THE MACAULAY INSTITUTE

RESEARCH TODAY FOR LAND USE TOMORROW

Annual Report **2002**

THE MACAULAY INSTITUTE

ANNUAL REPORT 2002

  

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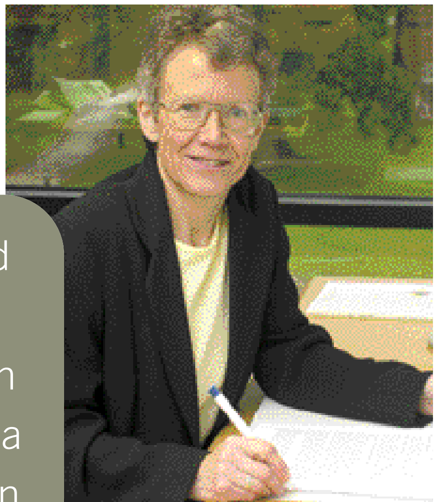
DIRECTOR'S INTRODUCTION

Professor Margaret Gill

Assessment of performance has become an accepted part of professional life: performance indicators abound and in most cases they have multiple targets. Along with the other research organisations sponsored by the Scottish Executive Environment and Rural Affairs Department, the Macaulay Institute is assessed in terms of Quality of Science, Knowledge Transfer and Exploitation and End-user Relevance. The Assessment process began in 2002 and, for the Macaulay Institute, was concluded in early 2003.

Development of a 'Vision' for the Macaulay was part of the preparation process and this was informed by an 'Away-day' allowing time for our researchers to consider the relevant policy documents emanating from the Scottish Executive. The 'Forward Strategy for Agriculture' and 'Custodians of Change' provided important building blocks for our Vision, with their recognition of the need 'for a more joined up approach to policy'. We believe that the Macaulay can contribute to this 'joined up approach', by providing integration across components of our environment (water, land, animals and people), based on scientific understanding.



it helps us to understand (and forecast) how management decisions in one small area can have a much greater impact than is initially visible

So what can scientific understanding contribute to policy development? Our understanding starts from research into the processes which affect our land. The landscapes that we see around us are the direct result of chemical, physical and biological processes (often instigated by the actions of humans) which have taken place in the rocks, soil and vegetation, which appear to be the more static parts of our environment. Yet dynamic processes are going on within the soils and vegetation and the diversity below ground (in terms of microbial species) is numerically greater than the diversity above ground. Understanding the factors which affect the speed and nature of these processes and the functions of the different microbial communities is part of the strategic science undertaken at the Macaulay Institute. This science, at and below ground level, is mirrored by similar studies above ground. The dynamics of both individuals and populations of animals in their interactions with the vegetation are studied and as this knowledge increases, it helps us to understand (and forecast) how management decisions in one small area can have a much greater impact than is initially visible.

Management decisions themselves, however, are also part of a complex process. One of the drivers is certainly policy, but within policy frameworks, individual farmers or estate owners may adopt very different strategies. It may never be possible to predict how specific individuals might react, but understanding the factors which affect decision making (see p10) and how the relative importance of these factors may change with time, can help us to understand the impact which future policies may have both on rural communities and the environment. During 2002, the number of social scientists in the Institute doubled, from 9 to 18. This demonstrates our continued commitment to our mission: 'To be an international leader in research in the management of rural land resources for the benefit of people and the environment'.

So where does the integration come in? It comes in at all levels. We integrate our knowledge of grazing, with our knowledge of plant growth. For example, the impact of defoliation on the exchange of nitrogen between plant and soil, to help to determine the productivity of both semi-natural grassland systems (p14) and how the chemical composition of plants can 'teach' animals to avoid ingesting feed which is bad for them (p18). At this level though, integration is providing us with knowledge to help the development of policies and management strategies of the future.

