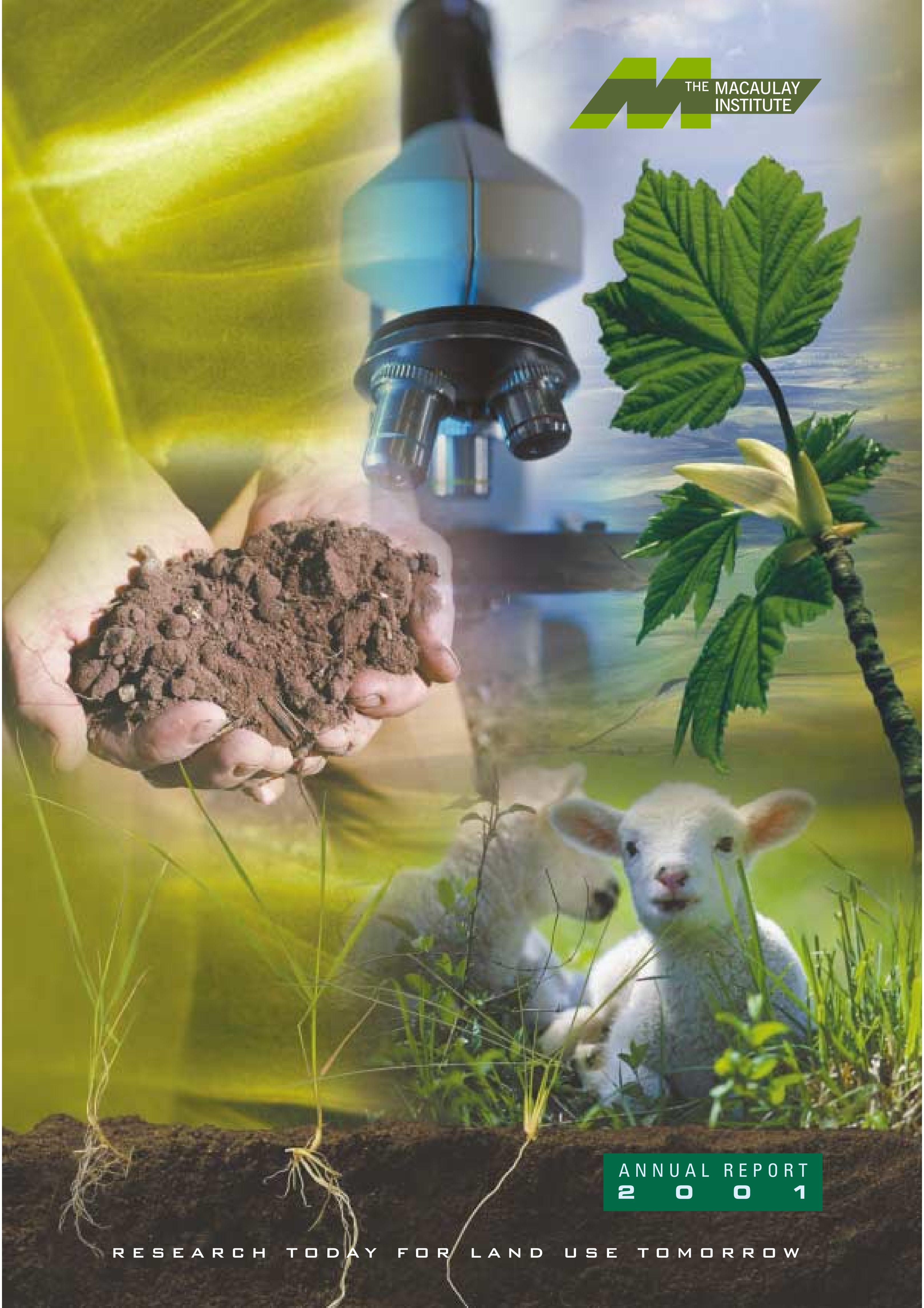

THE MACAULAY INSTITUTE

ANNUAL REPORT 2001

RESEARCH TODAY FOR LAND USE TOMORROW

THE MACAULAY INSTITUTE

ANNUAL REPORT 2001

Research Stations

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Hartwood, Shotts, Lanarkshire

Sourhope, Kelso, Roxburghshire

Bronwyd Mawr, Trecastle, Powys (with IGER)

The Macaulay Institute encompasses both the Macaulay Land Use Research Institute and Macaulay Research Consultancy Services, its commercial arm.

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DIRECTOR'S INTRODUCTION

Countryside issues were much in the news in 2001. The catastrophe of the Foot and Mouth Disease outbreak had far-reaching effects and highlighted for many people the degree of interdependence between different parts of the rural economy. For staff at the Macaulay Institute, this knowledge was not new.

Professor Margaret Gill, Director, Macaulay Institute

Our Mission Statement: 'To be an international leader in research on the use of rural land resources for the benefit of people and the environment' implies that we take an integrated approach to researching both the biological and the human processes associated with land use. It is for this reason that we have scientists with such a variety of backgrounds working at the Macaulay Institute, including social scientists and socio-economists, specialists in artificial intelligence, information technology and visualisation techniques, in addition to those from biological disciplines such as ecology and soil, plant and animal science.

Working together to harness this range of skills to achieve a common purpose is a challenge, but a rewarding one!

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During the year, one of our major successes was to win over £1.5 million of additional 'core' funding, largely targeted at projects which involved closer linkages between different disciplines. This money not only enabled us to employ an additional 10 post-doctoral scientists, but also created opportunities for methods developed within one discipline to be applied in another. There are exciting opportunities at these disciplinary interfaces for truly innovative science to deliver practical outcomes and for many of our new employees, it is these opportunities which have attracted them to work at the Macaulay Institute.

It is also this integrated approach which leads to our research being of particular interest to policy-makers. Over 50% of our 'core' projects funded by the Scottish Executive have been classified by them as policy-relevant but, in addition, we undertake contracts to provide objective scientific evidence requested by policy-makers to help them in the development or implementation of specific policies. Examples from 2001 were projects undertaken for the Scottish Executive on the development of methods for identifying Nitrate Vulnerable Zones and the use of our spatial databases to develop options for revisions to the Less Favoured Areas Support Scheme. Another example, the development of a strategic planning tool for wind farm development, was commissioned by the Countryside Commission for Wales. We also completed studies on the 'Impact of nature conservation designations on land values' for the Scottish Executive and on 'Natural heritage and local economic linkages' for a consortium led by Scottish Natural Heritage. However, our research is not only relevant to policy-makers in the UK, we made important inputs to the publication of a collation of outputs on the recovery of European waters from acidification and we hosted a workshop in Aberdeen for project partners from Central Asia, working with pastoral communities threatened by desertification in that region.

It is certainly important for us as scientists to listen to the views of people who live and work in rural communities

Given the added complexities of trying to achieve benefits for poor communities in developing countries through research funded by development agencies, researchers in those countries have long used participatory techniques to consult with relevant stakeholders, i.e. those who may be affected by adoption of the findings of the research. There is increasing interest in the use of participatory approaches in the UK and a major objective of our socio-economics research programme is targeted at evaluating such techniques. However, we also believe in 'practising what we preach' and one of the key objectives of our Corporate Plan (which was revised during 2001), is that of increasing the amount of two-way communication with the people we anticipate will use our outputs. Our ability to implement this policy during 2001 was constrained by restrictions associated with the Foot and Mouth Disease outbreak, but various activities are planned for the future. It is certainly important for us as scientists to listen to the views of people who live and work in rural communities and who are key players in the appropriate use of land for the benefit of both present and future generations.

The role of the farming industry in sustainable rural development was one of the key objectives of the Scottish Executive's 'Forward Strategy for Scottish Agriculture' which was published during 2001 and there were many activities identified by that strategy which are closely aligned with current research at the Macaulay Institute.

Headquarters at Craigiebuckler, Aberdeen

Listening to the needs of the Scottish Executive and to those tasked with implementing the strategy will help to shape our research programme for the future, since we believe that we have the skills and the commitment to deliver relevant research outputs based on high quality science. Our science strategy for 2002 and beyond includes an increased emphasis on the application of molecular techniques to increasing understanding of soil, plant and microbial interactions and the application of agent-based modelling approaches to increasing our understanding of the human dimension of land management. We are also continuing to 'scale up' the integration of our scientific findings, to provide support for decision makers (i.e. policy-makers and land managers) who in future will have to consider the impact of their policies and activities at the level of water catchments. Innovation in the transfer of our knowledge to those who can use it to bring benefit to both people and the environment is also an important part of our strategy.

The following sections highlight some of the outcomes of our research, organised to illustrate three themes of our work: scientific quality, the transfer of knowledge to users and examples of the practical relevance of our research. The 'Research Advances' section highlights research from our strategic research programmes on ecological and environmental sciences. These programmes seek to increase our understanding of the factors that affect the interactions between microbes and the soil, between soils and plants, between plants within vegetation communities and the impacts of the grazing animal on these resources. A better understanding of these interactions will enable Macaulay Institute scientists and those from other organisations to understand how ecosystems function and how natural changes may be modified by environmental changes influenced by man's activities, either directly through land management or indirectly through the widespread impacts of pollution.

The section on 'Knowledge transfer and exploitation' contains descriptions of some of the products of our research, chosen to illustrate different communities of people who use our research. Schoolchildren are one important audience and our 'Schools team' enjoy the opportunity to visit schools and encourage pupils to follow a career in science. Land managers and a variety of business sectors may benefit economically from implementation of our research findings, the example given being a method for rapid assessment of the impact of grazing and trampling on upland plant communities. We also have a responsibility to commercialise our science for our own economic benefit and while the nature of the Institute's research does not usually generate intellectual property which can be patented, one such example is given.

The final section on 'Examples of the practical relevance of our research' contains articles describing how some of our research outputs are helping policy-makers and people living in rural communities to bring benefits to our Scottish environment. Two of the research projects relate to biodiversity - one predicting future changes based on monitoring present numbers of plants and insects, the second looking at the cost-effectiveness of alternative policies.

This Annual Report can only give a snapshot of some of the research going on at the Macaulay Institute - we hope that you will be sufficiently interested to read more on our web-site: www.macaulay.ac.uk. The Macaulay Institute encompasses not just the Macaulay Land Use Research Institute, whose work is featured here, but also our commercial arm - Macaulay Research Consultancy Services Ltd. This company has been conducting market research and expanding into new markets in the last year, ensuring that our knowledge generated through research is applied as extensively as possible.

Professor Margaret Gill
Director
September 2002

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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

RESEARCH ADVANCES

The Institute's research programme includes strategic research on the interactions between soil microbes, roots, plants and grazing animals with the aim of understanding how to manage land resources for the benefit of people and the environment.

The following three articles give examples of recent advances in this research – for information on other areas please see our web site at www.macaulay.ac.uk

The Functioning of Grassland Ecosystems: The Role of Soil Microorganisms

Summary

The functioning and stability of terrestrial ecosystems are influenced by plant communities and their species composition. However, the mechanisms that control these two factors are poorly understood. Our research has shown that the below-ground soil microbial community may be an important factor governing plant growth and competition. Using novel molecular and phenotypic techniques it has been shown that extensively managed bent-fescue grassland, which contains a greater diversity of plant species than more intensively managed ryegrass grassland also contains a greater diversity of soil microorganisms. The extensively managed grassland also has fungal-dominated soils compared to more intensively managed grassland which are bacterial-dominated. Further, differences in livestock grazing pressure impact on soil microbial communities, which in turn feeds back to effects on plant communities. Research has indicated that the spatial scale of variation in soil microbial communities is considerably less than 10cm. Current research is attempting to measure the exact spatial scale of variation in microorganisms at the level of individual root zones to establish the scales over which plant and microbial communities are coupled. In addition, the links between microbial community structure and their function are being studied.

Land use is undergoing considerable change due to political and economic pressures

Context

Land use is undergoing considerable change due to political and economic pressures and strong public concern for the quality of the environment. These changes in land use include a movement to more extensive grazing systems in the hills and uplands (Figure 1). In such low input systems plant productivity is often governed by the supply of nutrients from the soil, which in turn is dependent on the activity of soil microbes. However, little is known about the composition and activity of the microbial communities in these grassland systems and how they influence the composition and productivity of the sward. Many previous studies on biodiversity of microbial

Figure 1. Upland grassland communities

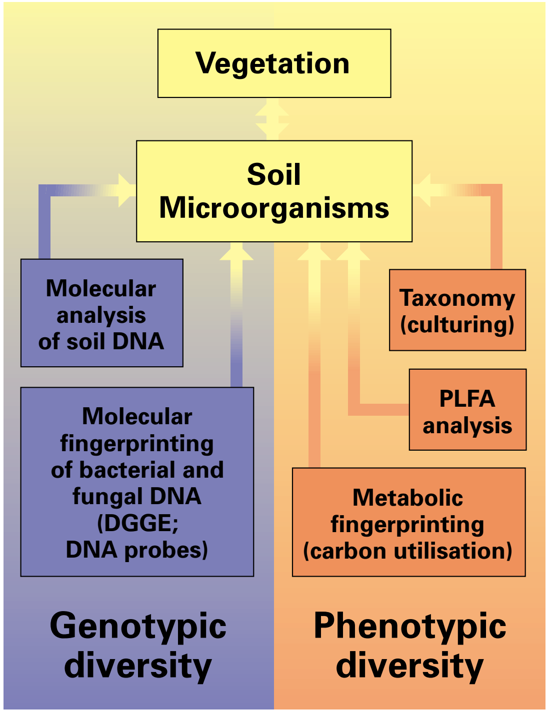

Figure 2. The range of genotypic and phenotypic methods being used to characterise soil microbial communities in Micronet

communities have been limited by the techniques available, which have tended to consider only the culturable component of the community. The development and application of molecular techniques and improved chemotaxonomic methods now enable the genetic composition and diversity of the total microbial community to be determined. However, quantification of microbial diversity and function requires a collaborative approach to ensure utilisation of the range of techniques necessary. This is being undertaken in a coordinated research programme, entitled Micronet, between the Macaulay Institute, the Universities of Aberdeen and York and the Scottish Crop Research Institute.

Soil microorganisms in grassland

A range of molecular and phenotypic methods (Figure 2) has been and is being developed to quantify the spatial and temporal diversity of microbial communities beneath a range of characteristic grassland types subject to different management intensities at ten sites in the UK. These techniques range from molecular fingerprinting techniques (Denaturing Gradient Gel Electrophoresis, 16S rDNA analysis), community DNA methods (DNA melting and reannealing kinetics, nucleic acid hybridisation), phospholipid fatty acid profiling, community level physiological profiling, as well as traditional taxonomic methods using culturing. The grasslands range from the extensive, "unimproved" *Festuca ovina - Agrostis capillaris - Galium saxatile* grassland (NVC - U4a), through the "semi-improved" *Festuca ovina - Agrostis capillaris - Galium saxatile* grassland, *Holcus lanatus - Trifolium repens* sub - community (NVC - U4b), to the "improved", intensively-managed *Lolium perenne - Cynosurus cristatus* grassland (NVC - MG6) (Figure 3).

The size and activity of the soil microbial community was higher under "unimproved" grassland (U4a & b) than under improved grassland (MG6), maintained by regular N fertiliser additions (Grayston et al., 1998a). Associated with these changes in microbial biomass were shifts in microbial community structure with "improved" grassland favouring the bacterial community and "unimproved" grassland favouring the fungi.

Such variation in soil microbial communities has been attributed to qualitative and quantitative differences in nutrient supply to microbes between the grasslands. In particular, it has been suggested that

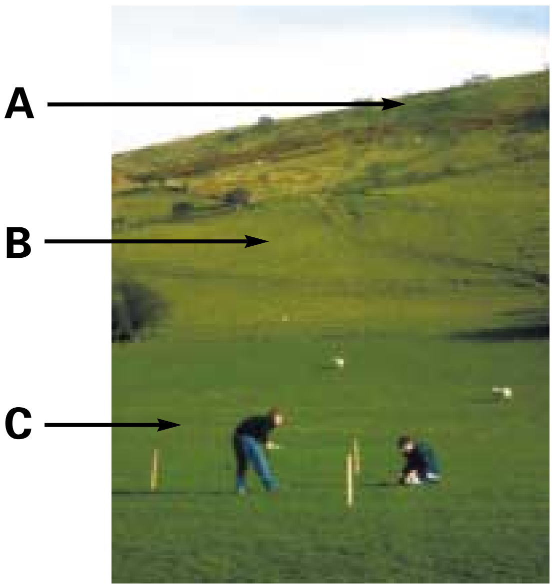

Figure 3. Unimproved (A), semi-improved (B) and improved (C) grasslands at the Macaulay Institute's Sourhope Research Station

differences between grasslands in plant species could exert strong selective pressures on the soil microbial community through plant specific changes in the quantity and variety of chemical compounds released from the roots (Grayston et al., 1998b). This is borne out by the fact that measurements of community level physiological profiling of microbial communities between grasslands were significantly different, mainly due to greater utilisation of sugars and citric acid by microbes in the "improved" grasslands and greater utilisation of carboxylic, phenolic acids and neutral amino acids in the "unimproved" grassland. These differences probably reflect nutrient availability to the microbes in these grasslands.

