adsorption. A full description of solute movement requires a modelling framework that can combine both physical and chemical

processes. The aim has been to develop a mechanistic understanding of the combination of heterogeneous transport and chemical interactions. To achieve this, a synthetic model system has been developed for experimental use (Van Beinum et al., 2000) which has used ORCHESTRA to develop a two-region model that can be combined with different sorption models.

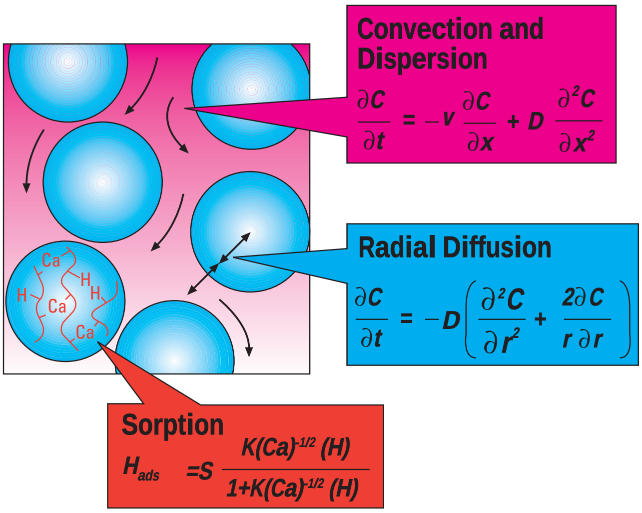


Figure 6. Solute transport through the column with alginate beads, predicted by a two-region model.

An experimental system (Figure 6) was developed to simulate a structured soil where convective-dispersive flow could occur between the aggregated structural units and diffusion could occur into the pore structure of these aggregates. Thus, a column was prepared which was filled with spherical gel beads, made from low-density calcium-alginate gel. The pore network, formed by the packing of the gel beads, represents the pathway for 'mobile' water movement whereas the water inside the gel structure represents the 'immobile' region where solutes can only migrate by diffusion. Flow experiments were performed by flushing the columns with calcium chloride solutions at different pHs. The overall process was predicted with the two-region transport model and an ion exchange model.

Figure 7 shows the measured pH in the effluent of the columns during the desorption and leaching of protons out of the column by dashed lines. The broken line shows the predicted breakthrough curve that would be expected in case of homogeneous flow with instantaneous sorption. In the case of diffusion limited mass transfer, the breakthrough is less abrupt, starting earlier and showing more tailing. The two data sets at 0.001 M $CaCl_2$ at different flow rates show that this non-equilibrium effect is larger in the case of a fast flow. The solid lines in Figure 7 show the results of model predictions. The input parameters for these predictions, such as the affinity parameter for the ion-exchange reaction, and bead and column dimensions, were all determined independently of the leaching results. The results show that the experimental data could be predicted very well. Current work with this system is now being extended to include other sorptive surfaces within the bead matrix.

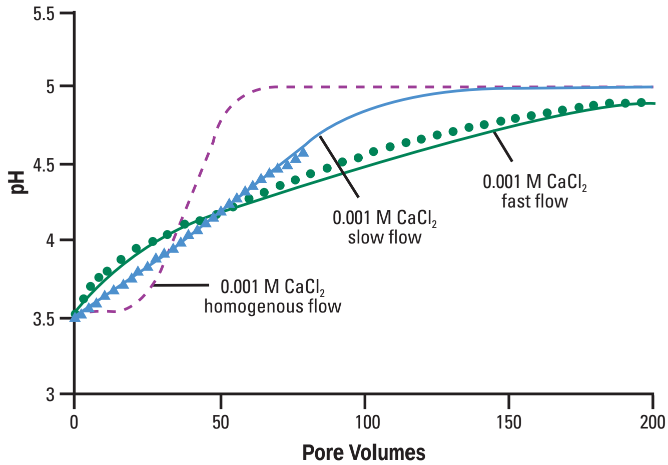


Figure 7. pH breakthrough curves from the alginate column at different $CaCl_2$ concentrations and different flow rates. Initial pH 3.5; Feed pH 5.0.

The flexibility and extendibility of ORCHESTRA will allow the additional reactions required to be incorporated as 'objects' in the model database.

Future Development

ORCHESTRA will be used to develop new models, which incorporate emerging ideas. For example, using the ability to define different phases (e.g. colloidal or gaseous) within a chosen hierarchy will make it possible to construct models in which colloids become detached from the soil matrix and become mobile. Furthermore, the processes regulating the production of colloids can be made a function of chemical parameters calculated in the other parts of the model. Other examples of potential application include the biological arena where root or microbiological processes could be included in models of soil processes.

It is important to recognise, however, that any model will only be as good as the understanding of the processes which are incorporated in it. Thus, although model implementation is facilitated by ORCHESTRA, it places even greater demands on our knowledge of the fundamental processes and mechanisms.

Contacts: David Lumsdon, email: d.lumsdon@mluri.sari.ac.uk, Wendy van Beinum and Ed Paterson.

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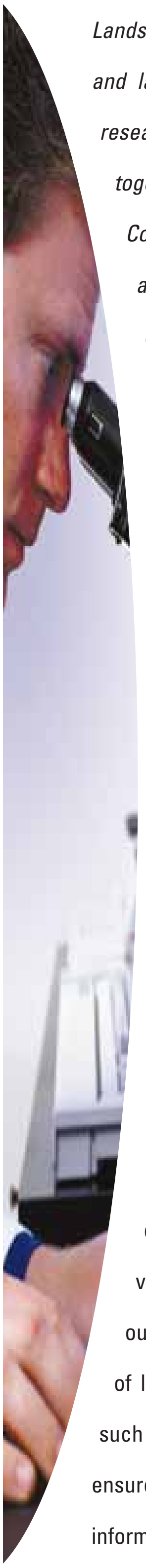
Novel Automated Approach to Measuring Landscape Change



Summary

Landscape change is a complex phenomenon. Monitoring of land use and land cover change requires an integrative approach where research efforts in a number of branches of science are brought together. The SYMOLAC (SYstem for MOnitoring LAnd Cover) project has demonstrated a technique for the analysis of complex problems through the development of the concept of task-oriented analysis and its implementation in a working system in the context of landscape change. It has used research ideas from computing science to develop a novel tool that addresses the special needs of describing landscape change using remote sensing. Knowledge from a wide range of scientific disciplines within the Institute is integrated so that this expertise can be effectively used in SYMOLAC to answer questions on landscape change. It demonstrates the role that an integrated approach to research can have in achieving an understanding of complex socio-environmental systems.

Context

Much of the evidence of the interaction of man with his environment comes in the form of visible landscape change. This is the outcome of local changes in the use of land, and of wider-ranging effects, such as climate change and the consequences of pollution. To ensure that the land use needs of future generations can be met, information on both the speed and types of changes in landscapes that are occurring is needed. At the scale of a landscape this is a task most suited to remote sensing approaches. These can range from the fine detail of aerial photography where objects smaller than a centimetre can be resolved to low resolution satellite imagery with a

resolution of the order of kilometres. Satellite imagery is readily available at present and there are plans in the near future for satellites that will provide data at resolutions that were only previously available in aerial photographs.

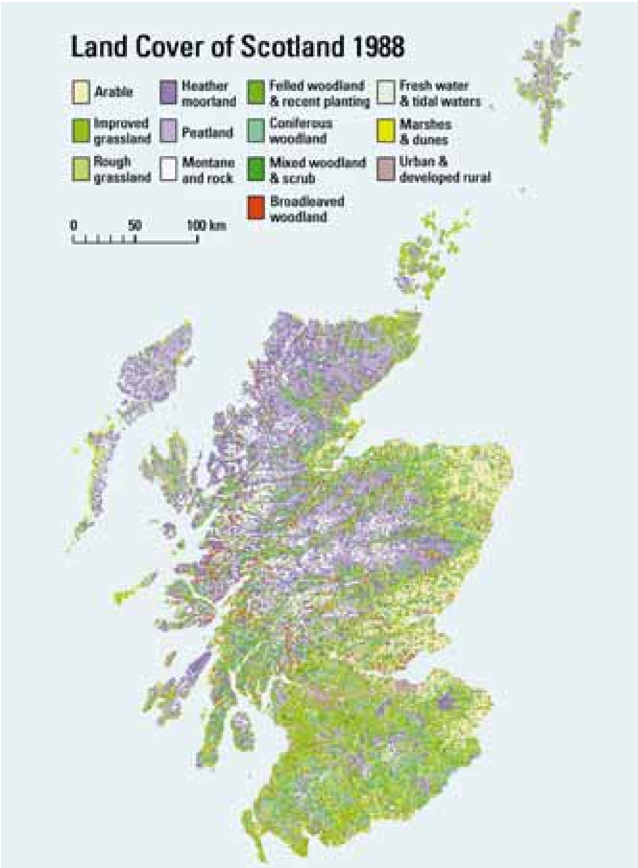
Much of the evidence of the interaction of man with his environment comes in the form of visible landscape change

Interpretation

There is, however, a significant amount of processing required before remotely sensed imagery can provide the information sought. Satellite images and aerial photographs are representations of the reflected light from the land surface. They do not have the resolution to be able to identify exactly which plant species are present or the precise physical conditions that exist in the area under observation. To provide that information there has to be a process of interpretation where a human observer, sometimes assisted by preliminary computer analysis, will allocate areas of land to different land cover or land use classes. The interpreter will make decisions using knowledge and experience of the forms of imagery used and the land cover and land uses of the area under investigation. This is a time-consuming process with, for example, the interpretation of the Land Cover of Scotland 1988 (LCS88), based on aerial photography, taking 25 man-years of effort to complete.

data will become readily available from new satellites and aerial surveys

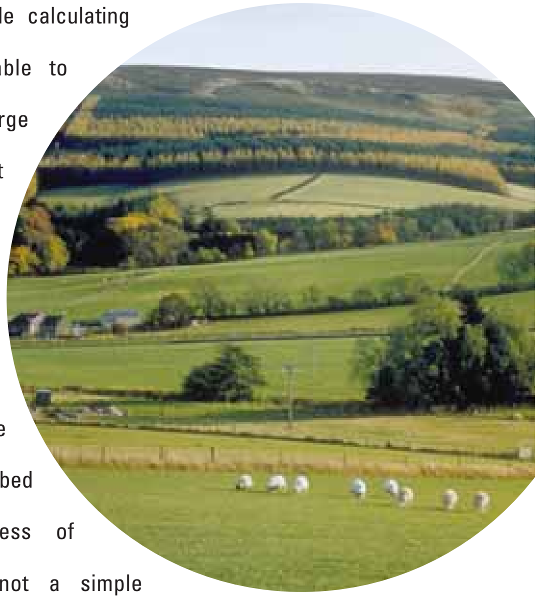
The use of aerial photographs or the high-resolution satellite imagery, which will become available over the next few years, will give a considerable amount of detailed information on landscape change in Scotland, through comparison with information contained within LCS88. The cost implications are, however, significant if a repeat census was to be completed using the same methods. LCS88 has shown how useful a census of land cover be as it is an important input



to a significant amount of research. It is certainly the case that other countries or regions would benefit greatly from taking such an approach but using human interpreters is a slow and costly process. If this were the only approach to take, it is likely that there would be little attempt to undertake a detailed census like that of the LCS88 even though the required data will become readily available from new satellites and aerial surveys.