Two of our Science Areas (Landscape Change and Catchment Management) focus on integration which is of more immediate relevance to two policies in particular: Reform of the Common Agricultural Policy (CAP) and the Water Framework Directive. In the article on p23 we describe a toolbox, developed to provide information to those interested in the potential benefits of silvopastoral systems and on p26 we report on the extent to which reductions in numbers of grazing animals can change the composition of plant communities in grasslands. Decreases in stocking density and the planting of trees are both practices which may become more common with the potential changes which may result from CAP Reform. These two articles are examples of how knowledge from research has practical relevance for land managers. Similar examples exist for our research relating to the Water Framework Directive, although the third article presented in this section is taken from a report specifically commissioned by the Scottish Executive to quantify both the economic and environmental impact of surface water abstractions (p29). This study, undertaken in partnership with a consulting company, illustrates an important way in which the knowledge generated through our research can help to inform policy. Institute staff undertook 100 consultancy contracts during 2002, meeting the needs of over 50 customers. Many of these consultancies are undertaken in partnership with other public or

Headquarters at Craigiebuckler, Aberdeen private sector organisations. Through this work, our research reaches a much wider group of end-users than might initially be envisaged. During 2002, there was a very significant growth in analytical services provided to the oil and gas sector (turnover of ~£500,000) and this contributed to a healthy profit (£230,000) for our consultancy company, which will be 'recycled' through the Macaulay Development Trust, back into research.

The third section of our report gives examples of other end-users of our research. The article on p33 illustrates the use of a chemical modelling tool designed to study the behaviour of soil contaminants. This tool was applied in practice to a site contaminated with chromium and to test the efficacy of various remediation processes. This is followed by an article which draws attention to the way in which modelling skills at the Macaulay can be used to interpret existing data sets to predict environmental risks (p36). With recent advances in Information Technology, there is ever increasing potential to integrate data-sets and provide outputs in map format. The importance of maintaining and upgrading datasets is increasingly being recognised and we are developing a policy within the Macaulay to make the datasets which we hold more easily accessible for research and policy purposes. The final article (p39) describes the application of farming systems research in Kazakhstan, in Central Asia. This research is funded by both the UK Government's Department for International Development and the European Commission and illustrates how the knowledge generated in our core programme can be transferred to a wider audience using additional sources of funding.

knowledge generated through our research can help to inform policy

This report gives readers a flavour of our research, our commitment to transferring the knowledge generated into practice and the relevance of our research to end-users, thus enabling you to judge for yourselves whether we are successful. As far as the SEERAD assessment process went, the external Group fully supported our vision and 'strongly endorsed the interdisciplinary approach that characterised the Institute's research'. The Group considered that the Institute 'was addressing highly relevant issues and was well positioned to meet the needs of end-users especially policy makers', but advocated that more attention be paid to interacting with land managers. Identifying how best to achieve this, in partnership with others, is one of the key targets for the current year.

In summary, both the assessment process and the report have provided much food for thought as to how we can enhance both the quality of our research and our effectiveness at knowledge transfer. It was gratifying that the Group recognized both the innovative nature of our interdisciplinary approach and the distinctive contribution which the Institute can make within the UK science base. I am personally very grateful to all staff of the Macaulay, for their commitment to the Institute, their hard work and for making it a great place to work.

Professor Margaret Gill

December 2003

RESEARCH ADVANCES

Photo taken by Rachel Helliwell, Macaulay Institute

The research advances from 2002 that are included help us to understand more about the decisions that are taken by farmers, the use of nitrogen by grasses and the ways in which grazing animals learn to select their food.

Agricultural development in Scotland: the influence of the changing social structure of 'family farms'.

Rob Burton

• Summary

While market pressures are increasingly reducing the economic viability of smaller farms in general, family farms have survived and continued to be an important component of agriculture in Europe. One important factor in ensuring this is the commitment and loyalty of the family farm unit. The flexibility in the labour supply it provides and the ready participation of family members enables farm families to respond rapidly to changing economic and environmental situations. Results from a preliminary survey of farms in the north-east of Scotland have demonstrated the important role of voluntary labour by offspring and retired parents in supporting the current enterprises and structure of family farms. The focus of planned research will be on understanding future agricultural change from the perspectives of family members who live off the farm but continue to be an integral part of the family farm unit.