The variation in microbial communities between grassland types is now clear

The dynamics of the processes important in these systems are being assessed through measurement of key enzymes and microorganisms involved in nitrogen and phosphorus cycling. The aim is to develop molecular probes to these processes and species to enable in situ detection of the processes and organisms active in nutrient cycling in soil. Design of a molecular probe for the enzymes involved in organic phosphate mineralisation is not possible at present, because of the lack of sequence data for these enzymes. The alternative strategy was taken of identifying the key organic phosphate mineralising organisms in organic P-spiked soil, using molecular fingerprinting methods, and developing molecular probes to them (Grayston et al., 2001b). Molecular probes have also been developed for the nitrate reductase genes involved in denitrification.

Temporal variation

The variation in microbial communities between grassland types is now clear. What is less clear is the nature of the changes over time in microbial communities of upland grasslands. To investigate changes over a year, soil microbial biomass, activity and community structure were measured across the unimproved, semi-improved and improved grassland referred to above, at three sites in the UK.

As in the previous study, microbial biomass was found to be highest in the "unimproved" (U4a) and lowest in the "improved" (MG6) grassland and soil microbial community structure shifted from one favouring fungi to one favouring bacteria with greater grassland "improvement". Soil microbial biomass, activity and community structure between grasslands were robust over the year. Broad-scale measures of soil microbial biomass and respiration showed little temporal variation, compared to measures of soil microbial community structure, which varied significantly with time (Figure 4) (Grayston et al., 2001a).

Impacts of grazing animals

Differences in livestock grazing pressures on the grasslands are also

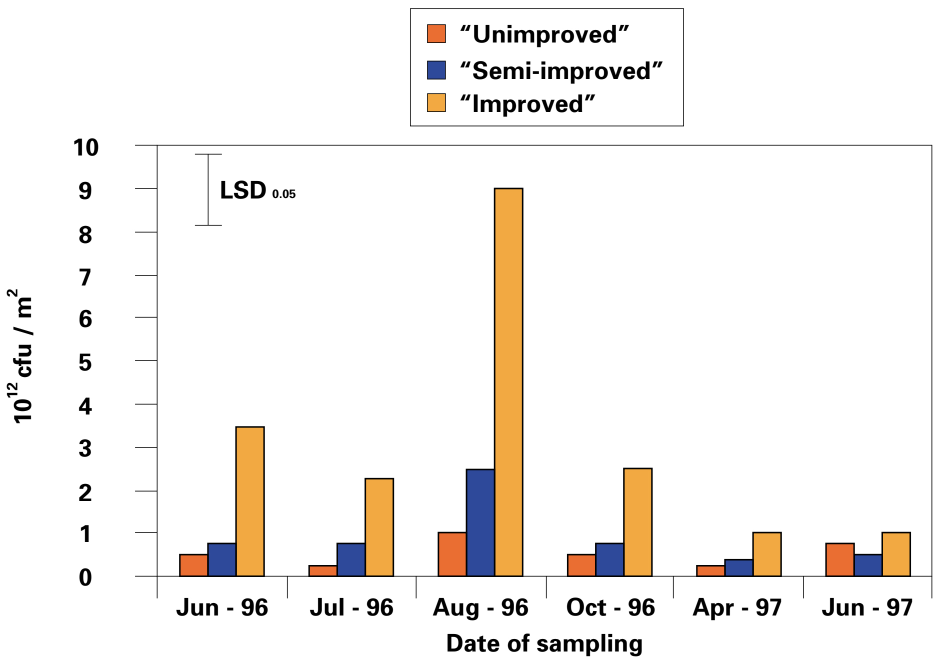

Figure 4. Temporal variation in bacterial populations across grasslands

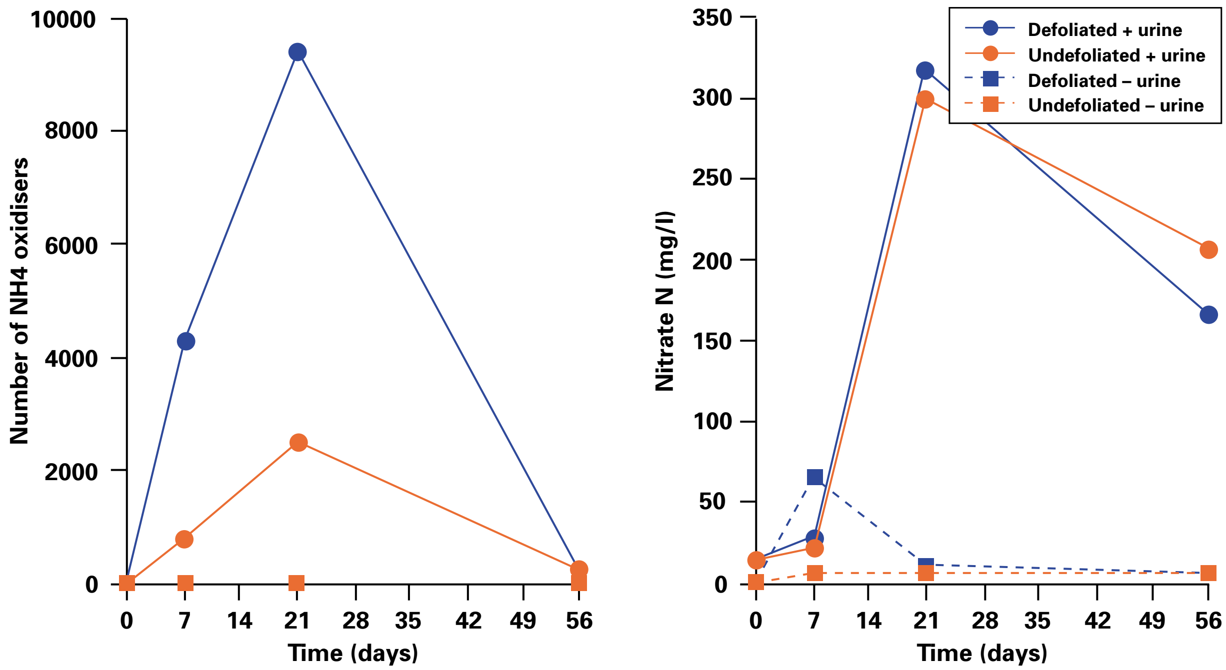

Figure 5. Populations of ammonia oxidisers and nitrate production in soils unamended and amended with simulated sheep urine

likely to greatly alter nutrient supply to soil microbes and hence influence the soil microbial community. A characteristic of these grasslands is that there is a gradient of grazing pressure, being highest in the "improved" and lowest in the "unimproved" grassland. Higher grazing pressures in the "improved" grassland will increase soil nutrient availability, due to: more efficient recycling of nutrients through the animal excreta pathway, increased flux of carbon to the soil through this pathway and as a result of defoliation. The increased nutrient flow in more heavily grazed grassland could account for the high microbial activity and preferential growth of bacteria in these soils. Direct experimental evidence of this has been found from studies in both sward boxes and in the field, by subjecting grasses to simulated grazing by defoliation and the application of simulated sheep's urine. Regular defoliation of grass significantly reduced microbial biomass in soil. Addition of simulated sheep's urine significantly increased the numbers of bacteria in soil. Soils amended with urine also contained significantly more ammonia oxidisers than un-amended soil and the number of these organisms correlated directly with the concentrations of nitrate in these soils (Figure 5). Molecular fingerprinting of these ammonia oxidisers, in research undertaken in collaboration with Aberdeen University on a NERC EDGE-funded initiative, has shown that the more heavily grazed "improved" grassland is dominated by an ammonium-tolerant species, whereas the lower grazed "unimproved" grassland contain a greater heterogeneity of ammonia oxidisers. Addition of urine to unimproved soils results in selection of these ammonium-tolerant species. Nitrification kinetics and ammonia oxidiser community structure were strongly correlated, demonstrating a clear link between community structure and ecosystem processes. The results suggest that heterogeneity in nitrification rates in grassland may be a result of heterogeneity in ammonia oxidisers.

Coupling between plant species and microbial communities

The degree to which plant species and soil microbial community structure and function are coupled was tested in a field experiment at the main Micronet site at the Macaulay Institute's Sourhope Research Station. Sixteen plots were created in an area of "unimproved" grassland (NVC, U4a) by removing the vegetation and either leaving the soil fallow or creating monocultures of either *Agrostis capillaris* (a dominant species previously growing on the site), or *Lolium perenne*

*Figure 6. Monoculture swards of **Agrostis capillaris**, **Lolium perenne** and fallow soil at the Macaulay Institute's Sourhope Research Station*

(a species not found in the unimproved pasture) (Figure 6).

Over an 18-month period soil microbial communities in resown soils were significantly different from those in fallow soils, but there was no significant difference between Lolium- or Agrostis-sown plots. This lack of difference between the two sown plots could have been due to the large degree of spatial heterogeneity of soil chemical and physical properties in the plots. Alternatively, soil microbial communities may be regulated by root and leaf litter inputs thereby evolving with the quality of the soil organic matter.

Spatial variation

The spatial variation in soil microbial communities is an important, yet rarely studied, aspect of plant-microbe interactions. In ecosystems where plants tend to be sparse, there is evidence that soil organisms are also affected by proximity to individual plants (Klironomos et al. 1999). In grasslands, however, plant density is very high and the spatial organisation of microbes relative to plant types is virtually unknown. The Micronet studies on UK upland grasslands have shown some evidence for community-level coupling (Grayston et al. 1998a; 2001a). However such relationships were apparently obscured by the extremely high levels of spatial variation that prevailed and the genetic composition of communities a few metres apart within a grassland could be as different as those separated by hundreds of kilometres (Clegg et al. 2000). Vegetation composition over the small distance of a few metres was less variable and, hence, other factors may be governing microbial community structure. One approach to exploring this is to statistically determine natural variation associated with a wide range of potential factors, and analyse associations or trends in such data. The advantage of this approach is that multiple interactions may also be identified. Accordingly, a study was conducted to assess the spatial variability in microbial communities in upland grassland. Ninety spatially-referenced soil cores were taken from an area of "unimproved" grazed grassland and a wide range of microbiological and chemical properties for each sample were measured, including basic soil chemical parameters and microbial community measures as well as the botanical composition of plants above the cores. Geostatistical analysis of the data revealed an absence of any spatial dependency of variance for the majority of over 120 variables measured but demonstrated the extreme variation in microbial communities in grasslands.

The advantage of this approach is that multiple interactions may also be identified

Future

Results from the spatial study, above, indicated that spatial structure in the majority of soil microbial properties is likely to occur at scales below 10 cm. The comprehensive studies, mentioned earlier, also suggested that there is evidence that plant species:microbial community links occur at the community level, but that the link is weak at the scale of a few metres. Thus, the data obtained so far point toward the need to establish whether plant species:microbial community links in upland grasslands occur at smaller scales than those measured to date.

Therefore, the main objectives for the future will be to:

- establish the scales over which plant and microbial communities are linked in upland grasslands. (This will be achieved at spatial scales ranging from the root zone to the plant community).
- identify the prevalence of specific associations between components of soil microbial communities.
- assess the links between such microbial communities and aspects of their function.

The outcome of this research will be an increased understanding of the degree of linkage between plant species and the soil microbial community structure, and the extent to which such structure relates to functional properties of the ecosystem. If it could be shown that conservation of microbial diversity is a prerequisite for maintenance of plant species diversity in grasslands, this will obviously be vitally important to those managers wanting to maintain diversity for environmental, conservation or amenity purposes.

References

Clegg, C.D., Ritz, K. and Griffiths, B.S. (2000). %G+C profiling and cross hybridisation of microbial DNA reveals great variation in below-ground community structure in UK upland grasslands. Applied Soil Ecology 14, 125-134.

Grayston, S.J., Campbell, C.D., Bardgett, R.D., Mawdsley, J.L., Griffith, G.S., Rodwell, J.S., Davies, W.M. and Edwards, S. (1998a). Biodiversity of soil microbial communities across a range of grasslands of differing management intensity. Journal of Experimental Botany 49, 40.

Grayston, S.J., Wang, S., Campbell, C.D. and Edwards, A.C. (1998b). Selective influence of plant species on microbial diversity in the rhizosphere. Soil Biology & Biochemistry 30, 369-378.

Grayston, S.J., Griffith, G.S., Mawdsley, J.L., Campbell, C.D. and Bardgett, R.D. (2001a). Accounting for variability in soil microbial communities of temperate upland grassland ecosystems. Soil Biology & Biochemistry 33, 533-551.

Grayston, S.J., Reid, E.J., MacDougall, R., McCaig, A.E., Glover, L.A. and Prosser, J.I. (2001b). Utilisation of novel biochemical and molecular methods to identify the key organic phosphorus mineralisers in soil. Aspects of Applied Biology 63, 1-4.

Klironomos, J.N., Rillig, M.C. and Allen, M.F. (1999). Designing below-ground field experiments with the help of semi-variance and power analysis. Applied Soil Ecology 12, 227-238.

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The Application of Biological Markers – A Macaulay Institute success story

Summary

Indigestible substances in the diet or those orally administered appear in the faeces and can be used to obtain information about the diet and its utilisation in farm livestock and wild herbivores. Techniques for measuring intake, diet composition, digestibility and rate of passage of material along the digestive tract of free-ranging herbivores have been pioneered at the Macaulay Institute using plant wax compounds and similar substances as faecal markers. In current development work, the range of applications of these compounds is being extended to include the measurement of plant species composition of roots and characterisation of past vegetation cover by examination of such markers in different soil layers. The potential of using the compounds present in the waxy cuticles of insects to determine the diet composition of insectivorous mammals and birds is also being investigated.

Context

In order to gain an understanding of the relationships between large herbivores (in particular, ruminant livestock and deer species) and their environment there is a need to obtain quantitative information on the dietary habits of these animals - what they eat, how much they eat and what is the nutritional quality of their diet. Not only does this information tell us about the animals but also the effect that they have upon their habitat through changes in abundance of different vegetation species as a result of defoliation effects and secondary influences such as trampling and return of plant nutrients via faeces and urine. Such knowledge is of considerable importance in the development of research models and decision support systems designed to predict the interactions occurring between large herbivores and their habitats. Quantitative techniques have been successfully developed at the Macaulay Institute to provide dietary information relating to free-ranging herbivores. These techniques are now used around the world.

Dietary Markers

Accurate measurement of the composition, intake and quality of the diets of free-ranging herbivores is not easy to make, especially if the degree of disturbance to the animals is to be kept to a minimum. However, their faeces, which can be collected relatively easily, can provide useful clues. Herbivore faeces mainly consists of residues of the plant material ingested by the animal and a range of such substances of plant origin can be exploited as markers allowing dietary digestibility, intake and composition to be estimated. The hydrocarbons from the waxy cuticles of dietary plants are particularly useful since they are present in most plants, relatively inert and indigestible, and can be easily and accurately analysed by gas chromatography.

The surface wax of most higher plants contains mixtures of saturated straight-chain hydrocarbons (n-alkanes) having 21-35 carbon atoms. Alkanes with odd-numbered carbon chains predominate (>90%). Different plant species have different patterns of individual alkanes, with most herbage species tending to have mainly C29- to C33-alkanes, whereas in many tree and browse species the shorter-chain alkanes predominate.

Measuring diet digestibility

As ingested feed passes along the gut of an animal, material will be removed through digestion and absorption, with the result that the concentration of an indigestible plant marker will be higher in faeces than in the original plant. Thus, representative samples of the diet and faeces can be used to estimate digestibility:

$$\text{Digestibility} = \left(1 - \frac{\text{Marker concentration in diet}}{\text{Marker concentration in faeces}}\right)$$

This concept for digestibility measurement has been recognised for well over 100 years. However, until relatively recently, the method was considered to be unreliable, because relative concentrations of the chosen markers (mainly plant fibre components of variable chemical composition) could not be determined with adequate consistency. Herbage n-alkanes as digestibility markers, first investigated within the Institute, have the advantages of being discrete compounds which can be analysed with high accuracy and precision. However, they are not perfect markers as they are not completely recovered in faeces. Recovery increases with carbon chain length from less than 50% for C21-alkane to over 95% for C35-alkane. Using a recovery correction, the longer-chain alkanes can be used to give reliable estimates of digestibility.