Automation

What is needed is some way of automating the interpretation of the satellite images or aerial photographs. Modern computers can provide considerable calculating power and are able to handle the large amounts of data that a census of land cover requires. However, that is not in itself a solution to the problem. As described above, the process of interpretation is not a simple calculation but a complex analysis that weighs many different sources of information and takes into account their quality and accuracy to come to an appropriate assignment of an area of land to a land cover or land use class. The area of research that investigates using computers for this sort of task is Artificial Intelligence (AI), a major branch of Computing Science. The history of AI research has been one of great promises but few results. The early researchers greatly underestimated the complexity of human reasoning. What has come out of the research, however, are a number of approaches to



handling knowledge and the variety of non-numerical data involved in human reasoning processes.

Research in this area started in the Institute by exploring the feasibility of automating an update of the LCS88. The first question that had to be answered was how to use the available tools from AI research to meet this goal. Knowledge-based systems are at the core of most AI research and were the obvious starting point. However, it was clear at an early stage that the systems available did not have the flexibility to meet the needs of land cover interpretation. Research has focused on the development of a new approach to using knowledge-based systems for complex analyses. This approach, termed task-oriented analysis, was at the core of the research.

Task-Oriented Analysis

Task-oriented analysis provides a way of automating a complex analysis problem where there is not a single optimum strategy for reaching a solution from a given set of input data. The relevance of this to land cover interpretation is clearly seen in the nature of land cover change. For a given classification of land cover there are only a limited number of changes from one class to another that are possible. Some of these changes are simple to detect, for example the felling of a forest plantation, while others, like the reversion of improved pasture, are more subtle and require higher resolution data and/or knowledge of changes in land management practices in the area of interest. Given a need to analyse for both events, a task-oriented analysis uses simple analysis of low resolution satellite imagery to detect possible felling. It then uses aerial photography, coupled with a more complex analysis of the texture of the image, to detect the reversion of improved pasture. In both of these examples there will be a level of uncertainty in the results with the possibility that the image analysis will not accurately detect land cover changes. There may be change occurring that does not alter the reflected light or the complex internal structure of a land area of a given class may in itself introduce problems. To help overcome uncertainties of this kind, a task-oriented analysis approach uses other forms of knowledge to improve the accuracy of the result. In the case of tree felling, small areas are rejected as too small to be an example of felling, and areas too far from the forest margin and not near a forest track, are taken as unlikely starting points. The detection of a reversion of improved pasture includes knowledge of the economic status of farms in the area and whether there have been any changes in subsidies that might make the upkeep of improved pastures uneconomic. All knowledge used in a task-oriented analysis has an uncertainty attached to it as do all the results from the analysis of imagery. The

The system contains procedures for combining these uncertainties to give an overall result which gives the system's confidence in the analysis system contains procedures for combining these uncertainties to give an overall result which gives the system's confidence in the analysis.

The completed task-oriented analysis system ETORA (Environment for Task ORiented Analysis) is a general purpose system for knowledge-based analysis using the task-oriented approach. This has been further developed with a commercial partner as part of a follow-on project completing the development of the automated interpretation system, SYMOLAC (SYstem for MOnitoring LAnd Cover).

SYMOLAC

Further research is expanding the knowledge of land use change that is contained within SYMOLAC. It has involved interviews with some of those who interpreted the LCS88 and experts in the biological and physical aspects of land cover and land cover change. This has formalized the knowledge of both the interpretation process and the current understanding of the many factors that contribute to land use change, from ecology to land management practices. This research is unique in that the resulting knowledge structure contains knowledge from a number of discrete, though interacting, domains. This is essential for the effective use of the task-oriented approach to analysis.

Knowledge from interpreters has been extracted that indicates a range of environmental conditions and managerial scenarios which will result in certain land cover types. Very few of the LCS88 land cover classes are uniquely defined by any one of these. Rather the interpreter maps land cover by considering evidence of individual factors in combination. The relative strength of the individual pieces of evidence change depending on the geographic location of the area and the general within-scene land management (as opposed to evidence of specific within-field practices, for instance). This can be illustrated by the example of Undifferentiated Coarse Grassland. This is described as being composed of communities that are dominated by one of the two grass species, Moor Mat Grass (*Nardus stricta*) or Flying bent (*Molinia caerulea*). Although they have significantly different habitat requirements, for example *Molinia caerulea* prefers wetter conditions, they are both contained within the LCS88 class of Undifferentiated Coarse Grassland. This class can also be produced by modifying the management of a particular area. Most of the areas in Scotland that fall below the treeline would naturally be covered in a variety of woodland types, if it were not for management of that land for sheep production or sporting purposes. Management practice has been to burn parts of the moorland periodically and to adjust stocking densities of sheep. Burning removes the heather and creates a niche that the grass species are able to fill before the heather recolonises it after two or three years. If the moor is overburned or overstocked, the heather can disappear to be replaced by these grasses. So by increasing the stocking rates of an area, the land cover can be modified to a grass community of either *Nardus stricta* or *Molinia caerulea* depending on the underlying environmental gradients. SYMOLAC uses knowledge like this, alongside knowledge from the analysis of remotely sensed imagery, to assess the most likely nature of the change that has occurred. Similar knowledge can be gathered for other regions or countries and the SYMOLAC approach used for landscape change monitoring in those regions or countries.

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Identifying Appropriate Policies for Controlling Nitrate Pollution

Summary

The major feature of diffuse pollution of waters is that emissions are not observable or at least they cannot be observed at a reasonable cost. There is much evidence that market-based measures, such as taxes or permits, are more effective than legislative or voluntary measures for controlling such pollution. Taxes can be based on emissions or inputs. Research at the Institute has shown that, contrary to widely held belief, emission taxes are not necessarily the most effective policy instrument when the relevant transaction costs associated with abatement of diffuse pollution of waters are taken into account.

Context

Water pollution from agriculture is a concern within the European Union (EU) as reflected by the numerous Directives and Regulations that either directly or indirectly deal with water pollution issues. The recently agreed Water Framework Directive (WFD) aims to unify and co-ordinate the rather fragmented structure of water policies in the EU. Many issues concerning water quality are primarily land use driven. Post-war intensification of agricultural practices, such as the substantial increase in the use of fertiliser and pesticides, and the specialisation and concentration of crop and livestock production, are considered the main drivers of increased non-point diffuse sources of pollution.

The distinctive feature of diffuse source pollutants is that it is virtually impossible to trace them back to a specific source and, therefore, it is not easy to assign responsibility to individual sources for their adverse environmental impacts.

The distinctive feature of diffuse source pollutants is that it is virtually impossible to trace them back to a specific source

Policy Alternatives to Control Agricultural Water Pollution and Possible Selection Criteria

Policies that could affect farmers' land use decisions, and hence control agricultural water pollution, include voluntary, legislative and market-based measures. Examples of voluntary measures are technical assistance, training and moral persuasion towards a more environmental friendly orientation of their agricultural activities. Legislative measures take the form of prescribed standards coupled with a likely non-compliance fine. In contrast, market-based measures, such as taxes or permits, provide incentives to farmers to reduce the intensity of their activities and, therefore, to reduce the amount of pollutants that those activities generate. Market-based measures work through the price system by changing the relative prices of agricultural inputs and or products. These modified relative prices may induce a less polluting resource allocation, either by switching cropping patterns or by reducing the intensity of the existing ones. In other words, market-based policies provide incentives which make it in the rational farmer's own interest to achieve an outcome prescribed by society.

There is a wide range of evaluation criteria for selecting policies to control agricultural water pollution. The most frequently used criteria are:

- economic efficiency, which refers to achieving a specific goal at the minimum cost;
- implementation ease;
- equity, which refers to how the costs of meeting specific

environmental objectives are distributed among farmers;

- political acceptability, which is directly related to the distributional impacts of possible policies, and
- dynamic efficiency, which refers to the ability of policies to induce changes towards a less polluting technology.

The consideration of the use of economic instruments (or market-based policies) goes back to the early 1920s when Pigou addressed the issue of externalities and the possible use of charges or subsidies that could bring a market back into equilibrium. Briefly stated, an externality is a form of market imperfection (or failure) that is caused by the divergence of private and social costs. Water pollution is a typical example of negative externality. In the absence of any regulation, a typical profit-maximising farmer is planning his or her production based on the relative prices of agricultural inputs and outputs. Such a farmer has no incentive to take the possible negative impacts of agricultural activities on the environment into account. Therefore, the social costs imposed on society by such negative impacts of agricultural activities are not properly reflected by the price signals of an unregulated market. As a consequence, the presence of externalities results in non-optimal allocation of resources and, therefore, welfare losses to society as a whole.

The economic efficiency of market-based policies is based upon a set of assumptions that are not always stated explicitly

All possible policies (voluntary, legislative and market-based) can be designed to eliminate negative externalities and therefore improve the quality of water. The final choice depends upon how successful they are in meeting the criteria described above. The main argument in favour of market-based policies over legislative ones is that economic instruments can achieve specific environmental objectives at a lower cost to society. The concept of a Pareto improvement is often used to describe the outcome of using market-based policies. A Pareto improvement refers to the observation that use of economic instruments for water pollution control results in higher welfare gains for society. These higher welfare gains are based on the observation that the on- and off-farm costs of water pollution control are lower under market-based policies regardless of how the on-farm costs are distributed.

The argument of economic efficiency of market-based policies is based upon a set of assumptions that are not always stated explicitly. The most significant among them are:

- there is a single regulator (government), which behaves as a welfare maximiser;
- all economic agents are represented as self-interested (or rent-seeking) and rational;

- there is perfect information or no information asymmetries between agents in the economy;
- there is a perfectly competitive structure of the market, and
- there are no transaction costs.