• Context

Since the development of agriculture the family farm has been the dominant form of farm management. Farmers from the Ancient Egyptians to the pre-Columbian Indians have managed agriculture through family-based organisational units. In Scotland, as elsewhere in the UK and Europe, family farms continue to dominate the farming landscape. However, like the rest of Europe and, in fact, as part of a more global trend, agriculture in Scotland is going through a period of change that is likely to test the resilience of the family farming system. As a result of political and economic changes in agriculture (such as the increasing control of supermarkets over the commodity chain and increasing globalisation of the market system) farming is going through what Lobao and Meyer (2001) describe as an 'agricultural transition', which they define as:

"the abandonment of farming as a household livelihood strategy. This transition is evident both in the mass decline of the farm population and in the structural transformation of agriculture, whereby most remaining farms are marginal units incapable of fully employing and sustaining families."

Photo taken by Paula Horne, Macaulay Institute

While there is little debate that this process is ongoing it is also widely recognised that there is a substantial amount of resilience within the family farm system. This is a feature which has enabled it to maintain dominance over corporate farming over the past 200 years despite predictions that it should readily succumb to corporatisation like almost every other industry in the developed economies (Marsden et al., 1989). Reasons suggested for this include the seasonality of agriculture and uncertainty of climatic conditions making it unsuitable for corporate organisation (Simpson et al., 1992), the advantages of continuity and experience (Hutson, 1987), and, importantly, the ability of the family farm to exploit its own labour supply through family loyalty and commitment (Gasson et al., 1988; Marsden et al., 1989). Thus, while market pressures are increasingly marginalising smaller farms, family farms through their flexibility in labour supply, accumulated knowledge of farming and the ability to cope with seasonal fluctuations in profit levels have managed to survive where neoclassical economic models suggest they should not. The key to this survival is the adaptability of the system and, as with any system that requires adaptation to survive, family farming must thus continually evolve to keep up with the wider structural changes in the industry.

family farms in Scotland are adapting to the current condition of the agricultural industry

Study of the social structure of family farms

Results from a preliminary study of 30 farmers undertaken around Huntly, Aberdeenshire, in February and March 2002 have suggested that family farms in Scotland are adapting to the current condition of the agricultural industry. As part of the Macaulay Institute's programme of research to develop effective models of land use change, this largely qualitative survey was designed to obtain a first impression of what may constitute the major drivers of land use change in the area. While much thinking has been concerned with changes in the structure of the family farm from the perspective of its social impacts, the impact of social change on land use has been largely ignored. Yet, because of the dependence of the family farm on the control of its own labour supply, changes to the family farm social structure can have substantial impacts on the availability of labour and, through the dependence of agricultural systems on labour, on the ability of the farm to maintain land uses with higher labour requirements.

While family farms around Huntly, as with the rest of the UK, have seen increasing numbers of spouses taking off-farm jobs, the main area of structural social change within the family has been instituted by farmers' approach to the question of succession. Traditionally, because of the strong social importance attached to keeping the family name on the farm (Marsden et al., 1986) and in not being seen by other full-time farmers as engaged in anything outside farming (Bartlett, 1986; Burton, 2003), farmers have encouraged their children (usually the eldest son) to remain in agriculture. However, this situation has been steadily changing over the last two decades. In a study in Wales, Hutson (1987) found in the mid-1980s that farmers were no longer encouraging their children to leave school early to work on the farm. In the Huntly study, far from simply not encouraging children to leave school early, the majority of farmers were actively encouraging their children to pursue an off-farm career before deciding whether to return to the farm. The sort of approach commonly advocated by those farmers with children yet to enter the farm is typified in the following responses:

" … the way it is just now, I wouldn't encourage it … I wouldn't stop him if he wanted to do it, but I would probably advise him to do something else for a while." (Mr D)

"No, I will let him do whatever he wants but I won't actively encourage him." (Mr M)

"I would try and discourage him. I would say get some education first, either University or learn a trade and get something behind him and then if he was to come back maybe 10-12 years time, then he can come back if he wants." (Mr A)

"The younger one would have been keen but I actively discouraged him, because I couldn't see the future for the family farm. He works mostly in Norway now. The boys left school, went to University and got their degrees." (Mr B)

[1] Hutson (1987) defines the family farm as "one in which the business principals, their successors and heirs are related by kinship and/or marriage. It is a business in which the members of the management team, if not the workforce, are related."