Measuring intake

In free-ranging herbivores intake can be determined if the digestibility of the diet and the output of faeces are known:

$$\text{Intake} = \frac{\text{Faecal output}}{(1 - \text{Diet digestibility})}$$

Digestibility can be determined using the method described above. Although faecal output can be measured by attaching bags to the animals and making total collections, it is more convenient and less disturbing to the animals if markers are used to estimate faecal output and small samples of faeces are collected. If a known amount of an indigestible marker substance, which is normally absent from the diet, is orally-administered to an animal each day (or more frequently), the marker will appear in the faeces, with its concentration stabilising after about 6 days. Then:

$$\text{Faecal output} = \frac{\text{Dose rate of marker}}{\text{Concentration of dosed marker in faeces}}$$

Before n-alkanes were considered as dietary markers, this approach suffered the disadvantages that the method did not allow for variation in diet digestibility among individual animals and could not be used for animals receiving cereal feed supplements or for non-ruminants. At the Institute a major advance was made by realising that intake could be determined using a dosed even-chain alkane marker (to measure faecal output) together with a dietary odd-chain alkane (to measure digestibility). Thus:

$$\text{Intake} = \frac{\text{Dose rate of alkane}}{\dfrac{\text{Faecal alkane}_j\text{ content}}{\text{Faecal alkane}_i\text{ content}} \times \text{Herbage alkane}_i\text{ content} - \text{Herbage alkane}_j\text{ content}}$$

where alkane_i is the chosen dietary odd-chain and alkane_j the dosed even-chain alkane marker. There is also the advantage that the concentrations of both markers are determined in the same analysis. Furthermore, as long as they are the same for both alkanes, the faecal recoveries of the markers need not be quantitative. Work at the Institute has shown this to be the case for C32-(dosed) and C33-(dietary) alkanes in sheep, cattle, goats and deer. In collaboration with other institutions, the method has been further evaluated in other captive plant-eating mammals, including moose, giraffe, pigs, horses, rabbits and wombats.

Measuring intake in wild herbivores

Except for obtaining crude estimates by watching animals graze or browse, the estimation of intake in wild, free-living herbivores has been virtually impossible until recently. The main problem has been the need to capture animals repeatedly in order to carry out intake measurements. For example, the n-alkane technique requires the handling of animals to administer marker doses. However, ways of obtaining intake estimates have been developed which require animals to be handled only once for administration of a marker which

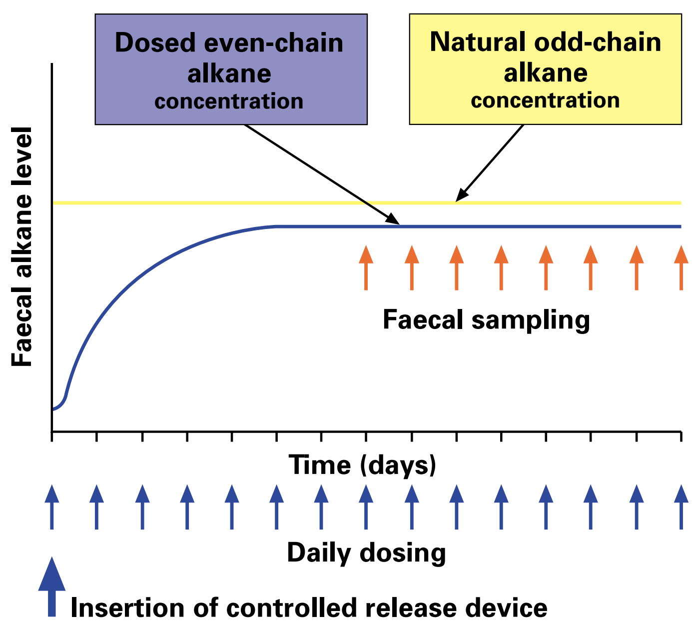

Figure 1. Intake estimation using an even-chain alkane supplied by daily dosing or a controlled release device: this method requires the equilibrium concentrations of dosed and natural dietary alkanes in the feed and faeces

is released at a constant rate daily (Figure 1)

Intraruminal controlled release devices

Controlled-release devices, which remain in the rumen of ruminants after oral administration, were originally designed to deliver anthelminthic drugs over an extended period. The Institute has collaborated with the Division of Plant Industry, CSIRO in Australia in the development and testing of Controlled-released devices impregnated with n-alkanes containing even-chain alkanes for intake measurement. (Dove et al. in press). These devices are now commercially available (Captec AlkaneTM). Using such devices, together with GPS-tracking equipment to locate faeces, it has been possible for the first time to measure intake in wild moose living in the Swedish boreal forest (Mayes et al., 2001).

Intake measurement using a single marker dose

Controlled release devices can be used for measuring intake in ruminants but not in monogastric herbivores. However, by analysing a series of faeces samples following a single dose of marker, it is possible to estimate the output of faeces. A similar approach can also be used to estimate intake using n-alkane markers; intake can be calculated by replacing the faecal concentration ratio of the

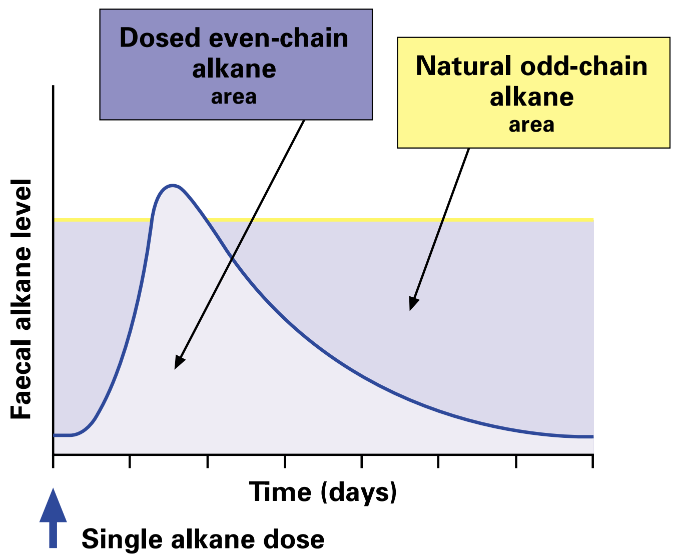

Figure 2. Intake estimation using a single dose of even-chain alkane: this method requires herbage alkane levels and the relative areas under the faecal concentration v time curves of the dosed and natural alkanes

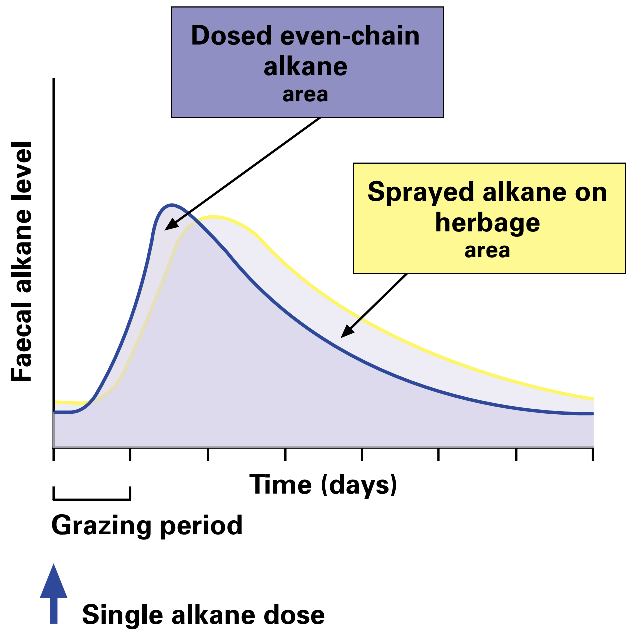

Figure 3. Estimating short-term intake: this method requires the relative areas under the faecal concentration v time curves of an even-chain alkane given as a single dose and a second even-chain alkane sprayed on to the experimental pasture together with the levels of these alkanes in the sprayed herbage

dosed and natural alkanes by the ratio of their areas under faecal concentration v time curves. This has been validated in captive rabbits (Letso, 1996). As long as faeces samples can be collected and identified as coming from known individual animals, intake can be determined following a single dose of alkane marker (Figure 2). Daniels et al. (in preparation) have made such measurements in wild wombats in S.E. Australia, by giving single doses of C32- alkane and glitter of different colours in order to identify which animal produced each faeces sample.

Short-term intake estimation

The n-alkane method is now widely used throughout the world to obtain dietary intakes, representing estimates averaged over a number of days. However in some circumstances, intakes measured over a period of a single day, or less, are required. A suitable method has been developed and tested (Duncan et al., 1999), in which the vegetation, to be grazed over a short experimental period (as little as a few hours), is sprayed with an artificial alkane (e.g. C36-alkane), while the experimental animals are given one or more doses of a second alkane (e.g. C32-alkane); a series of faeces samples are collected, continuing after the animals have been removed from the sprayed pasture (Figure 3).

The alkane methods for measuring intake require knowledge of the n-alkane concentrations in the animal's diet. Under conditions in which animals have the freedom to select a complex diet of a number of plant components, it is necessary to estimate diet composition in order to determine the n-alkane content of the total diet from the n-alkane levels in the individual components.

Measurement of diet composition

Markers found in faeces can also be used to determine the composition of a herbivore's diet. Diet composition can be estimated by exploiting differences in the patterns of individual n-alkanes among different plant species and plant parts (Figure 4). From the alkane pattern in an animal's faeces and those of the dietary components, diet composition can be estimated using a least-squares optimisation algorithm. This method has been validated using simple two-component diets, for example rush *(Juncus effusus)*/perennial ryegrass *(Lolium perenne)* mixtures (Figure 5). However, although in theory the number of dietary components that can be discriminated is the same as the number of markers available for use (about 10 for n-alkanes), in practice the reliability of the method declines as the number of components increases. In current research at the Institute, attempts are being made to refine this

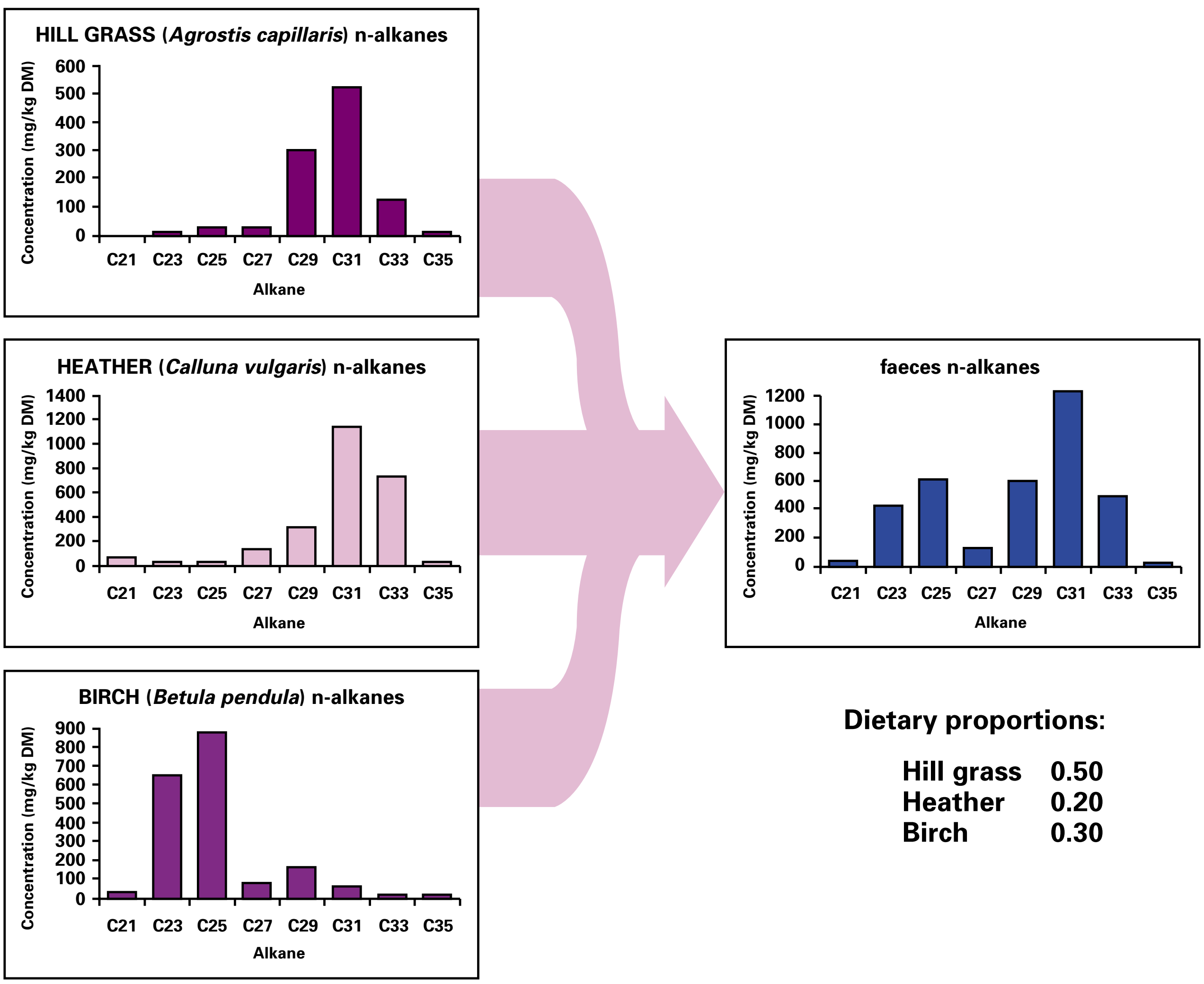

Figure 4. Differences in alkane patterns between plant species can be used to estimate diet composition. For example, the dietary proportions of hill grass, heather and birch can be determined from the alkanes in faeces from red deer

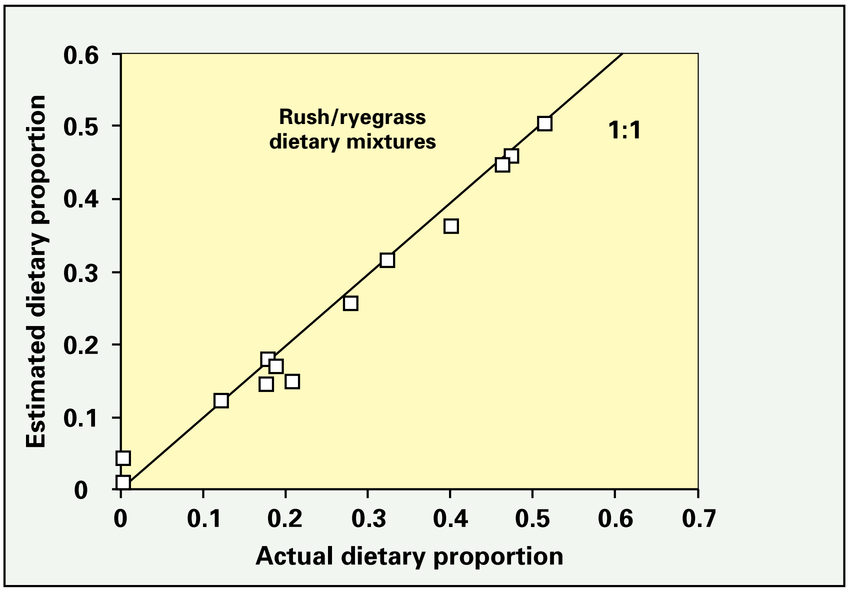

Figure 5. Relationship between actual proportions of rush in the diet of goats and proportions estimated using faecal alkane patterns

approach such that reliable diet composition estimates can be made under conditions in which animals may select highly complex dietary mixtures.

Such work includes the development of improved calculation and statistical methods for diet composition estimation, and the concept of grouping species in order to reduce the number of estimated components has been explored. However, the main emphasis of this research has been to search for different plant markers. Plant wax usually contains many classes of compounds which may have potential as diet composition markers (Figure 6). To be a useful diet composition marker the compounds must be accurately analysable, be consistently recoverable in faeces and show differences in composition between dietary plant species. Of the compound types that have been investigated, the long-chain fatty alcohols have shown the most promise to date. They have been particularly useful for diets containing plant species with low levels of n-alkanes, including white clover, Scots pine and certain grasses such as timothy, cocksfoot and Phalaris spp.