Some of these assumptions are fairly easy to relax. For example the use of well-respected biophysical simulation models can mimic reality and provide proxies for perfect information. In addition, the use of statistical tools, such as uncertainty analysis, risk management and meta-modelling, may overcome, in some cases, the inherent uncertainty attached to stochastic pollutants. The only merit of some of the other assumptions, such as representing the regulator as a welfare maximiser, or characterising all economic agents as rational and rent-seeking, is that they only have operational value. In other words, real problems are far too complex and a decision-making process needs to make some simplifications in order to construct and prioritise reality, sometimes at the expense of realism.

> a theoretical model has been developed and applied to define the problem of a cost-effective control of nitrate pollution of water

Emission Versus Input Taxes

Taxes can be based on emissions or inputs. The major assumption is that there is a relationship between unobserved emissions and observed inputs and, hence, there is an option to tax inputs instead of emissions. A number of studies have shown that a tax on emissions is a more efficient policy than a tax on inputs. However, in these studies no account of the transaction costs associated with different regulatory instruments of abatement has been taken.

In research at the Institute in collaboration with the University of Newcastle-Upon-Tyne (Kampas and White, in press), a theoretical model has been developed that defines the problem of a cost-effective control of nitrate pollution of water. The application of the theoretical model to the Kennet catchment in England requires representation of nitrate emission and inputs, and abatement costs within an economic model. This was achieved in three stages. Firstly, a Geographical Information System was used to describe land classes based on their soil properties. Secondly, nitrate emissions for all major soil/crop combinations were derived from the outputs of several simulation models and the concentration of nitrates in the drainage water was estimated from a hydrological model. A third stage assembled the information within a non-linear optimisation framework. The abatements costs were derived from the reported costs of monitoring and running Nitrate Sensitive Areas schemes.

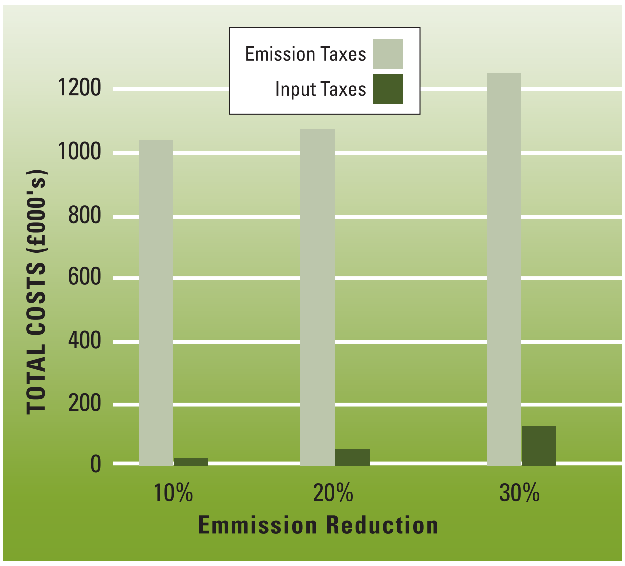

Figure 1. Relative Efficiency of Emission Taxes versus Input Taxes Based on the Total Costs.

Figure 1 shows that emission taxes are not the most efficient instrument when the relevant transaction costs are included. This demonstrates that the inclusion of transaction costs changes conventional wisdom that emission taxes can achieve environmental compliance at minimum cost. The empirical evidence provides support to the outcome of the theoretical model. In a real-life policy comparison, when the considerations of total costs should form the basis for ranking abatement policies, we have shown that emission taxes may not be the most appropriate policy instrument to use.

During the 1990s the use of pollution taxes in Europe accelerated substantially. The revenue from pollution taxes increased by more than 50% between 1990 and 1997 with almost half of the EU countries, Netherlands, France, Belgium, Denmark, Sweden and Austria, currently applying environmental taxes to control agricultural water pollution, either directly through water pollution charges or indirectly as agricultural inputs taxes.

The issue is no longer whether market-based policies have a role to play in improving water quality but rather what kind of approach should be adopted. They often offer a practical way of achieving water quality targets at lower cost than traditional legislative policies. The possible way ahead in terms of instrument choice is probably by combining various criteria and rules within a multi-criteria decision framework, which assures all agents are represented.

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References

Kampas, A. and White, B. (in press). Emission versus input taxes for diffuse pollution control in the presence of transaction costs. Journal of Environmental Planning and Management.

RESEARCH OUTPUTS AVAILABLE TO USERS

The traditional main format of research outputs has been as papers in scientific journals. However, using this as the sole means of delivering the outputs of research has resulted in many missed opportunities for research to have impact. Examples are thus given here of alternative forms of output - Decision support tools and specific items of equipment, while the list of scientific papers can be found on our web-site http://www.mluri.sari.ac.uk/publications/

Decision Support Tools to Link Ecology and Land Management

Summary

The emphasis of land use in the hills and uplands is likely to shift from agriculture to the management of the natural heritage and UK government and European Union policy reflects this. Adjustments will also result from changes in markets. Farmers and land managers will require to adapt their management in response to new environmentally-driven incentives and markets. One approach to providing information to assist their decision-making and that of government is through the development of computer-based decision support tools. Two such tools, called HillPlan and HillDeer, have been developed which use information on soils, vegetation, climate and numbers of grazing animals to predict the impact of management on vegetation change and animal productivity. Examples of the use of HillPlan demonstrate the different effects on plant communities of changes in the stocking rates of sheep and cattle.

Context

Farmers and land managers are currently under increasing pressure to review their strategic land use plans in the light of changes in markets and in agricultural support mechanisms. For example, most hill and upland farms in the UK are dependent upon financial support from the UK government and the European Union.

Public concern for the protection of the environment and its enhancement, and global pressures from food-producing competitors, are leading to changes in policy which will result in the need for change at the farm level.

The EU's Rural Development Regulation describes new forms of support for environmentally friendly and sustainable farm strategies based upon verifiable standards of good farming practice. In 2001, changes resulting from the Agenda 2000 agreement on Common Agriculture Policy reform confirm that support for farmers is a social and environmental measure. The changes have led in the UK to the replacement of the Hill Livestock Compensatory Allowances, which were paid on a headage basis for cattle and sheep, by the Hill Farming Allowance Scheme in England and the Less Favoured Areas Support Scheme in Scotland, which is area-based. This Scheme has a more explicit environmental objective than the previous headage payment scheme and provides a clearer recognition of the farmer's role in maintaining upland habitats, safeguarding the environment and maintaining the countryside. Financial payments will be made at a basic rate, according to land classification, with additional top-up payments to farmers who meet certain environmental and other criteria.

> Farmers and land managers are currently under increasing pressure to review their strategic land-use

How are farmers and land managers to respond to these new environmentally-driven incentives? They will still generate income by selling conventional products from domestic livestock. They may be able to attract enhanced prices if they can market their goods as having been produced under verifiable standards of good farming practice. However, they will also have to meet the area payment criteria which will set minimum and maximum stocking rates designed to ensure that the vegetation resources are managed appropriately. They must strike the balance between meeting financial and environmental objectives. However, the systems they manage are complex with many interacting relationships between the ecological components and the management controls that they can apply. The components and the interactions must be manipulated through management in order to achieve multiple benefits over the long term because impacts on vegetation can take many years, even decades, to become evident.

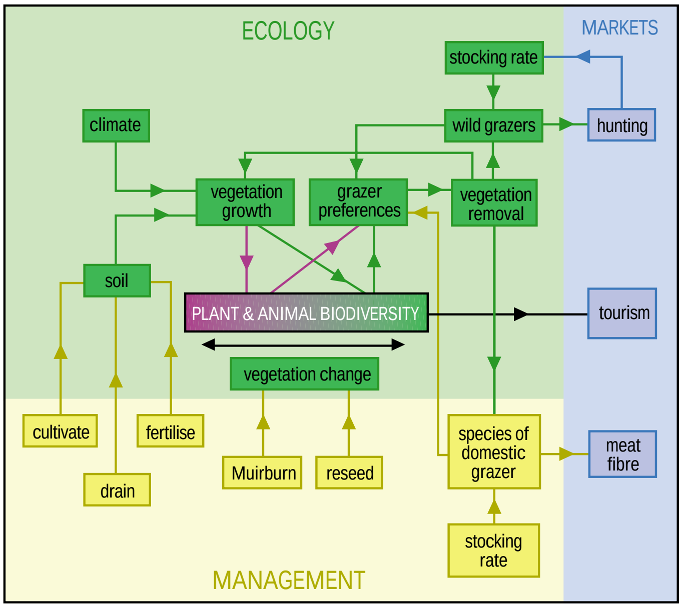


Figure 1. Diagram of the interactions between components in a UK upland system

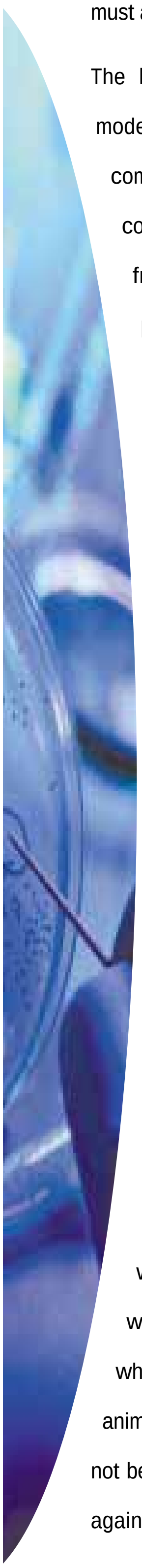
How can those who implement policy be confident that stocking rates can be set which guarantee, for particular mixes of vegetation, that environmental requirements will be met in the long term? Is it possible to find methods by which grazing agreements between farmers and those who implement policy can be reached? Is it possible to provide information that will satisfy the other stakeholders that the proposed plans will meet their expectations with respect to, for example, landscape and wildlife impacts?

The Use of Decision Support Tools

One approach to providing these answers lies in the use of decision support tools which can represent not only the individual components of hill and upland grazing systems; the climate, the soils, the vegetation and the grazing animals, but also the impacts of management upon them and the interactions between them.