Alkanes as passage-rate markers

The rate at which dietary material passes along the digestive tract of a herbivore is an important factor influencing the digestion and absorption of dietary nutrients, and the animal's intake. Passage rate, usually measured as mean retention time, is normally estimated from a faecal concentration v time excretion curve of an indigestible marker given as a single dose. Ideally a suitable marker should remain associated with dietary material throughout its passage along the gut. Unfortunately, most exogenous markers do not meet this criterion. However, it has been shown that the natural n-alkanes of plant diets remain attached to particulate material in the gut and thus would be suitable passage rate markers, if it were not for the fact that such n-alkanes would normally be present in the diet and faeces. If the animals were given a single feed of dietary material which was labelled with an isotope of carbon or hydrogen, passage-rate could be determined from the excretion curve of the isotope levels in the faecal alkanes. It has been shown that the method can be used by feeding plant material labelled either with ^{14}C or ^{3}H-isotopes. Furthermore, this approach offers the potential for estimating simultaneously passage rates of different dietary components labelled with separate isotopes (Mayes et al. 1997).

A much simpler approach is to use artificial even-chain alkanes as passage-rate markers. Such estimates have been obtained using a single feed of plant material sprayed with artificial alkanes. It is apparent that the estimates of mean retention time obtained are slightly lower than estimates made using isotopically-labelled plant material, suggesting that the artificial alkanes were not behaving as ideal markers. Work is currently underway to examine whether correction factors can be used to remove any bias in estimates of mean retention time.

Beyond herbivores

The relative long-term stability of plant wax compounds, species specificity and ease of analysis offers the opportunity for them to be exploited as markers for a range of applications within many disciplines in addition to that of herbivore ecology. The principle of using the alkane patterns in different plant species to estimate diet composition has been used to determine the species composition of samples of mixed vegetation (Dove,1992). Despite much lower concentrations in plant roots, alkanes have been used as markers to estimate the species composition of mixed root mats (Dawson et al., 2000). Alkanes have also been found in the organic matter of soil and the patterns appear to reflect the patterns in the vegetation growing on that soil. The possibility of n-alkane patterns in different soil layers being used to describe the vegetation cover throughout the last few thousand years is currently being explored at the Institute. Plants are not the only living organisms that have waxy cuticles. Insects, their larvae and many other arthropods have complex mixtures of long-chain hydrocarbons (mainly branched-chain alkanes) in the cuticular wax and, like plants, differ greatly between species. Since the digestive tracts of mammalian and avian insectivores are not profoundly different from those of herbivores, it may be expected that insect hydrocarbons will appear in the faeces of their predator, thus offering the opportunity of applying n-alkane marker techniques for measuring diet composition, digestibility and perhaps intake in insect-eating mammals and birds. Preliminary studies in collaboration with Aberdeen University have shown that faeces from wild bats contain complex hydrocarbon patterns. Furthermore, the hydrocarbon pattern in the faeces of captive bats was the same as that of their mealworm diet. Currently the application of the approach to birds is being investigated.

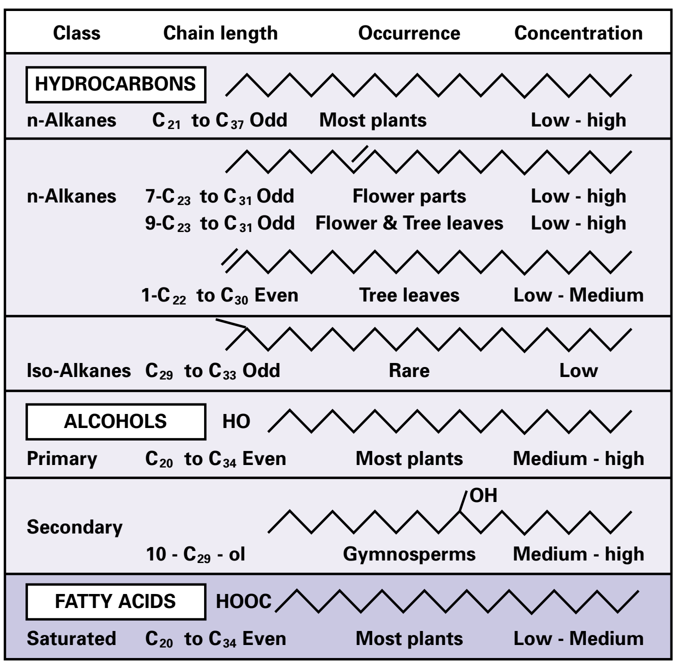

Figure 6. Classes of plant wax compounds that have been considered as faecal markers for determining diet composition

References

Daniels, M.J., Dove, H., Mayes, R.W., Abott, K.A., English, A.E. and Gordon, I.J. Estimating intake in wild herbivores using orally-dosed alkanes - a pilot study with the common wombat *Vombatus ursinus*. (in preparation)

Dawson, L.A., Mayes, R.W., Elston, D.A. and Smart, T.S. (2000). Root hydrocarbons as potential markers for determining species composition. Plant, Cell and Environment 23,743-750.

Dove, H. (1992). Using the n-alkanes of plant cuticular wax to estimate the species composition of herbage mixtures. Australian Journal of Agricultural Research 43, 1711-1724.

Dove, H., Mayes, R.W., Lamb, C.S. and Ellis, K.J. Factors influencing the release rate of alkanes from an intra-ruminal, controlled release device, and the resultant accuracy of intake estimation in sheep. Australian Journal of Agricultural Research (In press).

Duncan, A.J., Mayes, R.W., Lamb, C.S., Young, S.A. and Castillo, I. (1999). The use of naturally occurring and artificial applied n alkanes as markers for estimation of short-term diet composition and intake in sheep. Journal of Agricultural Science. 133,233-246.

Letso, M. (1996). A study of the use of n-alkanes to determine dietary intake and digestibility in grazing rabbits. MSc thesis, University of Aberdeen.

Mayes, R.W., Giraldez, F.J., and Lamb, C.S. (1997). Estimation of gastrointestinal passage rates of different plant components in ruminants using isotopically-labelled plant wax hydrocarbons or sprayed even-chain n-alkanes. Proceedings of the Nutrition Society 56, 187A

Mayes, R.W., Iason, G.R., White, N. and Palo, T. (2001). Measuring diet composition and food intake by moose in the Swedish boreal forest: integration of GPS and faecal marker technologies. Proceedings of GPS Conference, Tracking Animals with GPS of A.M. Sibbald and I.J. Gordon (Eds). Macaulay Land Use Research Institute, Aberdeen, 12-13 March 2001, pp77-80.

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Spatial Pattern of Vegetation and Grazing by Large Herbivores – Impact on Ecosystem Functioning

Summary

Through the effects of grazing, trampling and excretal returns, large herbivores influence the function and dynamics of many terrestrial ecosystems. The spatial distribution of different plant communities is thought to have a major influence on foraging behaviour and the impact on vegetation dynamics. This was explored experimentally, involving heather (*Calluna vulgaris)* and acid grassland mosaics grazed by sheep and red deer.

The foraging behaviour of sheep and red deer was influenced differently by the size of the grass patch in a grass/heather mosaic, with the utilisation of heather declining rapidly from the edge of the grass patch. The siting of grass patches on slopes also influenced the extent of heather utilisation and the impact of trampling of the heather plants. A model has been developed which predicts the degree of heather utilisation based on distance from a grass patch, the attractiveness of the grass patch and the density of large herbivores.

A survey of grass/heather mosaics at the landscape scale confirmed the importance of grass patches on heather utilisation as well as an additional effect of the proportion of grass within 1 km of the grass patch. The results demonstrate the importance of local, spatially explicit effects on the functioning of terrestrial ecosystems.

A model has been developed which predicts the degree of heather utilisation

Context

Large herbivores are considered to be a major driver of the functioning and dynamics of many terrestrial ecosystems. Through the effects of grazing, trampling and excretal return, they affect vegetation community dynamics and associated fauna. In turn, characteristics of ecosystems, such as the composition of vegetation communities, their productivity and their distribution, determine their foraging behaviour. In particular, the spatial distribution of different plant communities is thought to have a major influence on the inter-relationships between foraging behaviour and vegetation community dynamics. An understanding of these relationships is important for the management of landscapes containing semi-natural vegetation. Such vegetation is normally found in mosaics of different plant communities and is grazed by large herbivores in order to achieve nature conservation, agricultural or other objectives. A particular example of relevance in a European context is a landscape commonly found in Scotland, which contains a dwarf shrub community, predominantly heather (*Calluna vulgaris),* and an acid grassland community, and which is grazed by sheep and red deer (see Figure 1).

Figure 1. Landscape showing grass/heather mosaics in Scotland

Foraging behaviour and its impact

Dwarf shrub-acid grassland mosaics are an example of a two-phase mosaic. One component of the mosaic is normally distinctly preferred by large herbivores over the other. In the case of heather and acid grassland mosaics, the grassland component is preferred. It is also the component with the highest nutritive value for large herbivores. The degree to which the less preferred component, heather, is utilised varies seasonally and is predominantly determined by the green biomass per unit area of the acid grassland. The heather tolerates a lower degree of utilisation by grazing and suffers damage more readily through trampling than the acid grassland. In consequence, the nutrition of the animal and, hence, its productivity will increase as the proportion of acid grassland increases in the mosaic. Thus, the productivity of the heather and its proportion within the landscape will be influenced by the density of large herbivores. In this respect solely animal production objectives may require one management strategy whilst nature conservation objectives, related to heather, may require another.

Spatial patterns

The spatial pattern of vegetation in mosaics is determined by abiotic factors, such as soil type and topography, and by the impact of grazing and trampling. In a series of experiments at the Macaulay Institute, the spatial distribution of grazing by sheep and red deer was described for mosaics where the proportion of acid grassland in the vegetation mosaics was between 0.15 and 0.25. When acid grassland patches of different size were artificially created, the time spent grazing by sheep on the acid grassland plant community was higher on larger acid grassland patches whilst red deer grazing behaviour was unaffected by patch size (Clarke et al., 1995). The strong selection by sheep of grass on large patches was considered to involve a reduction in the cost of foraging across the less preferred areas of the tall heather, which would not have been such a high cost to red deer. In a subsequent experiment on smaller naturally occurring heather/grass mosaics, sheep were more affected by the scale of fragmentation than were red deer. Their habitat use favoured grass patches and paths within the mosaic more than that of red deer,

The impacts on heather vegetation may differ between sheep and red deer

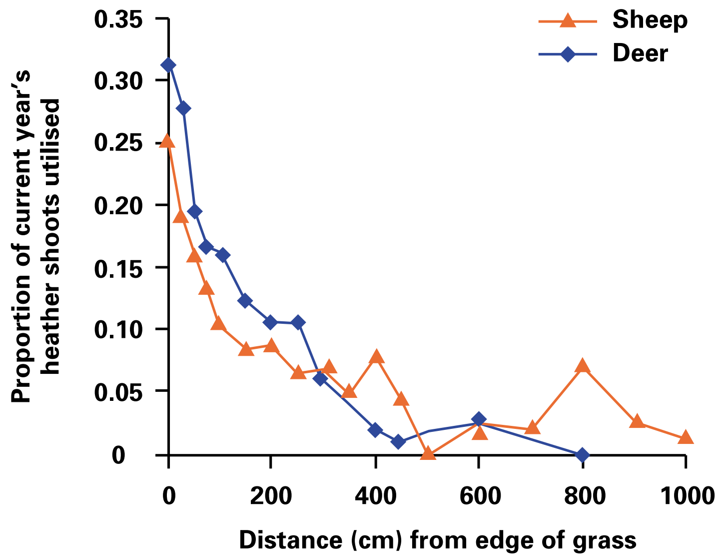


Figure 2. Heather utilisation by sheep and red deer with distance from edges of grass patches (from Hester and Baillie, 1998)

which ranged more evenly across the mosaic (Hester et al., 1999; Oom and Hester, 1999). These findings suggest that the impacts on heather vegetation may differ between sheep and red deer with sheep probably having greater impacts on the heather adjacent to grass patches and paths than red deer (Hester and Baillie, 1998).

These studies showed that the impact on heather is likely to depend upon the spatial pattern of grazing. It can be hypothesised that, if the grazing of the heather area is uniform, the effects of reducing productivity and cover associated with higher levels of utilisation will not be large unless the density of large herbivores is high. However, if the same degree of utilisation is highly localised, the impacts will be much greater. Figure 2 shows that high levels of utilisation of heather tend to be concentrated very close to the edges of acid grassland patches for both sheep and deer. The slope of the site also affected foraging behaviour with both species normally grazing whilst facing either uphill or across the slope. This resulted in significant directionally different trampling impacts and patterns of heather use around edges of the acid grassland patches (Hester and Baillie, 1998). This study demonstrated that both grazing and trampling can influence the

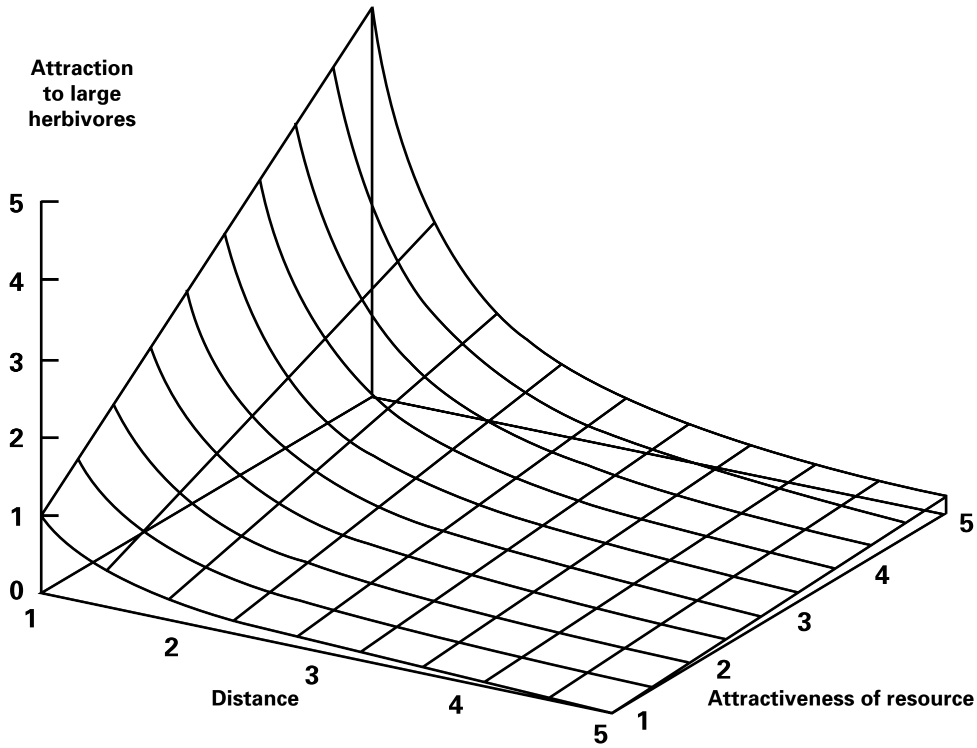


Figure 3. Relationship between distance from grass patch, attractiveness of resource and attraction to a large herbivore (from Oom et al., (2002)

impact on heather at the edge of acid grassland patches; trampling impacts have generally been ignored or underestimated in the past yet this study showed their effects to be highly significant in some areas.

A spatial interaction model, previously used in human geography to study and predict spatial patterns of consumer behaviour as a function of resource patterns, has been recently developed to predict heather utilisation by sheep (Oom et al., 2002). The model predicts heather utilisation based on the distance from an acid grassland patch, the attractiveness of the acid grassland patch and the number of sheep present per unit of grass area (see Figure 3). The results of this study suggest that in more fragmented mosaics of heather and acid grassland, a larger proportion of the heather will be affected by large herbivores. It also suggests that creating a large area of grassland might release grazing intensity from elsewhere in the mosaic.

Landscape effects

The experiments described above were of a relatively small scale, considering mosaics within an overall area of a few hectares. Can these findings be extrapolated to areas of 10,000 hectares, i.e. whole landscapes, grazed by red deer and sheep? This question was explored in a survey of heather utilisation adjacent to patches of acid grassland on 6 estates in the Cairngorm Mountains of Scotland where the mosaics of heather and acid grassland were distributed across landscapes. A sharp decline in heather utilisation with increasing distance from the edge of grass patches was found to confirm the results of the previous studies (see Figure 4). However, the proportion of grass in the local landscape (within 1 km of an acid grassland patch) also had a significant effect on heather utilisation. The greatest contribution to variation in heather utilisation was with measurements made at smaller scales, making it difficult to predict local heather utilisation from variables measured at the large scale, for example large herbivore density across the landscape. This has important implications for the development of decision-support tools in which the dynamics of plant communities are being described.

The boundaries between acid grassland and heather patches have been identified as high areas of heather utilisation and are thus the hotspots where changes in the cover of different plant communities will occur. The mechanisms involved in this change are likely to involve not only impacts of utilisation and trampling on heather cover but also excretal return of nutrients to promote changes in soil nutrient status at the boundary. This is the subject of current research.

KNOWLEDGE TRANSFER AND EXPLOITATION

As a sponsored body of the Scottish Executive Environment & Rural Affairs Department, we are tasked both with the effective transfer of our knowledge to 'end-users', i.e. people who will use our research outputs for practical purposes and, where possible, with exploiting our research with the aim of wealth creation. Scientific papers in research journals are one important means of communicating our research advances, but the next article describes ways in which we communicate our research findings to schoolchildren (Dr Miller's Toolkit) and the following one describes use of our research for the benefit of land managers. Further examples can be found on our website www.macaulay.ac.uk. The third article describes an example of a patent taken out as part of our responsibility to protect the intellectual property we generate.

Dr Miller's Toolkit for Countryside Change – Educating future scientists

Summary

Dr Miller's Toolkit for Countryside Change has been developed as a CD and has been used in an interactive manner at a wide range of events for school children aged between 8 and 14 years. It explores the background causes and potential impacts of countryside change. The original idea was developed from research on public participation in the ranking of preferences for different types of landscape. With the increased interest in sustainable energy, public debate on the interaction between wind turbines and the landscape stimulated the development of visualisation materials for science interpretation events. This led to involvement in developing materials appropriate to the Geography curriculum of schools, which led to the development of the Toolkit.

Figure 1. Future scientists, sketching their vision of future countrysides

Context

An editorial in Nature in December 2001 (Nature 414 6865), under the heading 'Educating future scientists' strongly encouraged scientists to seek out mechanisms that enable involvement with their local schools and encourage students to study science. This article describes how such a strategy was adopted in the development of a multi-media package 'Dr Miller's Toolkit for Countryside Change', and a related programme of school workshops on 'Future Countrysides.'

<u>Identifying the appropriate area of science</u>

There were three aspects of the approach adopted for our outreach activities which contributed to its success. These were: i) the choice of the topic area was highly relevant to the Standard Grade Geography curriculum of the Scottish education system; ii) public participation was a key aspect of the research itself; and iii) there was direct involvement of research staff in the outreach activities.

The theme chosen, i.e. countryside change, capitalized on topical issues that are of high national and international importance. For example, driven by international protocols originating in Rio (1992) and Kyoto (1997), the development of renewable energy production to reduce carbon emissions has led to considerable increases in the number of proposals for the erection of wind turbines, which has been a topic of controversy in regard to their impact on the landscape. In turn, this makes it an important subject for research and one in which public participation can be readily facilitated. Similarly, the origins of Biodiversity Action Plans and Local Agenda 21 Groups can be traced to the Rio Summit and, combined with legislation designating National Parks in Scotland, the topic of natural heritage content, quality and management has been an important topic for research.

Common to both topics is the relevance of research to increasing our knowledge base, and the need to develop techniques for exploring multi-faceted issues with the general public.

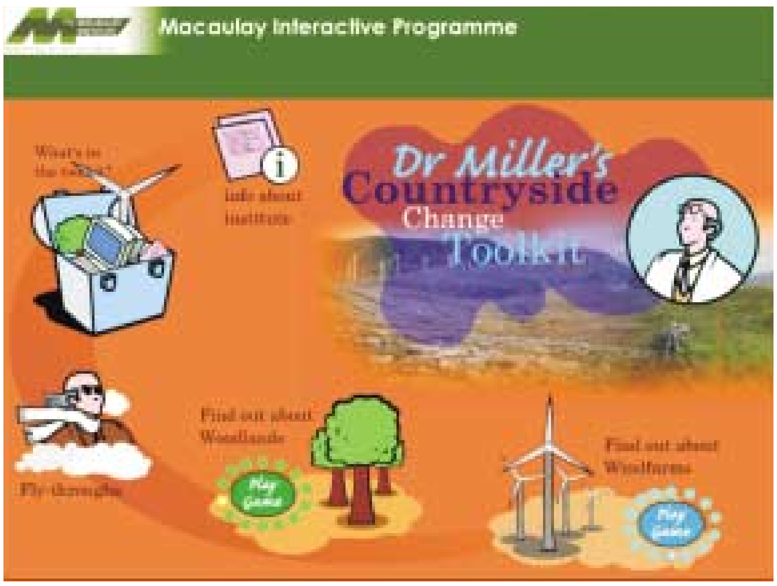
The public continue to have a significant role in the research which underlies the multi-media programme

Developing the right approach

Participation in the Edinburgh Science Festival since 1998 has improved our understanding of the commitment and resources required to communicate the purpose and key implications of outputs from scientific research to the general public. The origins of the Toolkit can be traced back to landscape research at the Institute, which used computer-based surveys and required public participation in ranking their preferences for landscape types. A PhD research project used the opportunity of the Edinburgh Science Festival in 1998 to undertake a computer-based survey.

The same theme was pursued at the Science Festival in 1999 but augmented by interactive 3-D landscape models in which the public could place wind turbines, buildings and then plot flight paths across the modified landscapes. That year also saw greater investment in its infrastructure and content, compatible with an exhibition geared for families, but requiring depth of materials to respond to the questions of why? how? and so what?!

The active participation of researchers in such events appeared to contribute significantly to the public's response to the exhibit, and the public continue to have a significant role in the research which underlies the multi-media programme 'Dr Miller's Toolkit for Countryside Change'. However, for periods of one to two weeks, the time involved implies a considerable investment for a small number of researchers.



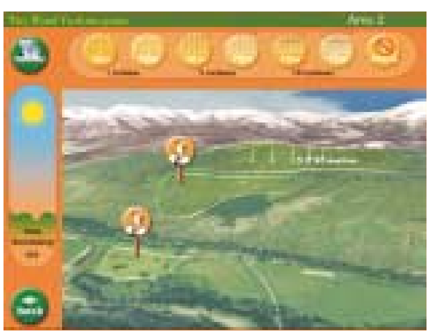


Figure 2 (above). Front page and main menu of the Toolkit
Figure 3 (below left). Interface to the 'Wind Turbine' game
Figure 4 (below right). Renewable energy (e.g. wind turbines) is one option for land use change

Inside the 'Toolkit'

In collaboration with an Aberdeen-based media company, a computer-based interactive sequence on the theme of land use change, which could be enjoyed as a stand-alone exhibit, was designed.

This uses video excerpts of Dr David Miller as his interaction with the general public was identified as one key aspect of the success of the Institute's participation in the science festivals. The 'Toolkit', which was subsequently developed, is an interactive multi-media computer sequence which incorporates

Figure 5. A selection of entries to the competition "Draw your own countryside" (6 years and under)

lively animated graphics, embedded video clips and interactive games to explore the concept of land use change. The sequence is designed to explain the background causes and potential impacts of countryside change. It features materials from the Cairngorm Massif, with the building of wind farms or planting of native woodlands being two case study options of land use change.

There are two modules which give background information about the case studies and the third main aspect of the 'Toolkit' is an interactive 'game' where participants can choose the most suitable combination of tree species and management for different land resources, and are then given feedback via video images of Dr Miller on the validity of their choice. To play a similar game on the site suitability for wind turbines, selection is from the number and height of turbines. The 'Toolkit' is aimed at ages 8-14, but experience has shown interest from all ages!

The sequence is designed to explain the background causes and potential impacts of countryside change

Implementation

The 'Toolkit', as one component of an exhibition on 'Future Countrysides', designed for the public attending science festivals, proved to be the most important factor in attracting the attention of younger visitors. It has been supported by computer-based videos, opportunities for hands-on computer-aided landscape design, and other supporting materials with the emphasis always on activity-based exhibits, ensuring that there was something for everyone in the family.

A key element to the Toolkit design is that it can be entirely 'stand alone', thus a display can be left unmanned, or supported by non-specialist staff. This ensures that some of the practicalities of attending an increasing number of public events can be addressed, and the quality of participation can incrementally be broadened and deepened.

It has been possible to import a small proportion of the Toolkit onto the Institute web site for on-line use. This complements the distribution of copies of the CD version, and facilitates a flexible approach to the dissemination of the materials, recognising that there are different ways of transferring knowledge to people.

Participation in local science festivals has built up good relationships with schools, which has led to the development of the 'Toolkit' into on-site workshops at schools. The use of the Toolkit is now established within some local schools but it is under frequent revision to incorporate feedback from teachers and pupils to ensure relevance to the curriculum, combined with language and imagery suitable for the target age group.

The future

Many organizations are developing ideas towards increasing public awareness and understanding of their role. This takes the form of games, teaching resources and projects, often tailored for children (for example, see the United States Environmental Protection Agency, www.epa.gov/epahome/educational.htm; the Countryside Council for Wales, www.ccw.gov.uk/kids/ the Royal Society's 'First for Science', www.sc1.ac.uk). Other examples are targeted at enabling schools to use advanced software packages for research into topical issues, providing resources and learning opportunities (for example, the AURISA 'Geographic Information Systems in Schools Competition' www.aurisa.asn.au/education/GISschoolscomp.htm/), and there are opportunities for collaboration in similar areas, extending the know-how from 'what?' and 'why?' to 'how to do it yourself with our help?'. Through working with local schools and in particular geography teachers, the Toolkit team have been invited to present their project at a Scotland-wide conferences for teachers and pupils during 2002. Further development of the outreach strategy will see more web-based resources being developed, and the launch of the Institute's 'Explore Scotland' educational project, based on the success of the Tookit, will give tailored on-line access to unique environmental datasets during 2002.

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www.macaulay.ac.uk/toolkit/

Figure 6. Hands on discussion of answers in a school workshop

Rapid Assessment of Grazing and Trampling Impacts on Upland Habitats

Summary

A rapid, cost-effective and accurate method for carrying out grazing and trampling assessments over extensive areas of upland vegetation has been developed and tested. It is based on measuring grazing and trampling impacts on a proportion of the vegetation combined with the prediction of impacts for the rest of the vegetation. Semi-natural vegetation communities account for over 60% of the land area of Scotland. The primary use of this land is for grazing by domestic stock and wild herbivores, notably red deer, and the natural heritage value of such habitats is high. Deer Management Groups (DMGs), where neighbouring estates collaborate in the management of geographically discrete deer populations, are developing management plans to achieve a range of objectives. A description of the current levels of impact of grazing and trampling on the vegetation is seen as a vital stage in the management planning process to aid decision-making and facilitate appropriate management of upland vegetation.

Semi-natural vegetation communities account for over 60% of the land area of Scotland

Context

The management of wild red deer in Scotland is a long-standing and widely debated issue. The increase in population size in the last 30 years has been due not only to an extension of deer populations into new areas, but also to an increase in deer density over much of their established range. This has been associated with reductions in stocking density of sheep in some parts of the Highlands. The Scottish situation is, however, a reflection of a wider trend, as deer populations throughout much of the Northern Hemisphere have increased over the past century. The causes vary between species and countries, but include abandonment of marginal agricultural land, reduced competition from domestic stock, increases in natural woodland and commercial forestry, less effective control through hunting and a reduction in the numbers of predators.

Various ecological issues have arisen as deer numbers have increased in specific areas, including degradation of habitat and suppression of natural woodland regeneration. Where the right to kill game is vested in the private landowner, as in Scotland, there is a potential conflict of interest between owners with mainly sporting interests and conservation agencies with a statutory responsibility for protecting the natural heritage.

Mosaic of dwarf-shrub heath and grassland with heavy impacts

Habitat resource and management planning

A significant proportion of the semi-natural vegetation communities of heather moorland, grassland and blanket bog have some form of nature conservation designation. Statutory agencies have an obligation under the EU Habitats Directive to ensure that habitats are managed to maintain favourable condition status. The primary use of much of this land is for grazing by domestic livestock and wild herbivores, principally red deer, and it is recognized that manipulation of herbivore impact is the principal means whereby favourable condition and biodiversity can be maintained. A means of achieving these objectives is currently being pursued through Deer Management Groups, where groups of estates are collaborating in the management of discrete populations of red deer.

A description of the current levels of impact by wild and domestic herbivores on semi-natural vegetation is a vital input in the management planning process. Deer Management Groups vary

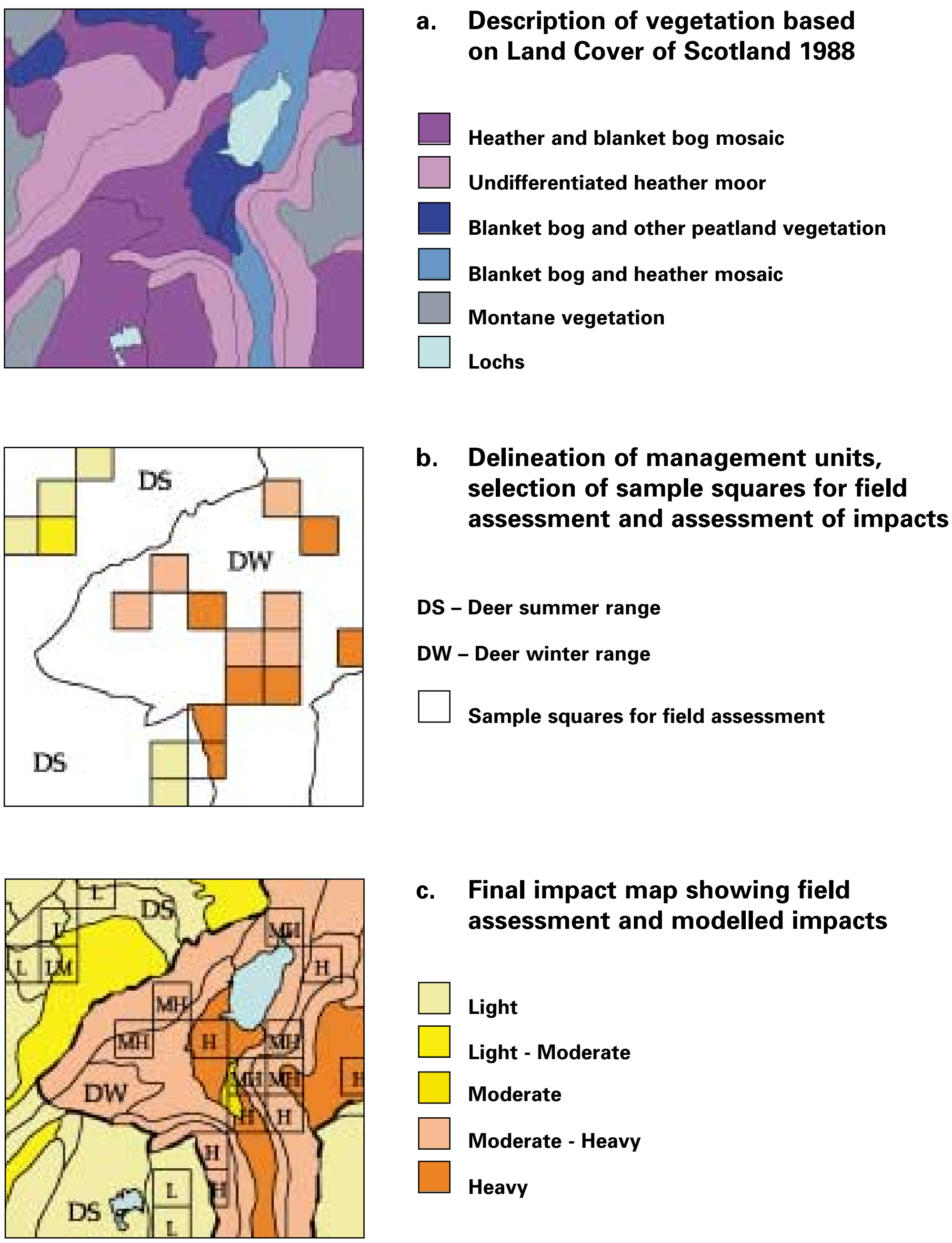

Figure 1. Stages in the process of rapid assessment of grazing impacts on upland vegetation