The management of hill vegetation by grazing animals lies at the heart of support through the Support schemes to the Less Favoured Areas in the UK, which aims to protect or enhance the diversity and structure of plant species through control of grazing intensity, and in some cases seasonality of grazing, within pre-defined limits. Figure 1 is a simplified structural diagram of a typical UK hillside. It shows the main ecological and management components and the links between them. Hill vegetation is of interest not only as a source of biodiversity and as a landscape resource but because it also supports domestic and wild grazers, both of which can be important to income, and a range of other animal species. The extent of change in both the species diversity and the structural diversity of the vegetation depends upon the balance between vegetation growth, senescence and its removal by grazing animals. How can we estimate what the impacts will be of a range of options for managing a hillside? For example, what will happen to the diversity of the hill vegetation if changes are made in stocking density, species of grazer and seasonality of grazing, or if heather is burned or an area of reseed removed?

In forecasting these impacts, the changes within the individual patches of hill vegetation, associated with the growth and death of constituent plant species, must be predicted. There must be knowledge of the grazing preferences of the different grazer species and the ability to predict what they will choose to eat and how much of it. There must be the ability to predict the consequences for the the balance of plant species which will result from their different patterns of growth, senescence and selective removal by the grazers. The seasonality of plant growth and senescence, and of animal requirements for energy and protein, must also be predicted.



The knowledge for constructing the models, which represent the components and their interactions, comes largely from research but also from the expert knowledge of people who manage and interact with hill resources. There is a sufficient understanding of the physiology of individual plant species to predict their growth (and senescence) in specific climatic and soil conditions and under particular levels of grazing. That understanding allows the creation of mathematical models to predict the productivity of individual plant species. There is also sufficient understanding of the competition between individual plant species as they seek light, water and nutrients required for their growth and development. For example, deep-rooted plants will survive better in periods of dry weather and the plant species, which are most preferred by grazing animals, will be heavily grazed and may not be successful in competing for light against ungrazed and taller growing species. This understanding is the basis of the forecasting of vegetation change.

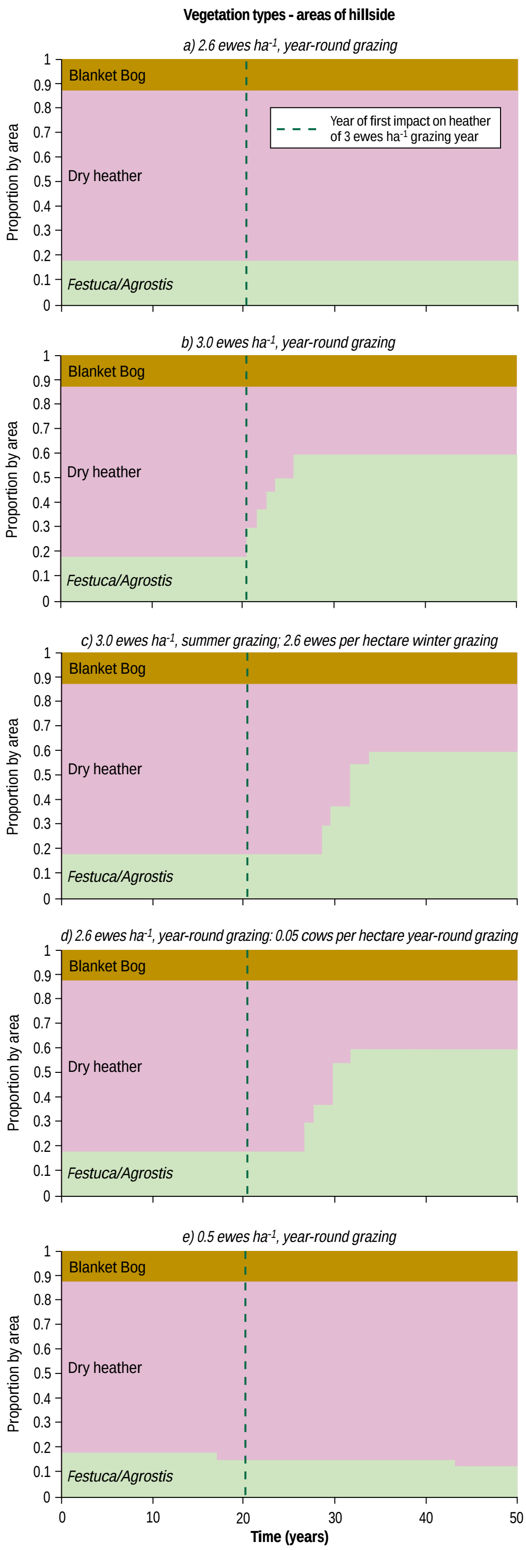


Figure 2. Examples of outputs from HillPlan for various scenarios.

Research and expert knowledge has also provided information about the preferences of grazing animals. Generally grazers will attempt to graze the plants of the highest feeding value but different animal species have different preferences and different abilities to select precisely. Seasonal differences in the availability of hill vegetation also will change animals' grazing patterns. Many hill sheep naturally heft or rake the hillside and this may result in them grazing less preferred species. Mathematics models allow the incorporation of this understanding into grazing models.

There is also knowledge about the nutrition of domestic and wild grazers, and models can be constructed of their growth and development based upon the plant material they graze and their physiological status. It is also possible to reflect the removal of domestic animals for market and the culling of wild animals such as deer.

The mathematics of all of these components are coded, using structured object-oriented methods, into linked and interactive models which form the basis of computer-based decision support tools. They represent the behaviour of the whole system, provided, of course, that information is available which describes the specific hill grazing being considered.

Clearly, the descriptive information must reflect the species and structure of the hill vegetation. The complex nature of the inter-relationships between the plant species themselves and between the vegetation patches they create must be reflected in an appropriate description. To complement the computer packages, we have devised methods of classifying and coding vegetation in a way that reflects its structure on a hillside. This classification takes less than a day to complete for any farm. This descriptive information includes details of animal species, breeds, flock/herd numbers and their locations, and provides the basic information from which the decision support tools can be run.

HillPlan and HillDeer

Using this approach the Institute has developed two decision support tools. One operates at the farm level, called HillPlan, and forecasts the changes in vegetation under a range of livestock management and heather-burning strategies. Livestock can graze the hill all-year round or livestock numbers can be varied over the seasons. Different species can be grazed: sheep, suckler cattle or red deer, alone or in mixed groups. Different classes of animals can be used, for example breeding ewes, hoggs or wethers, again alone or in different balances. Heather burning can be tested using different cycles of burning. HillPlan will forecast the balance of vegetation classes, the distribution of heather in different age classes and the mix of tussock and lawn areas for grassy vegetation types for any combination of livestock number and burning pattern. The next version of HillPlan will also forecast the productivity of the grazing animals.

An example of the output from HillPlan is shown in Figure 2 which demonstrates for a single hillside that, on a dry heather hill with a proportion of productive hill grasses and an area of blanket bog on the hill top, year-round stocking with sheep is compatible with retention of heather cover if an appropriate stocking rate (2.6 ewes per hectare) is used (Figure 2a). Increasing the stocking rate to 3 ewes per hectare year-round reduces heather cover dramatically after 20 years (Figure 2b). However, retaining 3 ewes per hectare in summer and reducing winter stocking rate to 2.6 ewes per hectare delays the onset of heather loss to around year 27 (Figure 2c). Reducing to 2.5 ewes per hectare in winter sustains heather cover over a 50-year period. Stocking year-round with the equivalent total biomass of sheep at 3 ewes per hectare using cattle (0.05 cows per hectare, 10% of total biomass) and sheep (2.6 ewes per hectare, 90% of total biomass) delays the onset of heather loss until around year 25 (Figure 2d). Changing the year-round grazing balance to 20% cattle (0.1 cows per hectare) and 80% sheep (2.4 ewes per hectare) sustains heather cover at its starting level. Heather cover can be extended in the long run by reducing year-round stocking rate to 0.5 ewes per hectare (Figure 2e). In all of these examples, the blanket bog remains unaffected. Results from a range of options as shown in this example can be used to decide upon the most appropriate grazing scheme for the hillside.

The second decision support tool, HillDeer, operates over much larger areas being designed for use by Deer Management Groups, each of which covers a number of estates extending to hundreds of square kilometres. It also predicts the changes in the balance of vegetation and in the sustainable populations of red deer.

The term "decision support tool" has been chosen carefully to reflect the fact that the packages are designed to assist in decision making; they do not make decisions. They should be used to compare options and to assess the impacts of different management strategies. The forecasts they generate should contribute to the decision-making process. Decision support tools may, in the future, be used at individual farm level as the basis for negotiating grazing agreements between farmers or other land managers and those who provide financial support. As such, the basis of their forecasts must be transparent to all parties concerned. The structures of the decision support tools that the Institute has developed are based wherever possible on published information in order to guarantee their transparency and their credibility.

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Soil Water Probe for Environmental Management

The determination of soil water content is fundamental to many environmental studies, including the relationships between land use and water quality and quantity. The need for new instrumentation was identified as important to many Institute projects and resulted in the development of a new probe in the early 1990s. This probe was designed to overcome some of the difficulties with existing methods by applying a novel measuring technique that is now patented in the UK, Europe and the USA.

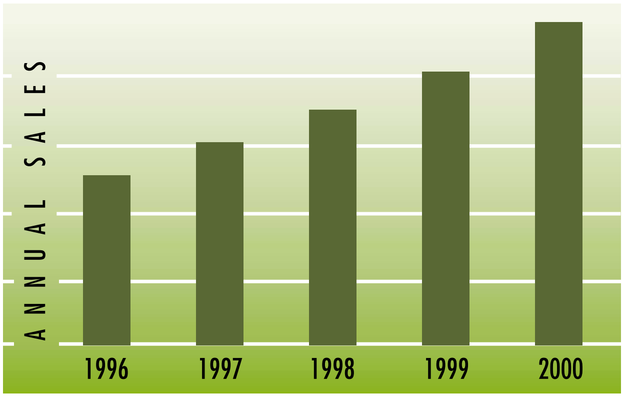

Figure 1. Relative annual sales of the ThetaProbe.

The water content of the soil determines its dielectric properties as water has a dielectric constant of ~81, compared to soil ~4, and air ~1. The probe generates a 100MHz signal into the soil, some of which is reflected back dependant on the dielectric properties of the soil. The reflected part of the signal combines with the applied signal to form a standing wave and the voltage of the standing wave acts as a simple sensitive measure of soil water content.

The probe, now named ThetaProbe, was subsequently developed commercially and has been marketed successfully (Figure 1) since late 1995 by Delta-T Devices of Cambridge under a licence agreement.

A Profile Probe has recently been developed by Delta-T Devices, based on the same technique, that allows soil water measurements to be made at either 4 or 6 points to a depth of 1 metre through pre-installed access tubes. Both types of probe are illustrated in Figure 2.