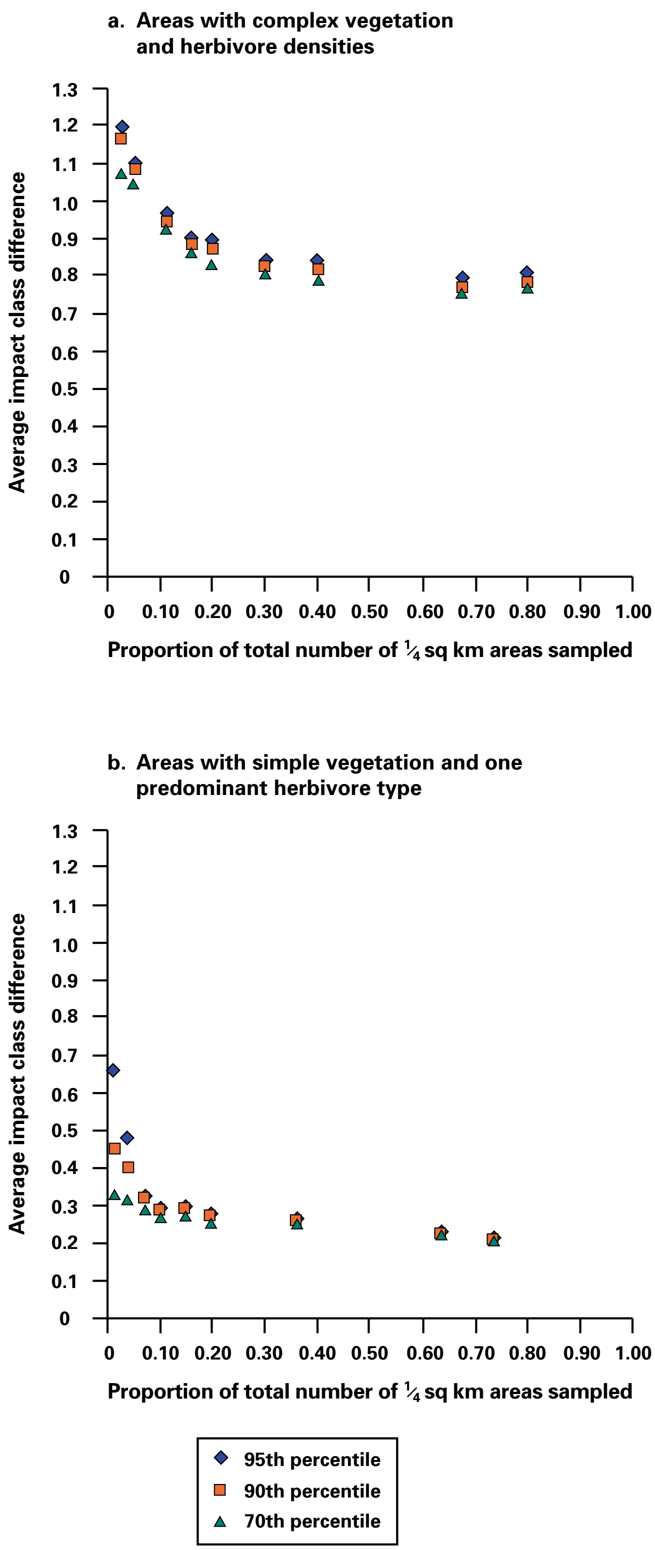

Figure 2. Relationship between proportion of area sampled and average class difference between observed and predicted impact classes, all vegetation types (percentiles of deviation from 100 simulations)

considerably in size from around 200 to over 2000 sq km, and across Scotland there are 45 groups presently operational, covering in excess of 90% of the red deer range. Recent publication by Scottish Natural Heritage of 'A Guide to Upland Habitats - Surveying Land Management Impacts' has provided a descriptive framework for classifying impacts on the principal upland vegetation types. This has greatly facilitated the process of assessment by providing a standardized approach. However, for extensive areas such as Deer Management Groups, surveys based on complete coverage of the whole area in 1/4 sq km blocks are considered too time-consuming and expensive in most instances.

Methodology for rapid assessment of impacts

From previous work, it has been determined that the distribution of vegetation types, density of herbivores and management are the principal influences on the grazing impact on a vegetation type in any particular locality. In a collaborative project with the Deer Commission for Scotland, Scottish Natural Heritage and Biomathematics and Statistics Scotland, a method has been developed and tested that enables impact assessments to be carried out rapidly over extensive areas with a high level of accuracy. This approach is based on a combination of sampling a proportion of the area and predicting the impacts on the rest of the vegetation. The Deer Management Group is first divided into land management units (mainly estates) on the basis of information obtained from estate managers, with regard to areas occupied by sheep, deer or both species. The boundaries of these management areas are overlain on a vegetation map base derived from the Land Cover of Scotland 1988 dataset (Figure 1a). A Geographical Information System-based computer model is used to select 1/4 sq km sample areas for field assessment from within each of the vegetation types within a management unit, according to a specified sampling intensity (Figure 1b). The sampling intensity is proportional to the square root of the area of each vegetation type occurring within a management unit. This is to overcome the issue, of potentially over-sampling the more extensive vegetation types, which are often less preferred, while under-sampling the less extensive vegetation types, which are often more preferred, if the sampling intensity was proportional to area. On the more preferred vegetation types, such as grassland and mosaics of grassland and dry heather moorland, impacts are generally more variable.

For the purpose of assessment of grazing and trampling impacts, upland vegetation is sub-divided into the main habitat types of acid grassland, tussock grassland, dwarf-shrub heath, wind-clipped heath and blanket bog. Areas of habitat are assessed as belonging to one of three classes - Light, Moderate or Heavy, depending on which of a defined set of characteristics, indicating current and previous grazing intensity, best describes the vegetation. The main indicators vary according to habitat and include height, morphology and structure of plants, browsing intensity, extent and intensity of trampling, and presence of dung. Intermediate classes of Light/Moderate and Moderate/Heavy impact are used where more than one impact class occurs on a particular habitat within a sample square. These are determined according to the proportions of the main impact classes occurring.

On the more preferred vegetation types, such as grassland and mosaics of grassland and dry heather moorland, impacts are generally more variable

The method assumes that there is a theoretical underlying continuous scale of impacts ranging from 0.1 to 0.9 and the classes are allocated numerical scores and ranges along this scale. Following assessment of grazing and trampling impacts in the field, the overall impact class for each vegetation category and management unit combination is determined by calculation of the mean impact class from the relevant sample squares. A final coloured map of overall impacts is then produced with the mean impacts for each vegetation type for each management unit used to classify the remaining un-sampled areas. The location and impact recorded on the sample squares assessed in the field are also shown on the map (Figure 1c).

The accuracy of the method was tested by comparing the results from the use of the method with complete survey datasets recorded for the same Deer Management Groups. It was found that accurate predictions to within one class, based on the five classes described above, can be maintained with a sampling intensity of between 10% and 25% of the 1/4 sq km sample areas (Figure 2). In terms of cost-benefit analysis such sampling intensities are optimal, in that they define a point from which there is a decreasing return in terms of improving accuracy against increasing inputs of cost. The optimum sampling intensity for any given area is influenced by a number of factors, notably the complexity of vegetation patterns occurring, the numbers and types of herbivores present, and their ranging behaviour. In areas where patterns are relatively simple, a lower sampling intensity than 10% may be sufficient, whereas areas with greater complexity of vegetation patterns and herbivore use may require a higher sampling intensity than 25% to achieve an acceptable level of accuracy for management planning purposes.

This rapid cost-effective and accurate method, based on a combination of sampling and predicting impacts, can be used for resource assessment over extensive areas. The method is aiding decision-making in Deer Management Groups with approximately 30% of such groups already having used the method. Moreover, it has the potential to be applied to rapidly assess impacts of grazers in situations beyond the uplands of Scotland.

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Application of Endophytic Bacteria in Phytoremediation of Soil and Groundwater Pollutants

Industrial contaminants are found in significant levels in polluted sites in most of the industrialised countries of the world. Evidence suggests that many of these compounds are toxic and carcinogenic, constituting a potential health threat through their bio-accumulating properties. Some of the more volatile compounds are greenhouse gases, influencing the global climate. They appear in soils, ground- and surface-water due to spillage, loss and improper waste disposal, eventually accumulating in sources of drinking water. A recent report of the United States National Academy of Sciences estimated that up to $750 billion could be spent on the remediation of more than 400,000 hazardous waste sites in the U.S. alone.

Up to $750 billion could be spent on the remediation of more than 400,000 hazardous waste sites in the U.S. alone

For these reasons, fast, cost-effective, technically practical and, in many cases, in situ treatments are necessary for the removal of contaminants from soils. Phytoremediation is well established as a major "soft treatment" strategy for remediating contaminated soil and groundwater. Phytoremediation of organic contaminants is based on the combined action between plants and associated microorganisms, such as mycorrhizal fungi and bacteria (Figure 1) in removing contaminants from the soil by uptake and degradation. Classes of organic compounds for which removal rates from soil are known to be enhanced in the rhizosphere (i.e. the soil fraction influenced by plant interactions) include chlorinated solvents, pentachlorophenol, petroleum hydrocarbons, PAHs, pesticides, herbicides and explosives, to name a few. It is recognised that the rhizosphere supports ten to a hundred times more microorganisms than does the rest of the soil, although the exact role played by the indigenous root-associated bacteria during phytoremediation applications is unclear and constitutes a topic of intense research.

Soil contaminants, particularly those with high solubilities, are readily taken up by plants although certain organic pollutants may not be degraded or may be only partially degraded, resulting in their accumulation in the plant, leading to a potential toxicity hazard for the plant. Furthermore, in the case of volatile pollutants, plants may, in turn, release the compounds, or their metabolites, through the stomata, negating the beneficial results of the phytoremediation (Figure 1). Recently, the European Commission has funded a project within the Quality of Life and Management of Human Resources Programme ("ENDEGRADE"; project number: QLK3-CT2000-00164) in which the Institute is a participant. Its objective is to ascertain whether endophytic bacteria can be utilised to enhance

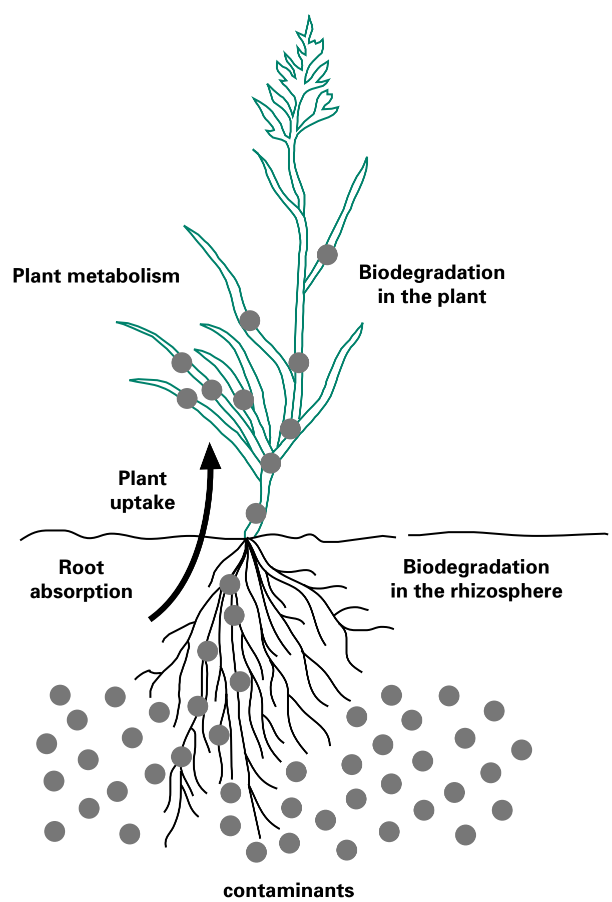

Figure 1. Principle of phytoremediation of soil pollutants

Figure 2. Installation of a phytoremediation barrier for the treatment of a BTEX-TCE plume. Phytoremediation will be carried out using a hybrid poplar species, enhanced using endophytic bacteria

the phytoremediation of organic pollutants in soil and groundwater. Endophytic bacteria are bacteria that live within plants without any apparent deleterious effects. In fact, endophytic bacteria are known to exert various beneficial effects on their host. Within the ENDEGRADE project, it is hypothesised that selected bacteria, probably originating within the rhizosphere and able to function as plant endophytes, will act to degrade toxic organic compounds within the plant vascular system, thereby assisting the plants in the complete metabolism of soil contaminants. When the plants used for phytoremediation applications are taking up pollutants at high rates, the concentration of the toxic compounds in the plant sap will be maintained at low levels, effectively reducing toxicity, as well as volatilisation from the plants (Figure 2). This concept is now the subject of a recent U.S. patent application (patent application number: 60/291344).

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EXAMPLES OF THE PRACTICAL RELEVANCE OF OUR RESEARCH

The mission statement of the Macaulay Institute is : *to be an international leader on the use of rural land resources for the benefit of people and the environment*. The following four articles focus on how examples of our research outputs can help policy-makers and people living in rural communities to bring benefit to our Scottish environment

The Effect of Nature Conservation Designations on Scottish Land Values

Summary

Ministers are currently proposing to revise the Sites of Special Scientific Interest (SSSI) system. To inform their discussions, the Scottish Executive commissioned the Macaulay Institute to:

1) assess what effect SSSI designations have had on land values, and 2) consider the potential effect on land values of a stepwise increase in availability of positive management agreements in SSSI areas.

The results from the study suggest that designation has not had a significant effect on Scottish land values. At the same time, the study highlighted a minority of site-specific cases where designation can and has influenced the price received for a parcel of land. In some of these latter cases, for example on sporting estates and/or where the potential buyer values highly protecting the nature conservation value of the land, the effect of designation has been positive. In others, for example commercial farms where there was potential for development and/or alternative (conservation damaging) land use, the effect has been negative.

In terms of the proposed reforms, an important generic finding was that increasing the use of positive management agreements has an additional benefit over and above that of conserving natural heritage values. In particular, for risk-averse farmers it reduces the need to hedge against uncertain farm gate prices. In general the study suggests that the interests of conservationists and both new and existing land owners are moving closer together.

The results from the study suggest that designation has not had a significant effect on Scottish land values

Context

SSSIs cover almost 12% of the total land area of Scotland with most designated land being privately owned and managed as part of farms, estates or forests. Designation currently has three implications for land owners and occupiers: it means they are less likely to receive planning permission or grant support (eg through the Woodland Grant Scheme); it gives them a right to compensation for not carrying out an activity which could potentially affect the conservation value of the land; and, in some cases, it provides them with an opportunity to enter into a positive management agreement to further enhance the conservation value of their site.

Trying to assess the impact of designation on the price of land is complicated not only by the fact that only around 1% of the total land area in Scotland is bought and sold each year but also by the unique characteristics of land as an economic commodity. Land performs several simultaneous functions. It provides a flow of income streams for land owners and tenants through its use as an input in production and is a capital asset held for investment purposes. Land also provides space and amenity values for owners, tenants and other users, and supports wildlife intrinsically valued by society as a whole. Each parcel of land has a unique combination of soil quality, environmental features and climate. It is fixed in location and land is fixed in overall supply. Given these special features of the land market, the effect of designation on land prices was explored using a combination of approaches including Geographical Information

System (GIS)-based analysis, a survey of Scottish land agents and a statistical analysis of the land market from 1989 to 1999. Mathematical programming analysis was carried out to assess the impact of increased use of positive management agreements.

SSSI designated land in Scotland

A GIS-based analysis of SSSIs in Scotland revealed that designated land varies significantly in economic potential. Eight per cent of SSSI land is covered by arable crop, and good and improved grassland, 9% is poor rough grassland and bracken, and over 57% of SSSI land is heather moorland or peatland (see Figure 1). Only 5% of SSSI land is within a 30-minute drive of a population settlement of 10,000 people or more (see Figure 2). It is within these accessible areas that pressures for development are likely to be most intense.

Findings from the survey of land agents

The survey of Scottish land agents not only explored their perceptions of the impact of designation on land values but also, more generally, the changing role of nature conservation in the land market.

The opinion of land agents was that designation, in the majority of cases, has little bearing on market prices. However, they noted that in specific cases designation could lead to either an increase or decrease in the price of properties. SSSI designation was most likely to be positively viewed on sporting estates where a diversity of interests exist and where conservation objectives are more easily integrated into the overall management plan of the property. In such cases there is often a co-incidence of conservation and sporting interests and the existence of SSSIs is highlighted within the sales process. In contrast, designation was viewed more negatively by potential buyers of commercial farms where it may have a constraining effect on profitability or potential for developments. Designation was also more likely to be thought of negatively in cases where there was uncertainty surrounding its impact for landowners or its future implementation and some agents noted that extra administrative procedures can put off potential buyers.