ThetaProbes have established an excellent reputation for reliability and precision and have been sold in over 60 countries to a wide range of users including Universities (from Adelaide to Zimbabwe), Research Institutes and commercial organisations. Current applications include agriculture, horticulture, hydrology, civil engineering, irrigation and environmental science, but also the unusual from the determination of water content of sports turf to an EC humanitarian project to evaluate the effect of soil water on the performance of mine detector technology.

Projects using ThetaProbes within the Institute include investigations into the impacts of land use, the detection of environmental change, via the UK Environmental Change Network, and the transport of solutes, such as nitrate, and particulates, such as phosphorus.

Further information on the development of these probes is available on the Institute's web pages at: http://www.mluri.sari.ac.uk/~jm0188

The Delta-T website contains further technical and commercial details at: http://www.delta-t.co.uk

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The ThetaProbe.

Figure 2. The Profile probe.

Spray-drier to Improve Sample Preparation for X-Ray Powder Diffraction

X-ray powder diffraction (XRPD) is an analytical technique used throughout industry and academia for the identification and analysis of crystalline substances, for example the minerals in soils. As the name indicates, the sample must be prepared as a powder and for many applications a so-called 'random powder' is necessary. A random powder is one without texture. In practice this is extremely difficult to achieve because most powders are composed of individual particles whose shape causes them to adopt a preferred orientation. Clay minerals are prime examples because most are shaped like flat pieces of paper and are easily aligned if pressure or shear is applied. XRPD data obtained from such samples are extremely sensitive to the amount of texture present. As a result, preferred orientation is often quoted as the main obstacle to the development of quantitative methods of analysis by XRPD methods.

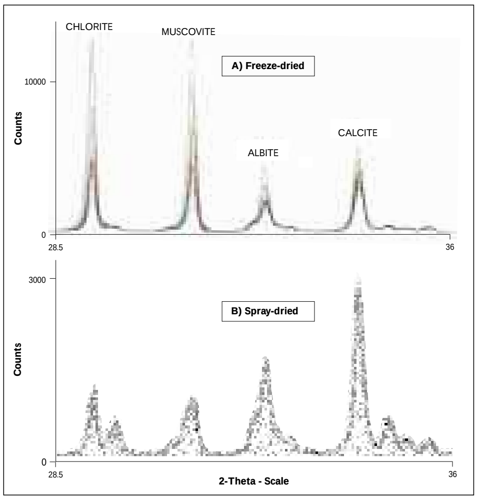

Figure 1. XRPD patterns of a synthetic mixture of 25% chlorite, 25% muscovite, 25% albite and 25% calcite, all minerals which frequently exhibit preferred orientation. A) XRPD patterns from 18 separate loadings of a freeze-dried portion of the mixture by 3 different operators (red, green, blue, 6 patterns each). B) XRPD patterns from 18 different loadings of a spray-dried portion of the mixture by 3 different operators (red, green, blue, 6 patterns each).

The problem has been solved at the Institute using a technique known as spray-drying. Essentially, a sample is mixed with water and sprayed into a heated chamber where it dries in the form of spherical spray droplets. Both the spherical shape of the resulting granules and the way spheres pack together ensure that the powder has no texture. Spray-drying is a well-known industrial process used widely to produce granulated flowable powders, especially in the ceramics, pharmaceuticals and food industries. Indeed, the potential of spray-drying for preparing a random powder sample for XRPD has been recognised for some time, prompting several attempts to use it.

However, in the past the technique has not been widely adopted largely due to problems with the recovery of small samples at the scale required for XRPD. These problems were overcome at the Institute using a modified artist's air-brush to spray the sample into a specially designed chamber from which it is simply collected on a sheet of paper.

The motivation for its original development was provided by a variety of both research and commercial applications that required quantitative analysis by XRPD. It has now been successfully incorporated into both (see figure 1). The potential of the technique has been demonstrated in several scientific papers and, because of the demand, the Institute now produces the equipment to order. This commercialisation of the spray-drier technology began early in 2000. Thus far ten kits have been purchased by a variety of both industrial, academic and government-funded laboratories. Most have gone to the USA, others to Germany, Ireland and the UK, and it is likely that the Macaulay Spray-drier will soon be a well-known piece of equipment in many laboratories worldwide.

Further information is available at:

www.mluri.sari.ac.uk/newcommercialservices/spray/index/html

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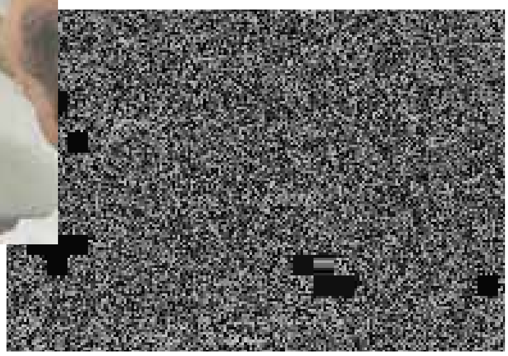


APPLICATIONS WHICH SUPPORT ALTERNATIVE LAND USE OPTIONS

The devastation of the outbreak of Foot and Mouth Disease in the Spring of 2001 in the UK has caused many farmers to question whether they wish to re-introduce livestock to their land. The Macaulay Institute has for some time been assessing the relative advantages and disadvantages of alternative uses of land and two of these are described below. The third article in this section draws attention to the environmental costs of different types of farming, which are becoming of increasing importance world-wide and which should be considered in relation to the evolution of livestock farming post-Foot and Mouth Disease. Further information on decision making post-Foot and Mouth Disease is available on a specific web-site, www.mluri.sari.ac.uk/fmd

Identifying the Potential for Native Woodland in Scotland

Summary

The expansion of the area of native woodland, which is part of the UK's Biodiversity Action Plan, requires a strategic approach in order that resources can be targeted and biodiversity and other benefits can be maximised. To help realise this, The Native Woodland Model has been developed to support the needs of Scottish Natural Heritage (SNH) and the Forestry Commission. It is a Geographical Information System (GIS)-based model which predicts site suitability for native woodland by mimicking the reasoning and decision-making required in the planning of new areas of woodland. The primary outputs are a digital dataset and a map which are available for any area of upland Scotland and these have been used by a range of organizations in a number of applications. With the Forestry Commission, SNH are developing a targeted approach towards the achievement of native woodland Habitat Action Plans and the creation of forest habitat networks within the Scottish Forestry Strategy. SNH are also using the Native Woodland Model to demonstrate the potential for wood products from native woodlands in Rural Development initiatives. It also provides much of the basis of the Cairngorms Forest and Woodland Framework. The Institute is currently investigating the feasibility of a similar approach to help support open range Habitat Action Plans e.g. for heather moorland.

Context

Native woodlands in Scotland have been reduced to less than five per cent of their former extent because of a number of factors including timber extraction, agricultural improvement, climate change and grazing. However, the UK is committed to reversing this trend and targets for the expansion of native woodlands, both

through new planting and natural regeneration, have been set within Habitat Action Plans (part of the UK Biodiversity Action Plan). There is also growing interest in Forest Habitat Networks which, based on research by SNH, shows that the biodiversity benefits of woodlands can be enhanced by their spatial relationship and connectivity with each other. Different types of woodland grow better on different sites and the Native Woodland Model was developed to help provide objective and consistent guidance on where this woodland expansion is best suited. This research was conducted mainly to support the needs of SNH and the Forestry Commission.

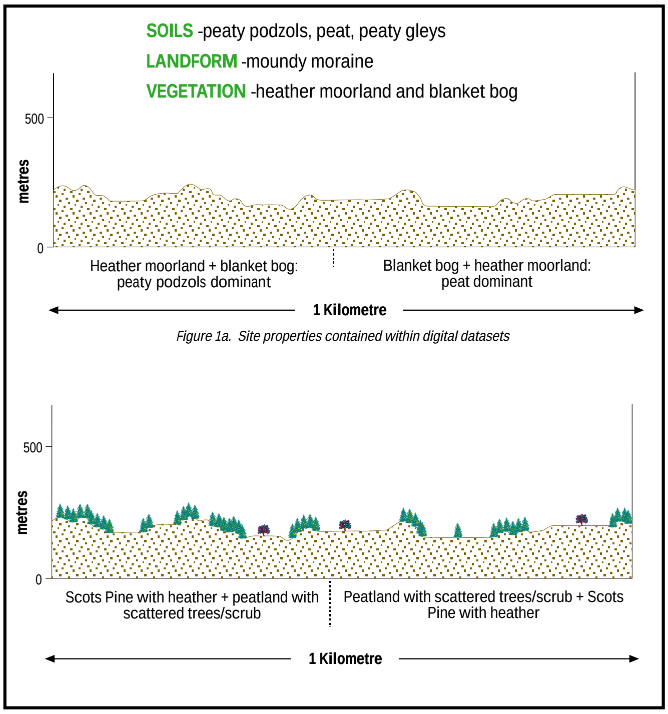


Figure 1a. Site properties contained within digital datasets

Figure 1b. Native woodland prediction

Our Approach

Our approach, although developed within a GIS, differs little from the one that a practical forester or ecologist would adopt when planning a new woodland. Indeed we have set out to replicate the approach but for strategic use over large areas without the need for ground survey. In practice, information on site factors which influence woodland growth, such as geology, soil conditions (drainage, fertility and acidity), climate (temperature and exposure), topography (slope and rockiness) and current land cover and use would be collected and assessed. These would then be compared with the conditions suited to different woodland types. For example, ash is known to prefer base-rich soils whereas Scots Pine is tolerant of, and indeed prefers, more acid conditions.

The Native Woodland Model follows this logical approach, but the key difference is that the information on site conditions has already been collected and is stored within two datasets (soils and land cover) in the GIS. When combined, these data provide information similar to that which would be collected during on-site assessments.

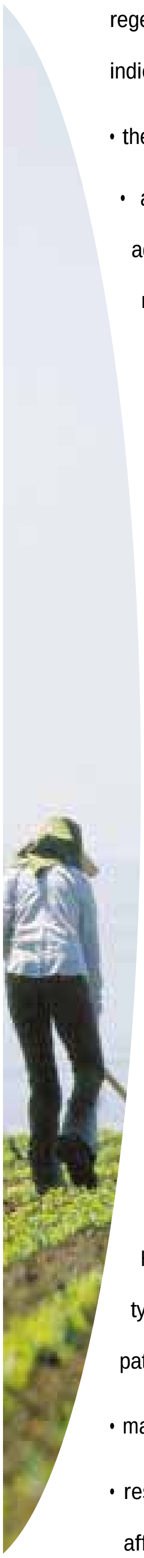
However, the key to the modelling is the translation' of these data into meaningful field descriptions of different sites and to use this information to assess the most appropriate woodland type(s) for each site. Figure 1a demonstrates how the two datasets can be integrated to provide extra detail on the relative proportions of soils within complex terrain such as moundy moraine, a typical landform in upland Scotland. Figure 1b indicates how this information is then used to provide subtle, but important, differences in the assessment of native woodland potential.