More generally, agents argued that the land market had become more diverse in recent years. Different purchasers are in the market for different reasons with some new buyers specifically having nature conservation objectives in mind. It was felt that, overall, landowner attitudes to designation had become far more tolerant over the last 20 years with the attitudes of farmers helped by the type of positive management agreements embodied in the previous Environmentally Sensitive Areas Schemes and proposed to be

Landcover	Area (ha)	%
Arable	1879	0.2
Good and Improved grassland	69250	7.7
Poor rough grassland, bracken	84113	9.3
Heather moorland	319821	35.4
Peatland	205864	22.8
Montane	56973	6.3
Coniferous woodland	15586	1.7
Mixed and broadleaved woodland	27484	3.0
Fresh waters, marshes	48010	5.3
Salt marshes, dunes, rocks and cliffs	34058	3.8
Developed	1693	0.2
Other	39246	4.4
Total	**903977**	**100**

Figure 1. Landcover of SSSI-designated areas in Scotland

increased as part of the SSSI reforms.

Statistical analysis of the Scottish land market

To test the views of the land agents, an analysis of the Scottish land market was carried out. This aimed to quantify the influence of different characteristics, including designation, on land prices. Analysis was based on data provided by the Scottish Executive Environment and Rural Affairs Department (SEERAD) on land sales greater than 5 hectares since 1989. Potential explanatory variables included those reflecting both the production-related characteristics of the land and non-production or "consumptive" characteristics (such as amenity value and accessibility).

The following variables were found to be significant factors determining agricultural land prices: size of area with the larger the area the lower the price per hectare, the time of sale, land quality (the highest two land classes increased the sales price, the lowest two classes had a negative influence), some types of land cover, particularly moorland and peatland, the extent of developed land in the area and peripherality. Sales of land intended for non-agricultural use were more sensitive to the area of land already developed and distance from a major service centre.

The analysis found no significant effect of SSSI designation on land prices. The analysis also failed to find empirical evidence to support the notion of an increase in the influence of non-production-related factors on land prices, suggesting instead that the Scottish land market is still dominated by traditional interests.

The impact of proposed SSSI reforms

Four farm-level programming models (relating to hill, upland, cereal and mixed farms) were developed using past information to explore the impact on land use patterns, farm revenues and land rents of different positive management agreement scenarios. Analysis took into account the potential value to farmers of the risk-free nature of management agreement income under varying assumptions relating to the risk preferences of farmers.

In all cases, reductions in farm revenues, associated with complying with management agreements, were offset by compensation payments. However, the extent to which compensation exceeded the loss in farming income varied between farm types. On all farms and under each of the schemes considered, land rents were found to increase. High-risk farmers were found to suffer most in relation to farm incomes from entering into the management regimes. However, for this category of farm, compensation payments not only offset potential farming losses but also decreased the difference in total revenues and rents between them and risk-neutral farmers.

Overall, the results of the modelling suggested that entering into positive management agreements will result in higher land rents and thus, if rents are capitalised into land values, higher land prices. Importantly, they also suggested that the increased availability of positive management agreements, as part of any reform to the SSSI scheme, may not only lead to enhanced conservation interest but also have the additional benefit of stabilising farm returns and alleviating the disadvantages of increasingly uncertain agricultural output prices.

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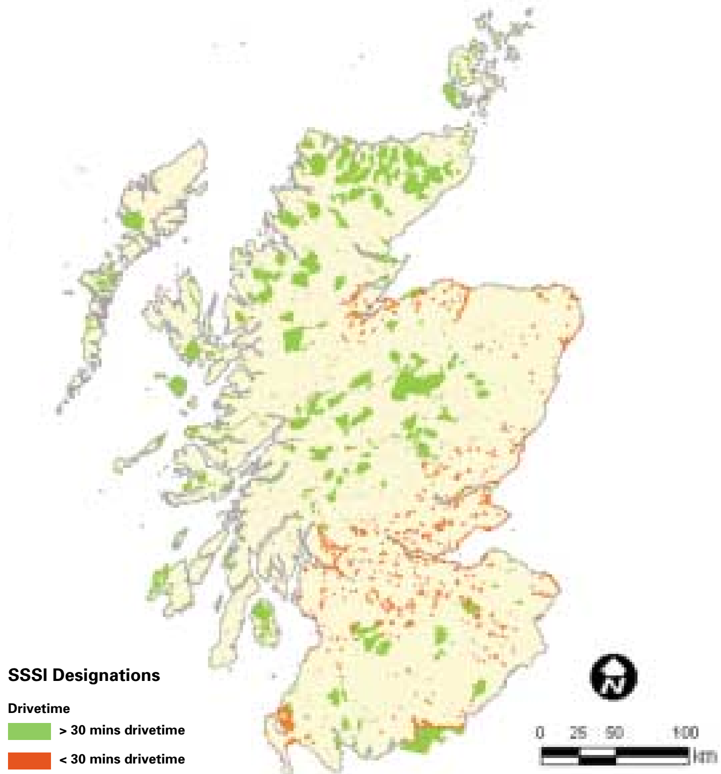

Figure 2. The accessibility of SSSI-designated land in relation to population centres of 10,000 or more

Measuring the Cost-Effectiveness of Delivering Biodiversity Benefits

Summary

By the end of 1997, more than £23 million of public exchequer money had been paid to farmers managing habitats through the Environmentally Sensitive Area (ESA) scheme. This scheme does not select entrants on the basis of cost-effectiveness, and nor does its successor, the Rural Stewardship Scheme (RSS). This study demonstrates that there are potential gains to targeting habitat management incentives by cost-effectiveness. The policy implications are that the environmental and economic characteristics of 'biodiversity producers' need to be more closely considered in the current context where the environmental stewardship role of farmers is being increasingly emphasised. An important extension of this work is to consider how to determine a practical means of achieving this targeting, such as the ranking of criteria for farm selection.

Context

Over the last decade government-sponsored countryside stewardship schemes have become more important. The agricultural sector has been a particular focus of such schemes. In Scotland, approximately 75% of its land area is in agricultural production, and the potential for both positive and negative impacts on conservation value is one motive for such agri-environmental schemes. In addition, the agricultural sector is in transition, and environmental and cultural landscape payments are one aspect of a policy-stimulated sector diversification.

The first major agri-environment scheme was the ESA scheme, instituted under the UK's Agriculture Act (1986). The scheme has recently been superseded by the RSS in Scotland. Several contingent valuation studies have suggested that the public willingness to pay for agri-environmental schemes is greater than the public exchequer cost, implying an unfulfilled demand. However, environmental monitoring evidence has recently emerged across Europe, including Scotland, that the first generation of agri-environmental schemes has not been associated with general improvements in conservation value, where the latter is measured by the richness and diversity of different species groups including plants, birds and insects.

Cost-effectiveness of the Environmentally Sensitive Area scheme across farm types

It is widely acknowledged that there is variability in socio-economic and environmental characteristics across farms. Since schemes, such as ESAs and the RSS, do not formally select entrants on the basis of high baseline biodiversity or great potential for biodiversity change, it is unsurprising that conservation benefits have been inconsistent. Furthermore, these schemes do not prioritise low-cost entrants, and scope would be expected therefore for cost-effectiveness improvements.

In this study, the cost-effectiveness of different farm types participating in the ESA scheme in Scotland was compared, with a view to determining whether there were potential gains to targeting management incentives by farm type. Farm types were defined on the basis of enterprise mix; the four predominant farm types in Scotland are Specialist Sheep (Less Favoured Area, LFA), Specialist Beef (LFA), Cattle and Sheep (LFA) and Mixed farms.

The cost of habitat management to the public exchequer was measured using data from the Scottish Executive Environment and Rural Affairs Department of reimbursements to farms participating in the ESA scheme. Average costs per hectare to the public exchequer were calculated for each category of farm type. The most important source of data on biodiversity used in this study was the environmental monitoring of the ESA scheme, jointly being undertaken by the Macaulay Institute and the Centre for Ecology and Hydrology. These data were used to calculate indices of baseline habitat quality for three habitats managed under the ESA scheme: heather, herb-rich grassland and wetland.

It was found that the largest farms in Scotland, belonging to the Specialist Sheep (LFA) category, incurred the lowest costs per hectare to the public exchequer. A major cost component in the ESA scheme is the fencing of habitats to enable stock control. Specialist Sheep (LFA) farms required significantly less fencing per hectare compared to other farms, accounting for their low cost of management. Low fencing requirements on these farms could be explained by either large perimeter to area ratios, or being more extensive systems, requiring less stock control.

Analysis of the environmental monitoring data revealed that there were significant differences in quality of habitat between farm types. Specialist Beef (LFA) farms had the highest plot-level heather biodiversity score and Specialist Sheep (LFA) farms the lowest. It is speculated that the Specialist Sheep (LFA) farms were most likely to utilise heather as a forage because they have the lowest proportion of in-bye land. Specialist Beef (LFA) farms also had the highest plot-level herb-rich grassland score. Mixed farms had the highest wetland habitat quality score, possibly explained by low stocking rates per forage hectare.

The potential gains to targeting biodiversity management incentives by farm type are illustrated here using Lorenz curves. These curves are used to calculate variability, measured as the area between the curve and a 45^{0} diagonal. The greater the variability (shown by the hatched area in Figures 1 - 4) in cost or biodiversity, the greater the potential gains to targeting high biodiversity and/or low cost managers.

In Figures 1 and 2, the data were analysed using the mean values of biodiversity and cost, respectively, for the four farm types. Variability here is rather small, and thus the gains to targeting by farm type are also rather small. In Figures 3 and 4, the data were analysed using the individual cost and biodiversity values for all 290 farms. Variability in this case is very great, and the potential gains to targeting are very great. The figures clearly show that, while there is much potential gain from targeting, this targeting should be according to a classification of farm unit that captures farm heterogeneity better than the farm type category used here.

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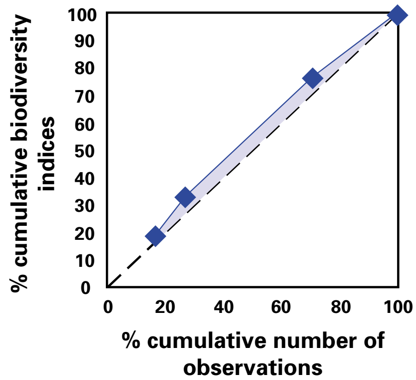

Figure 1. Lorenz curve of biodiversity of species-rich grassland, by farm type

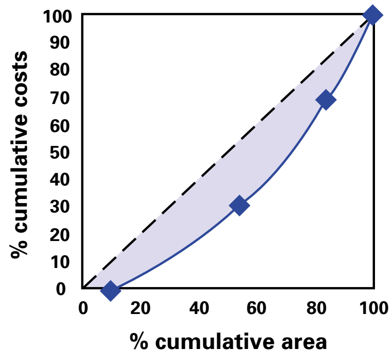

Figure 2. Lorenz curve of cost for species-rich grassland, by farm type

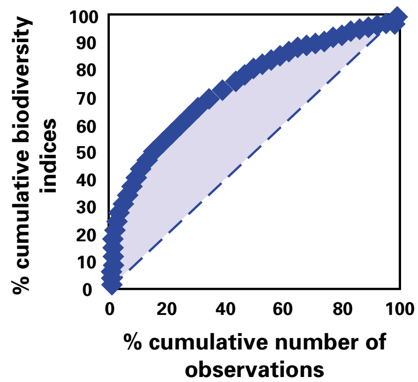

Figure 3. Lorenz curve of biodiversity of species-rich grassland, by individual farm

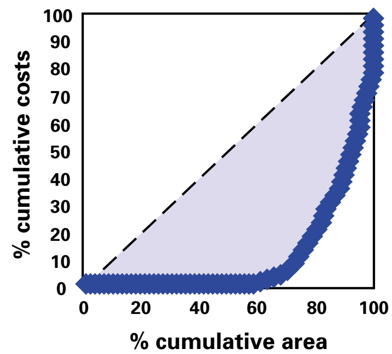

Figure 4. Lorenz curve of cost for species-rich grassland, by individual farm

The Impact of Farming on Biodiversity at the River Catchment Scale

Summary

The increasing productivity of agriculture and the progressive industrialisation of farming practices, particularly in the last 60 years, has caused losses and reductions of plant and animal species. These have occurred as a result of several changes to the way land is farmed:

* Marked reductions in the variety of non-farmed habitats, such as field boundaries, wetlands and moorland,

* Polarisation of agriculture into farms with either livestock or arable enterprises, hence the loss of traditional mixed farming, and

* Shifts to autumn tillage and greater dependency on artificial fertiliser application and pesticide crop protection instead of crop rotations.

The general detrimental effects on biodiversity have not been evaluated in an integrated study that takes account of landscape factors like land form and the proximity and area of remaining non-farmed land covers. It is important to assess whether these environmental factors, that may influence the distribution of wildlife at the landscape level, interact with agricultural management to modify the effects of farming on wildlife. A three-year collaborative study with the Scottish Agricultural College and the University of Glasgow used a field assessment of different wildlife species and the

Taxon	Fitted variables	Trend	R^2 value
Vascular plants	Aspect Penetrability of soil Inorganic fertiliser inputs Non-farmed habitat features	– + – –	0.65
Cryptogams	Soil pH within "500m radius" Land cover within "500m" Broadleaved woodland area within "500m"	– – +	0.76
Birds	Pesticide use Available phosphorus Broadleaved woodland area within 500m Number of land covers Land values within 375m	– – + – +	0.52
Ground Beetles	Slope Hedgerow plants Land cover change Plant species Crop cover within 875m	– + + + –	
Spiders	Altitude Plant species present Non-farmed habitat features	+ + –	0.70
All species	Inorganic fertiliser inputs Topography/exposure Hedgerow plants Pesticide use Boundary features	– – + – +	0.67

Table 1. Summary of regression models describing the distribution of biotic species in the Strathearn catchment according to soils, land form, cover and management

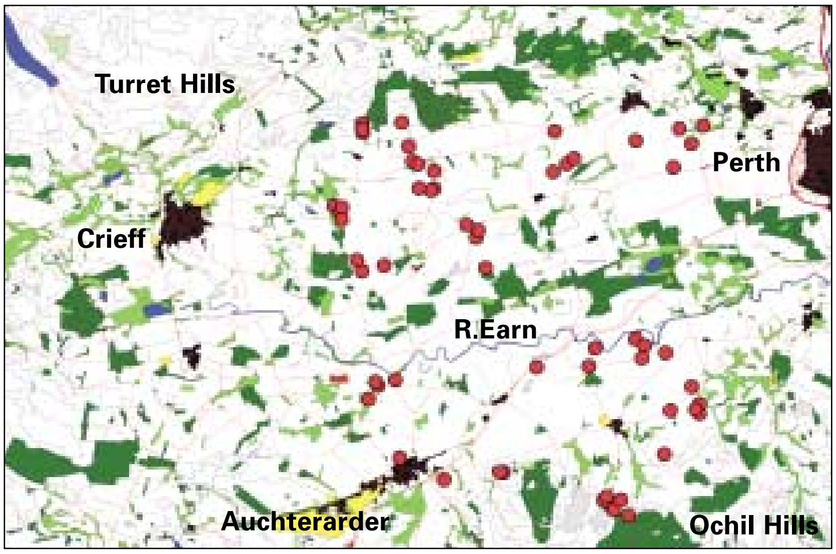

Figure 1. Strathearn study area illustrating the 61 locations where samples of plants, animals and soils were collected and land cover information was collated (red circles). Black - urban, yellow - recreation land, blue - water, light green - broadleaved and mixed woodland, dark green - coniferous woodland, grey - upland mosaics, white - arable and pastoral land

collation of environmental information for the lower River Earn catchment to assess these interactions. Computer-based modelling was used to measure the influence of farming or wider environmental influences on farmland biodiversity. These results were used to build a model that can estimate the changes in the distribution of species that could result from future changes in farming practices.

Context

Over many centuries, agriculture has continually altered the appearance of the countryside, and this has translated into changes in the distribution of habitats and wildlife (Rackham, 1986). In the latter half of the twentieth century, artificial fertilisers provided a means of maintaining soil fertility, synthetic herbicides and pesticides suppressed weeds, pests and diseases of crops and anthelmintics suppressed parasites of livestock in intensively grazed pastures. The size and power of tractors and the progressive mechanisation of all aspects of crop and grassland management allowed the rapid cultivation and harvest of crops by fewer farm workers. The outcome for wildlife has been detrimental in two respects. Field sizes have been increased to allow the efficient use of modern machinery, thus removing a large proportion of the boundaries composed of semi-natural habitats, that sustained many plants and animals in the farm landscape (Fry, 1991). The polarisation of the countryside into arable and livestock areas has also removed much of the traditional rotational management, and the shift to autumn tillage of cereals and oilseed rape, with increased reliance on agrochemicals, has also removed the broadleaved weeds, their seeds and arthropods (Wilson et al., 1999; Robinson and Sutherland, 2002) as resources for wintering "farmland" birds.