Outputs, Uses and Applications

The primary outputs from the Native Woodland Model are maps indicating the potential distribution of the different woodland categories (Figures 2 and 3). These maps are simplifications of the much more complex model outputs. They do not represent a vision for the woodlands of the future, but provide an assessment of woodland potential and a framework within which all other land use interests can be discussed.

The Native Woodland Model has recently been applied throughout the Scottish uplands to fourteen of SNH's Natural Heritage Zones, but there are no constraints on the size or location of specific areas in which end-users might have a particular interest, for example, within the embryonic Loch Lomond National Park (Figure 2).

Within the Cairngorms Forest and Woodland Framework (Cairngorms Partnership, 1999), we have taken the output beyond a land suitability



assessment and used it to determine the appropriateness of a range of woodland management options (natural regeneration and new planting). Figure 3 indicates:

- the location of existing native woodland;
- a 500 metre-wide zone immediately adjacent to existing woodland where new woodland could establish by natural regeneration, and
- the most appropriate native woodland type which could be established only by planting, i.e. that which is too distant from significant existing seed sources.

The Framework identifies woodland priorities and provides a regional context within which Woodland Grant Scheme applications can be assessed. In this way it provides guidance to landowners of the most appropriate woodland types in different areas and is already being used to support specific Woodland Grant Scheme applications.

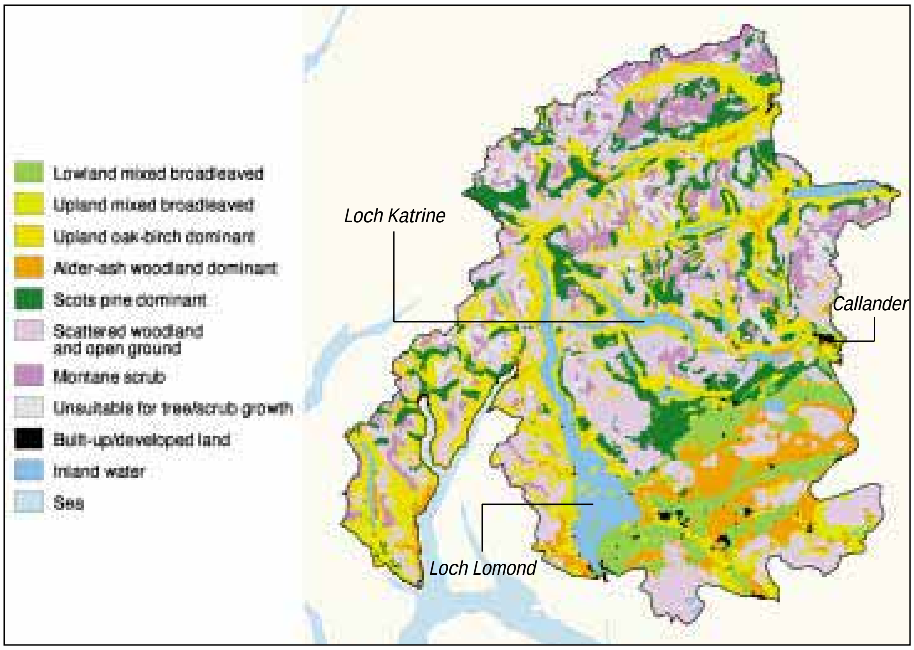


Figure 2. Assessment of Native Woodland Potential in Loch Lomond and the Trossachs Proposed National Park

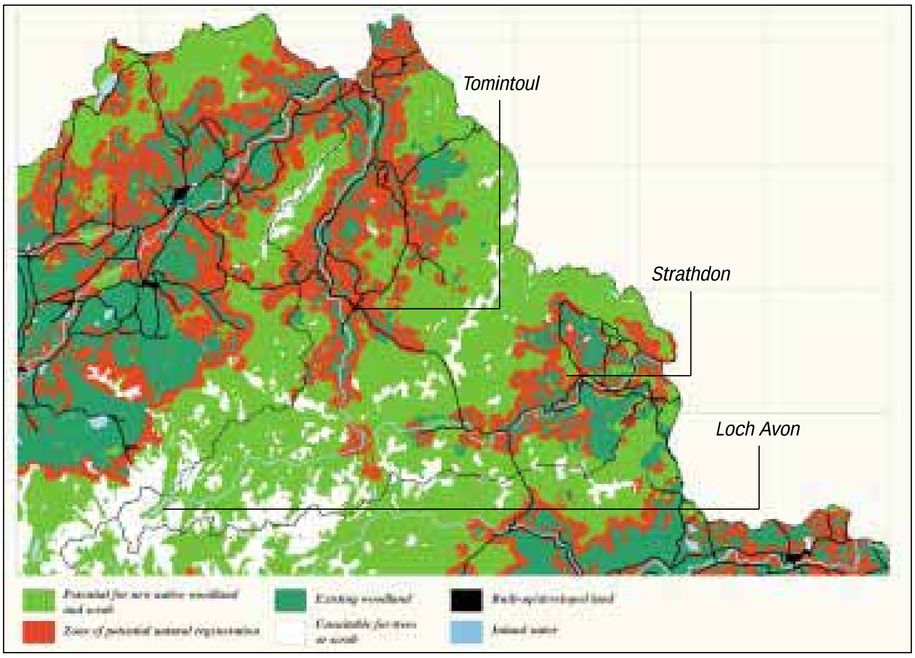


Figure 3. Native Woodland Options in Strathdon and Glenlivet

Habitat Action Plans for woodland types (such as Scots Pine, oak or ash woods) all follow a similar pattern, setting out targets in the following terms:

- maintenance of existing woodland;
- restoration of the native woodland type onto areas currently afforested which occupy Ancient Woodland Sites by a certain proportion of the current area; and
- expansion of the woodland type onto open ground by a certain proportion of the current area.

There is no national survey identifying the location or extent of these native woodland types, with the exception of Scots Pine woods. This meant, for example, that we could neither map existing oak woods, nor calculate the nature of the targets for restoration and expansion. The Native Woodland Model in conjunction with the new Scottish Semi-Natural Woodland Inventory has provided a means of allocating existing semi-natural woods to Habitat Action Plan types. This allowed the analyses of the datasets to produce mapped and quantified sites meeting the Habitat Action Plan targets outlined above. An analysis currently underway (with the Forestry Commission) will produce maps and digital data for all of upland Scotland by Natural Heritage Zone and Habitat Action Plan type.

There is a considerable interest in the development of local businesses adding value to products of native woodland, in particular timber. SNH has commissioned work from Highland Birchwoods to establish potential sustainable timber productivity from native woodlands and the thresholds for native saw log supply which would support a local sawmill. A remote area of the west Highlands has been analysed using the Native Woodland Model to identify the most productive sites for oak wood and ash wood, and these have been combined with the Scottish Semi-Natural Woodland Inventory to assess which of these sites are currently wooded. The results of the study are summarised in the table below.

	Existing native woodland	Existing coniferous Plantation	Existing non-wooded land
Area (ha)	16,156	102,021	50,534
Potential annual sustainable native saw log harvest (tonnes)	3,231	20,404	10,071

Table 1. Potential for native timber production based on Native Woodland Model predictions

Taking a value of 0.2 tonnes of saw logs per hectare per annum, the maximum production from suitable woods far exceeds a threshold of 700-1000 tonnes which is the annual requirement of a small sawmill producing native saw logs. While considerable reductions from this potential would be necessary to allow for designated sites, plantations maintained in conifers and restrictions on new planting, it is clear that there is potential in this area to undertake long-term development to create a productive hardwood resource. These examples show the potential of the Native Woodland Model to provide planning information in relation to native woodland.

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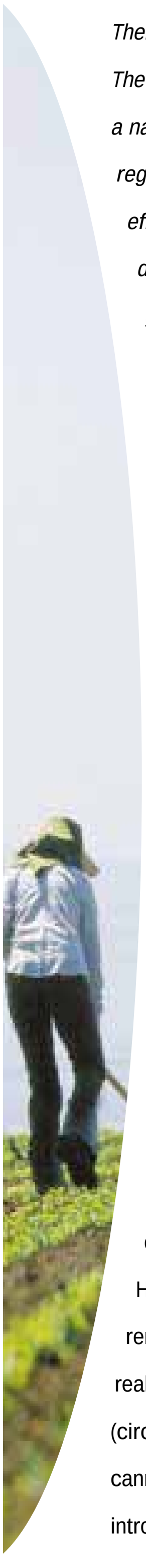
[1] Scottish Natural Heritage

Providing Options for Expanding Renewable Energy Capacity



Summary

There is a drive to increase renewable energy capacity in the UK. The Macaulay Institute has contributed inputs to the development of a national energy policy, has advised on specific developments at a regional level and identified opportunities for improving the efficiency of existing technologies. A methodology has been developed which provides a national picture of the potential for growing short-rotation coppice, an objective method for identifying locations of biomass-to-energy plants and an assessment of the impact of different uptake rates by farmers. In the context of wind farms the Institute has provided 3-D models of the visualisation of potential developments to a range of clients. In relation to efficient hydro-electricity generation, remotely sensed satellite image data have been used to forecast snow accumulation and run-off, and hence downstream effects on water yields and electricity generation.