Little research has been carried out to evaluate the compound effects of these shifts in farming practices at the landscape scale. From 1998-2001, the Macaulay Institute, in collaboration with the Scottish Agricultural College and the University of Glasgow, carried out a project assessing the distribution of plants and animals across the lower River Earn catchment that is under predominantly agricultural land use (Figure 1). The objective was to measure and estimate the extent to which the distribution of farmland biodiversity was a direct product of agricultural management, as compared with the influence of landform and the proximity of non-farmed land covers (e.g., forestry and wetlands).

Data collection

Sampling of a range of biological taxa was carried out on representative agricultural land covers, replicated across the river catchment, to allow the analysis of the relative influences of land form and land use (61 independent sites in 1998-1999 and 14 new sites to test models in 2000). Standard field methods were used to survey vascular plants, cryptogams, birds, beetles and spiders. Data on land form and land cover were extracted from databases of land cover, soils and digital elevation, along with finer resolution data collected by field survey on arable and pastoral landcovers, field boundaries and remnant biotopes. Management data were collected from landowners and farmers for each of 75 fields where the biota were sampled.

Spatial modelling and GIS

A combination of data collation and extraction using Geographic Information Systems and the use of geostatistical tools and multiple regression models enabled the progressive development of models of the distribution of species in the river catchment. Effective and accurate multiple regression models were obtained for cryptogams, vascular plants, ground beetles and spiders, less so for summer birds, when using a combination of field and wider environmental variables (Table 1, page 39). The predictive accuracy of these models was generally maintained when spatial interpolation was used to obtain an indication of the species numbers of these taxa across the river catchment (e.g. Figure 2d).

Findings

The research has developed a model to express biodiversity at the river catchment scale, based on agricultural and other land covers, and land form. The model was used to estimate the effect on farmland biodiversity of different scenarios of change in agriculture. This can allow an assessment of the compatibility of changes in agricultural land cover, necessary to maintain a viable agricultural sector, with the sustainability of the natural heritage function of agricultural landscapes.

A scenario of change was based on trends evident from the annual agricultural census, 1970-1990, and a linear extrapolation of those trends. The results of this scenario suggested a modest increase in general species diversity in the river catchment between 2000 and 2020 after a prolonged period of general decline in species across the river catchment since 1970 (Figure 2). Figure 2 illustrates the modelled changes for the combined taxa of cryptogams, vascular plants, ground beetles, spiders and birds over a 50-year period. The changes are a function of increases in alternative crops, set-aside and farm woodland and an equivalent reduction in sheep-grazing and spring barley, the traditionally dominant agricultural land covers of the area under the initial period of the Common Agricultural Policy. The scenario used in this example demonstrated the resolution of the estimates of species diversity at the landscape scale. It shows that the reversal of the trends in species loss which occurred between 1970 and 1990, particularly in lower altitude areas, will proceed at a slow rate from 2002 to 2010. However, there are a number of assumptions in the model for example that the factors, that were significantly associated with variability in species diversity across the catchment in 1998 and 1999, were of equal importance before that time and will maintain their importance into the future.

The next stage of the research is to validate the model with data derived from other catchments in Scotland. In general terms, the model has made an important contribution by indicating the general direction of the response of biodiversity to agricultural land use, as well as determining the magnitude of the effects of land use compared with physical environmental factors. As such, it represents a helpful tool to explore the response of wildlife species to the rapidly changing agricultural systems of the early twenty-first century.

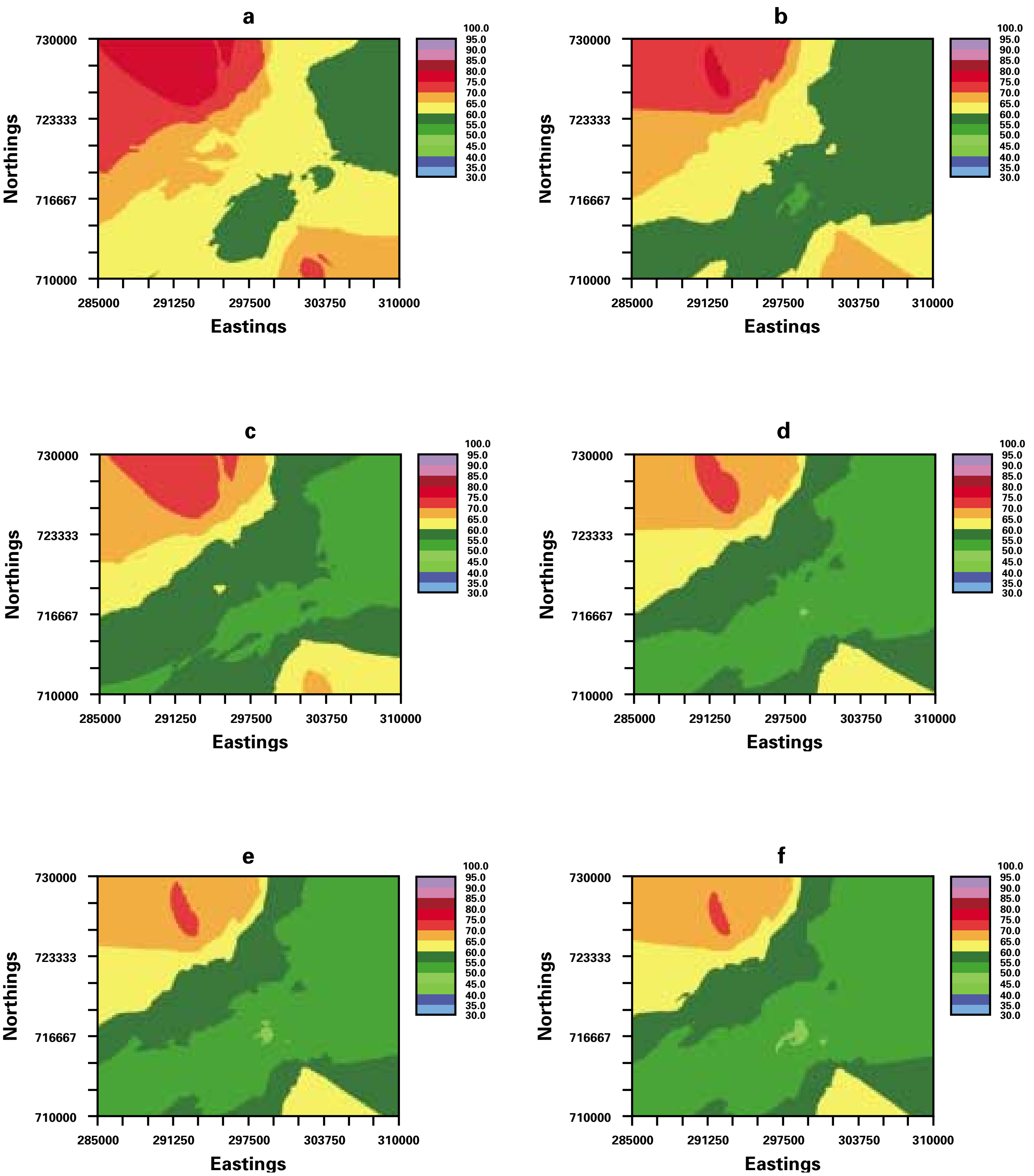

Figure 2. Estimated distribution of species of combined taxa (cryptogams, vascular plants, ground beetles, spiders and birds) on agricultural land in Strathearn 1970-2010 derived from the multiple regression and interpolation models. The scenario used trends in the June agricultural census data 1970-1990 and a linear extrapolation of those trends in 2010 and 2020 (a - 1970, b - 1980, c - 1990, d - 1998-1999, e-2010 and f - 2020). The colour spectrum blue to white reflects 30 to 100 species with intervals of 5 species

References

Fry, G.L.A. (1991). Conservation in agricultural ecosystems. In: I.F. Spellerberg, I.B. Goldsmith and M.G. Morris (eds) The scientific management of temperate communities for nature conservation. Blackwell Scientific Publications, Oxford.

Rackham, O. (1986). The history of the countryside. Dent, London.

Robinson, R.A. and Sutherland, W.J. (2002). Post war changes in arable farming and biodiversity in Great Britain. Journal of Applied Ecology 39, 157-176.

Wilson, J.D., Morris, A.J., Arroyo, B.E., Clark, S.C. and Bradbury, R.B. (1999). A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. Agriculture, Ecosystems and Environment 75, 13-30.

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Community Involvement in Catchment Management – the Example of Tarland

Summary

The Tarland Catchment Initiative has been put in place to develop and implement an objective strategy for the sustainable use of this small catchment of the River Dee and to improve the quality of the catchment's riparian water resources and the habitats that they can support. The Macaulay Institute is part of the steering group for the project along with the local estate, Scottish Environment Protection Agency, Scottish Natural Heritage and other organisations involved in the management of the River Dee. The Institute provides expertise on land management and its effect on water quality. A participatory approach is being taken, involving the whole of the local community to access the aspirations and knowledge of local stakeholders. An improvement plan has been drawn up which involves a mixture of low cost modifications to existing land management strategies and a programme of 'soft' engineering. The Initiative may act as an exemplar for the management of catchments in relation to achieving the EU Water Framework Directive's objectives.

Context

The Tarland catchment is a tributary of the River Dee in N.E. Scotland. Within the catchment there are a range of land use types. On the upper slopes heather moorland gives way to plantation forestry and fields in which beef cattle and sheep are grazed. Interspersed between these grass fields are fields of barley.

It is this mosaic of land uses, a historical legacy of land improvement and increased intensity of management, that has increased the pressure on maintaining high levels of water quality within the catchment of the Tarland Burn. There are over 15 individual tributaries which drain the area and this network of streams measures in excess of 50 kilometres. The tributary is particularly important as it is the most westerly area of the River Dee which contains both intensive agriculture and associated population settlements. Initial assessments of water quality, and of the aquatic and riparian habitats across the catchment, suggested that there is considerable potential to improve these aspects of the local environment.

Against this background a number of organisations and individuals have come together to create what, to date, has been called the Tarland Catchment Initiative. The membership of the consortium steering group consists of the MacRobert Trust Estate, the Macaulay Institute, Scottish Natural Heritage, Dess and Aboyne Water Project, the national regulatory authority (Scottish Environment Protection Agency, SEPA) and the North East Rivers Project. The aim of the Initiative is to advise and implement an objective strategy for the sustainable use of the catchment and to improve the quality of the catchment's riparian water resources and the habitats that they can support. The initial focus of the Initiative is to reduce the impact of high concentrations of suspended soil sediments and coliform bacteria in selected streams.

Participatory approach

An important element of the work is that it should be participatory and include not only the aspirations and views of the local stakeholders but also actively utilise and build on their knowledge and experience of the catchment. To achieve an improvement an approach based on assessment, implementation and post-implementation assessment is being undertaken.

Work, undertaken by the Macaulay Institute, has started on the assessment and evaluation of water quality in relation to the habitats found across the catchment. In terms of the fisheries status the consortium has been fortunate in the input and support from both the Dee Salmon Fishery Board and the Dess and Aboyne Water Project. The Dee Salmon Fishery Board has undertaken a number of electrofishing surveys within the catchment, whilst the Dess and Aboyne Water Project is providing background information on habitats.

The improvements that are proposed by the Initiative are largely based on simple, low-cost modifications to existing land management practices. In relation to riparian management it is hoped to test four improvement strategies. These are: fencing, tree planting, soft engineering and restocking. The programme of improving existing fencing will be undertaken to allow the stabilisation of bankside vegetation and regeneration of shrubs and tree cover. In addition fencing should reduce coliforms from faecal material and sediment input from cattle poaching. A further potential treatment will be the creation of tree cover within the buffer strips through a replanting programme. The establishment of trees should provide an opportunity for cattle shelter, enhanced nutrient uptake and reduction of excess nutrient loss from susceptible areas of fields to the rivers. In addition, trees will increase and enhance both riparian and aquatic habitats through the provision of shade and shelter and a supply of invertebrate food for birds, fish and other wildlife.

In order to achieve further improvements, particularly associated with suspended sediments, a programme of 'soft' engineering is being considered. This will consist of the creation of small-scale ephemeral wetlands which will be allowed to flood during high river flows. These flood features would act to lessen the available energy for carrying suspended sediments which, in turn, would be deposited and trapped in the wetlands created. All of the improvements suggested will utilise practices promoted in the SEPA's Habitat Enhancement Initiative. Finally, further evaluation of the improvements, relative to an unimproved control stream, is being made by a programme of restocking with native, hatchery-reared salmonids.

In order to maximise the potential benefit to both land managers and those affected by the state of the river and riparian zone, a programme of consultation and participation has been a key feature. The specific aim of this consultation process is to utilise local knowledge and skill in deciding the best management option to alleviate local problems arising from, for example, sediment inputs. Similarly it is envisaged that, where measures such as tree planting are suggested, it will be possible to combine both the need in the riparian areas (as a provider of shade, food and habitat for wildlife) with that of land management (in providing shelter for cattle). It is through the use of local participation that the best sites for achieving success for these different uses can be selected.

The specific aim of this consultation process is to utilise local knowledge and skill

Throughout the Initiative, the educational opportunities for land managers, the local schools and the wider general public are being exploited in order to demonstrate the range of environmental benefits arising from the programme of work. In part it is planned that this will be achieved through the creation of increased access to river and stream banks where sign-posted boards will explain the works being undertaken and its features which the Initiative are trying to promote. In addition, it is planned that occasional hands-on projects will be arranged in which children and adults will participate in some of the work involved. Furthermore a summary of the approach, methods, data and results used by the Initiative will be published both in a report and on the internet in order that other initiatives may benefit from the experience gained.

Future

The Initiative is a relatively new venture, having been established in May 2000, but it has already attracted funding from the North-East Rivers Project in order to act as a demonstration project. In the future it is planned that the Tarland Initiative will work closely with the plans being developed for the management of the River Dee catchment. In the context of the EU Water Framework Directive, and its focus on management at the catchment level, and the need to involve local communities, the approach taken in the Tarland Initiative could be a forerunner of similar initiatives to ensure delivery of the objectives of the Framework.

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Tracking Animals with GPS

Dr Angela Sibbald, Macaulay Institute, hosted the first international conference on the use of Global Positional Systems for tracking animals at the Institute in March. Over 50 delegates from 17 countries around the world gathered to hear about research using satellite tracking technology to study the movements of free-ranging animals.

25 T B Macaulay Lecture

Professor Chris Pollock, Director of Research at the Institute of Grassland and Environmental Research, Aberystwyth gave the 25th T B Macaulay Lecture entitled "21st century agriculture: if new technology is the answer, are we asking the right question?"in May. The lecture was followed by a Discussion Forum on "Will the use of GMO technologies be positive or negative for our environment?"

Anne Begg, MP

Anne Begg, MP for Aberdeen South, visited the Institute in August and spent time discussing the Institute's educational programme.

2001

International Science Exhibition

Visitors to the Macaulay Institute display in the exhibition hall at the Royal Botanic Garden in Edinburgh in April enjoyed the many different attractions on offer. Visitors, young and not so young, were fascinated by the satellite technology, the computer visualisation techniques and the competitions.

HIBECO workshop

Over 40 scientists from across Northern Europe met at the Institute in June for a coordination group meeting of the EC project "Human interactions with the mountain birch ecosystem". The project focuses on the impact of human activity and environmental factors on the mountain birch forest ecosystem.

Aberdeen Techfest 2001 Schools Programme and Exhibition,

A workshop based on Dr Miller's Toolkit for Countryside Change was taken to different schools in Aberdeen in September.

Management Team and Board of Governors

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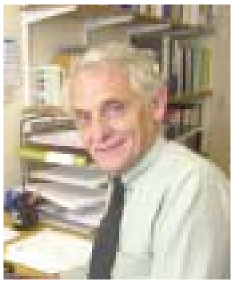
Director

Prof John Milne
Deputy Director

Mr David Murdoch
Head, Finance and Administration

Dr Dick Birnie
Spatial Planning and Renewable Resource Use



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Dr Bob Ferrier
Catchment Management

Prof Iain Gordon
Animal Ecology

Prof Pete Millard
Soil Plant Microbial Interactions

Prof Robin Pakeman
Plant Ecology

Prof Clive Spash
Socio Economics

Director Maggie Gill (front, second right) is pictured with Board of Governor members and the Management Team

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