Context

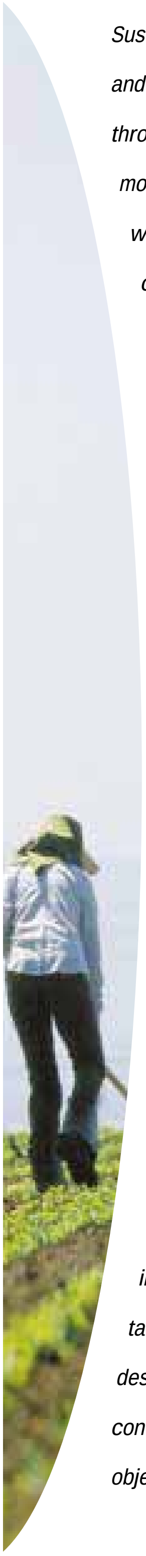
A commitment to increasing renewable energy capacity is a key element of UK government policy on climate change and sustainable development. It aims to provide 10% of UK electricity needs from renewables by 2010. The existing energy capacity in Scotland is provided by fossil fuels (60%), nuclear energy (23%), hydro-electricity (15%) and wind power (<1%). However, Scotland has the most favourable environment for renewable energy of any European area. Wind energy alone could realistically provide around 20% of existing peak electricity demand (circa. 5.7 GW). Recognising that renewable energy generation cannot compete on cost-grounds with fossil fuel, the government has introduced a support system to encourage long-term investment in renewables (e.g. Scottish Renewables Obligation). These changing priorities have significant implications for rural communities, land use and landscapes in Scotland. The Institute has provided inputs to national policy (e.g. energy from biomass production), advice on specific developments (e.g. potential visual impacts of wind farms) and has also contributed new data to improve the efficiency of existing technologies (eg hydro-electricity). This article provides some insight into these inputs.

Wind Energy

Throughout the UK, potential wind energy developments are contracted on the basis of cost and not location. In an attempt to provide lower cost energy, developers have been forced to select sites with high mean wind speeds - inevitably these are hill tops which often also have high natural heritage and amenity values. Of particular concern to the countryside and conservation agencies are the visual impacts of the turbine structures and their rotating blades. The Institute has been working with Scottish Natural Heritage and the Countryside Commission for Wales to develop relevant computer modelling techniques. These have three functions:

- to provide a means of visualising the new structures in the existing landscape. This involved creating a 3-D model, using a combination of digital maps and photographs, and can include dynamic modelling rotation of the turbine blades;
- to provide a means of quantifying the visual impacts of the structures by calculating which part of the structures will be seen from where - these are called Zones of Visual Influence ; and

Linking Farming to the Environment through Sustainability Accounting Methods



Summary

Sustainable development, and the interdependence of the economy and the environment, are important items on political agendas throughout the world. If society is to move towards a more sustainable development trajectory, it will need to have consistent, reliable and comparable indicators of progress to inform difficult and complex resource-use decisions. Many resource-use decisions are made at the level of the firm, and there has been a growing interest in the impact of the activities of individual firms on the environment and what this means with respect to sustainable development. By extending conventional measures of financial performance to include the costs and benefits associated with the activities of individual businesses that are normally outside conventional accounting systems, it is possible to derive firm-level indicators of sustainability. These accounting systems can be applied in an agricultural context to gain insight into the contribution of individual farms to sustainable development and the approach taken to incorporating the effect of greenhouse gas emissions is described. Such accounting systems are particularly relevant in the context of government support for farms to meet environmental objectives.

Context

Sustainable development is now firmly placed at the centre of UK Government policy. Sustainable development sets a broad and challenging agenda and will require innovative approaches to economic, environmental and social policymaking. Part of the challenge is to develop indicators that will inform the policy process and provide a means of measuring progress towards policy goals. The Government has recently published a new national set of around 150 sustainable development indicators. Whilst these indicators provide a valuable insight into progress on a diverse range of issues, they are limited in a number of key respects. For example, as with all sets of indicators where each indicator is quantified using a different unit of measurement, they cannot be amalgamated to give an indication of the overall sustainability of the economy. Furthermore, they can provide only a limited understanding of the nature of the many trade-offs that are being made where there are limited resources or conflicting objectives.

Agriculture is the largest form of land use in Scotland, with some 75% of Scotland's land area currently under some form of agricultural production

Agriculture and Sustainable Development

Agriculture is the largest form of land use in Scotland, with some 75% of Scotland's land area currently under some form of agricultural production. It is recognised that the industry makes an important social and environmental, as well as economic,

contribution to sustainable development. The changing objectives of government, as reflected in financial support for farmers, put a particular emphasis on the need to produce environmental benefits from farming. Scottish agriculture is characterised by a wide range of farm types and a broad bio-physical spectrum of farming environments. The industry's interaction with the environment is considerable and complex with the potential to have both significant positive and negative impacts on important environmental resources. The nature of these economy-environment interactions is dependent on a range of inter-related factors including farm type and location. Measures of farm performance that take these interactions into account, and set them in the context of the wider role of agriculture in sustainable development, will help to provide answers to important policy questions, such as which agricultural activities should be supported or discouraged and in which locations. Exploring the use of integrated economic and environmental accounts to provide indicators of sustainability at the farm-level is a key part of the research programme of the Institute.

There are many costs and benefits associated with the activity of an individual farm that are external to conventional economic indicators of business performance. By extending financial accounts to incorporate these non-market costs and benefits, it is possible to derive a farm-level indicator of sustainability. The indicator is derived from a body of sustainability theory referred to by economists as the "capital maintenance concept" (Solow, 1986). Economic development employs a range of capital stocks including manufactured, natural, human and institutional or social forms of capital (Berkes and Folke, 1994). The development of an economy is deemed "weakly" sustainable as long as the aggregate value of stocks is maintained (Pearce et al., 1993). A central, but controversial, assumption that underpins this theory is that it is possible to substitute one form of capital for another in the development process.

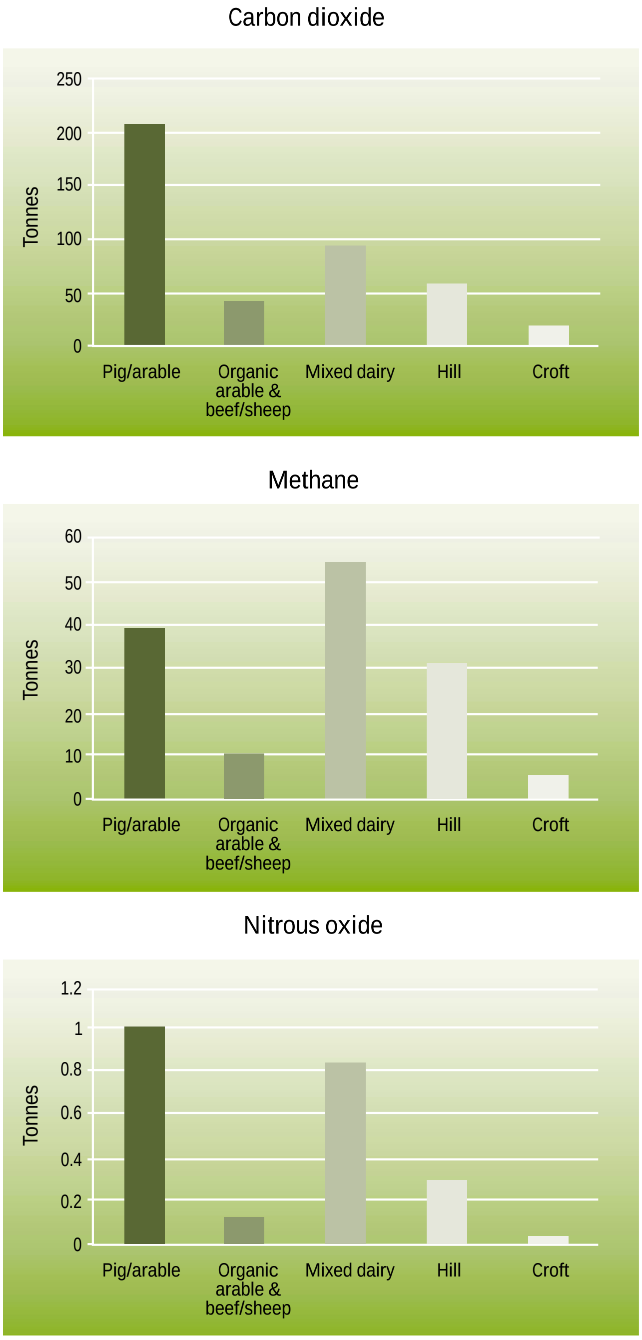
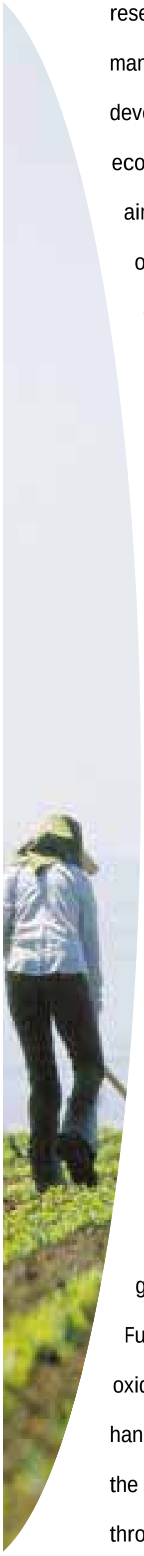


Figure 1. GHG emissions for five case-study Scottish farms.

Accounting for Sustainability

In order to derive a farm-level sustainability indicator, it is necessary to account for the non-market costs and benefits associated with the activity of the farm under consideration. This requires knowledge of the interaction of modern agricultural systems with the environment and, at the same time, an ability to quantify the full economic value



that society places on public goods, such as biodiversity and landscapes, as well as the loss of value associated with environmental damage, for example from pollution. The aim of the research is to explore, drawing on existing farm level financial and management information, the potential development of a system of integrated economic and environmental accounts aimed at producing a single measure of farm level sustainability. An example of the type of approach that can be adopted is now given.

The aim of the research is to explore, drawing on existing farm level financial and management information, the potential development of a system of integrated economic and environmental accounts

Accounting for Greenhouse Gas Emissions

One example of a cost, which is external to conventional indicators of economic performance, is the cost to society associated with climate change. Although the subject of ongoing debate, the balance of evidence suggests that anthropogenic greenhouse gas emissions have a discernible influence on the global climate. Agriculture is a significant contributor to the UK's emissions of greenhouse gases, being responsible for around 8% of total emissions. The major greenhouse gases associated with agriculture and land use are methane, nitrous oxide and carbon dioxide. In particular, agriculture is one of the main sources of methane and nitrous oxide, contributing somewhere around 25%-37% and 49%-52% of total UK emissions respectively. Methane is produced by ruminants and is also generated by the anaerobic fermentation of organic manures. Further emissions arise from dirty water and silage effluent. Nitrous oxide emissions are associated with fertiliser use, and manure handling and storage. Emissions of nitrous oxide are largely due to the activities of biogenic bacteria. This activity may be enhanced through the addition of fertiliser N. Losses of carbon stored in the soil or above-ground vegetation can occur as carbon dioxide through the conversion of forest land or other land to intensive agricultural uses. In addition, emissions of carbon dioxide are generated from on farm use of fossil fuel.

Using an inventory method, based on emission coefficients, the total annual emissions of methane, nitrous oxide and carbon dioxide were estimated for five case study farms representing a range of Scottish agricultural systems (Figure 1).

The extent of emissions of each gas is largely a function of farm type, the size of the farm and farm management practice, such as manure management. Using estimates of the marginal external costs of these greenhouse gas emissions (Table 1), it is possible to estimate the total external cost associated with emissions from each farm. The upper and lower range values reflect the considerable level of uncertainty associated with these estimates.

	Lower range	Upper range	Preferred estimate
Carbon dioxide (£/t)	47	113	63
Methane (£/t)	239	353	263
Nitrous oxide (£/t)	4,267	17,333	7,530

Table 1. Marginal external costs of greenhouse gas pollution (from Pretty et al., 2000).

The estimated external costs of greenhouse gas emissions can be added to the internal operating costs for each farm to give a revised figure of farm Net Value Added (Table 2). Estimated on this basis, the external costs of greenhouse gas emissions represent a significant proportion of the farm Net Value Added.

	Pig/arable	Organic arable & beef/sheep	Mixed dairy	Hill	Croft
Output from crops	356	61	47	0	0
Output from livestock	445	30	189	55	6
TOTAL OUTPUT	801	91	236	55	6
Subsidies	94	17	30	52	9
Inputs	(712)	(61)	(194)	(61)	(9)
GROSS FARM INCOME	183	47	72	46	6
Depreciation	58	11	24	5	1
Net Value Added	125	36	48	41	5
External cost of greenhouse gas[1]	31	6	26	14	3
Revised Net Value Added	94	30	22	27	2

[1]Estimates based on preferred marginal external cost estimates from Table 1

Table 2. Measure of revised Net Value Added for five case study farms for a single annual accounting period (£'000)

Farm-level Sustainability

Despite advances in scientific and economic understanding, these accounting techniques have only been applied to a limited range of environmental issues. A considerable amount of further research is required before a comprehensive accounting system can be developed. However, if all non-market costs and benefits were accounted for, a revised Net Value Added could be used as a farm-level indicator of "weak" sustainability for a given accounting period. The indicator is highly sensitive to changing economic circumstances, such as annual fluctuations in commodity prices and changes in the system of subsidies, and, therefore, the value of the indicator for a single year must be interpreted with care. However, repeated negative values of a revised Net Value Added would suggest that a farm is making a negative contribution to sustainable development.

Contact: Gary Hill, g.hill@mluri.sari.ac.uk

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- to enable the exploration of alternative siting options aimed at reducing visual impacts either overall or selectively. These models and quantitative assessments have been used as evidence in Public Enquiries related to two wind farm projects in Wales and increasingly the developers themselves are interested in using these facilities to improve their siting design prior to submitting a planning application.

Energy from Biomass

The principal potential source of energy from biomass production in Scotland is short-rotation coppice. However, residues from conventional forestry may also be an important source and the Institute is examining the consequences of using these on sustainable forest management (in collaboration with Forest Research). At present there are no biomass-to-energy plants in Scotland but plants have been constructed in northern England, for example, the Arbre project in Yorkshire, and in Northern Ireland. Costs associated with the growth and supply of feedstock for biomass-to-energy plants are critical and vary according to location. In partnership with the Energy Technology Support Unit, and under contract to the Scottish Executive and Department of Trade and Industry, a methodology has been developed which has provided:

- a national picture of the potential for growing short rotation coppice;
- an objective method of identifying and comparing different potential locations where biomass-to-energy plants could be sited, based on an analysis of potential feedstock supply, the road network (for minimising transport costs) and the National Grid (for connection costs). Table 1 illustrates the type of relatively simple comparison which can be made; and
- an assessment of the impact of different uptake rates by farmers.

Location	Feedstock supply (dry tonnes) within travel time of:	
	30 minutes	60 minutes
Newburgh (Fife)	900,240	2,706,400
Sorbie (Ayrshire)	141,320	366,400

Table 1: Potential annual feedstock supply from short rotation coppice (dry tonnes) for two contrasting sites

Growing short rotation coppice requires a prior, and long-term, commitment from growers - time between planting and first harvest is typically 4-5 years - but currently the incentives available are very small. This type of analysis provides a framework for objective targeting of financial incentives. In addition, there is generally a lack of knowledge on the husbandry relevant to growing short-rotation coppice in Scotland. This goes beyond the yield relationships of different willow or poplar clones at different sites into the long-term yield profiles for contrasting production systems. To help fill this gap, the Institute has been conducting field experiments in collaboration with the Central Scotland Countryside Trust to provide information on these husbandry issues.

Hydro Power

Energy from hydro-electricity is a mature technology in Scotland and, although there are small 'run of river' schemes being contracted under the Scottish Renewables Obligation, the principal interest is in improving the matching between supply and demand with existing schemes. This is a problem common throughout Europe and a particular factor is the amount of water that is stored in the winter snowpack and how its melting contributes to the volume and pattern of run-off supplied from the catchment to the reservoir. Where run-off is not sustained, reservoir levels may have to be lowered and/or generation reduced. Knowledge of snowpack build-up and persistence is, therefore, vital to annual production forecasting. The Institute has been working with a European team to assess the potential for using remotely sensed satellite image data in forecasting snow accumulation and run-off. This work has been done in close collaboration with the electricity supply companies and environmental organisations who are concerned with the downstream effects on water yields and quality from controlled rivers. This project has provided a real-time forecasting system that is available across the internet (see http://bamboo.mluri.sari.ac.uk/hydalp/hydalp-home.html).

Contact: Dick Birnie, r.birnie@mluri.sari.ac.uk, David Miller, Jane Morrice, Mike Proe, Willie Towers and Gary Wright.

'Talk Environment' seminar, MARCH

This was one of a seris of seminars organised by Robson McLean and KPMG. Usually held in Edinburgh and aiming to stimulate discussion of environmental issues within the business community, a wide range of guests enjoyed Dr Miller's 3D visualisation as part of his presentation on 'Access to environmental data in Scotland - now and in the future'.

N retentions in Heathlands and Mountains, MARCH

Bob Ferrier hosted this three-day workshop at the Institute. Delegates from Norway and all over the UK met to discuss this EU project.

Mid Zambezi Valley and Modelling workshops, JUNE

Iain Gordon hosted the annual Mid-Zambezi (M-Z) Valley and Modelling workshops at the Institute in June. In conjunction with the University of Edinburgh, students from Zambia, Zimbabwe and Mozambique received training in modelling of natural resource management. The students were joined by delegates from France, Portugal and South Africa for the M-Z Valley workshop.

China, JULY

While on a visit to the Huazhong Agricultural University, Dick Birnie, Mr Li of the Institute of Soil Science in Nanjing, China and the head of the local community in Shitiamba, visited erosion control experiments to explore the potential for controlling erosion on steep slopes, using perennial fodder crops, mulches and hedges.

Lewis Endowment Trust, AUGUST

The Institute administers The Lewis Endowment Trust, which is currently funding two Township development schemes that aim to integrate their agricultural, environmental and social development opportunities. Director, Margaret Gill, is pictured visiting a crofter who combines machinery contracting, sheep and cattle farming and Harris Tweed weaving as an integrated components to his crofting business.

Farm Visits Glensaugh Research Station, FEBRUARY and Sourhope Research Farm, AUGUST

We were delighted to welcome a range of guests including local Councillors, MSPs, SNFU members, members of our Board of Governors and neighbours to two of our Research Stations this year. Ian Wright is pictured describing some of his work with beef cattle, at Sourhope, our farm in the Scottish Borders.

International Association of Vegetation Science, MARCH

Robin Pakeman hosted a three-day workshop of the Long-term Vegetation Dynamics sub-group of the International Association of Vegetation Science. Delegates travelled from Norway, Hungary, The Netherlands, Liverpool, Ulster and Edinburgh to meet at the Institute.

Macaulay Lecture and Exhibition, MAY

John Home-Robertson, MP, MSP opened our 24th Macaulay Lecture and Exhibition. Professor Jeff Maxwell, who retired from his post as Institute Director in October, gave the lecture.

Turkmenistan, SUMMER

Roy Behnke visited Karakoum Desert in Turkmenistan, to investigate livestock movement patterns for an EC-funded project.

'Dr Miller's Toolkit for countryside change', Edinburgh Science Festival, APRIL, techfest, SEPTEMBER

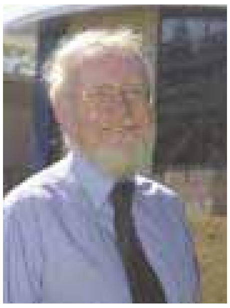
The Institute participated in the Edinburgh Science Festival at the Royal Botanic Gardens in April and in the Techfest Family Activities Weekend in September, at the Aberdeen Exhibition and Conference Centre with Dr Miller's toolkit for countryside change.

Aberdeen Techfest 2000 Schools Programme, SEPTEMBER

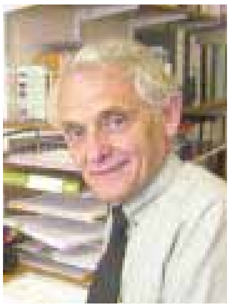
We took a workshop based on Dr Miller's toolkit for countryside change to different schools in Aberdeenshire.

KEY CONTACTS

Prof Margaret Gill
Director



Dr John Milne
Deputy Director



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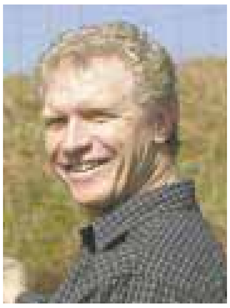

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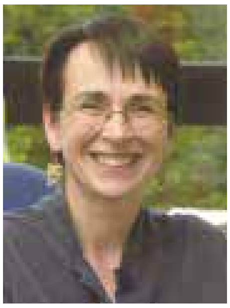

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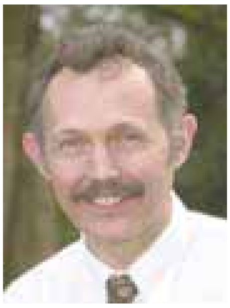

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Integrated Catchment
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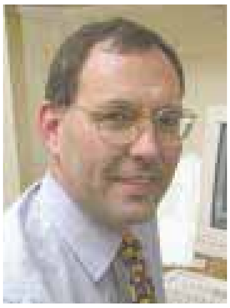

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