The result of this approach has been that the vast majority of farmers' children live and work outside the farm boundaries after leaving school – many, for example, in the oil industry in Aberdeen.

In addition to discouraging children from remaining on the farm, the economic pressure that family farms are under has meant that, in order to maintain the existing land uses (predominantly mixed livestock/barley systems in this case), farmers require the labour of not just the potential successor, but also of other children working off the farm and from their elderly retired parents. This is particularly problematic given that at certain times of the year (e.g. lambing, calving and at harvest) agriculture experiences peaks in demand where labour availability becomes a critical factor (Errington and Gasson, 1996). According to McCrostie-Little et al. (1997), the advantage of utilising this source of labour is that "children returning to the farm may be unpaid or paid less than the rates for hired labour, and thus their labour contribution could help ensure the survival of a family farm whose viability was marginal." The failure of these sources to provide labour on the farm can have implications for land use, in that the farmer – where he/she is unable to afford/find hired labour – may have to change the existing system for one which is less labour-intensive. For example one farmer suggests that without the voluntary labour from his son and father:

"I wouldn't be able to run it the way I am at the moment. I would have to reduce the stock. Certainly the breeding sheep – I start lambing in March and that is a lot of work - I would have to change that, whether I would move into buying store lambs and fattening them or something along that line." (Mr S)

Other examples of the impact of a reduction in voluntary labour include: a forced reduction in the size of a suckler herd; two cases where a change from turnips to silage production was precipitated by the loss of voluntary labour and two cases where, in the anticipation of losing voluntary labour, farmers are planning an unspecified simplification of the farm system to suit management by one person. With many farmers now encouraging their children not to enter the agricultural business this problem is likely to be exacerbated in the near future. Changes in the social structure of the family farm can thus provide a real driver for land-use change in Scotland.

It may be suggested that reliance on voluntary labour is simply a continuation of the principle of the traditional family farm but if we use Hutson's definition of the family farm as one based on the kinship relationships of the management team, clearly the use of (and often reliance on) voluntary labour from outside without management responsibilities represents another stage in the development of the family farm. Payments to the children, if any, were generally not in the form of wages, but rather payment in kind through, for example, an additional Christmas present. Some farmers even noted that the children perform the farm tasks simply because of the enjoyment that they get from using farm machinery or working with the animals . For example, Mr P suggested that his children are not 'working' on the farm despite doing most of the field work because:

"The work they're doing they only have to sit in a tractor and enjoy themselves – that's all it is. They're just enjoying themselves."

This informal and often intrinsic form of reward is perhaps one of the reasons that none of the farmers considered this form of labour worthy of recording in the June Census figures (which fail to record voluntary labour independently). Research into the contribution of voluntary labour sources is scarce (particularly that of farmers' children – McCrostie-Little et al., 1997) and, what there is, tends to be based around feminist discourse on the role-based exploitation of the farmer's wife as an unpaid labour source on the farm (e.g. Whatmore, 1991). Thus there is considerable scope for investigating the role of voluntary labour in supporting the family farm.

Future directions

At the moment most farmers in the area of the study appeared to have sufficient labour to draw on to maintain at least the core of their existing systems. One critical question that must be asked in the future, however, is what will happen to land use if this supply of voluntary labour is exhausted? At the moment most farmers' children have direct experience with working on/growing up on the farm and it is these children who are returning to the farm to work. However, their children are likely to grow up in an urban environment with neither an attachment to agriculture, nor the skills to simply return to the farm to undertake farm labour. Thus, even if the second generation was to return to the farm having worked in the city for years, the third generation may not have the same aspirations or skills. This raises a number of research issues for the future. Is an agricultural system reliant on voluntary labour sustainable in the long term, or is it simply a transitory stage? What will happen to the agricultural industry and the countryside in general when (or if) the next generation of farmers from non-farming professions succeed to the farm as part-time farmers as their parents hope? Another major area of interest is how the changing labour structure of the family farms currently influences land use choices and the prospects of the farm for non-agricultural rural development? Furthermore, if farmers are not recording voluntary labour on the June Census forms and yet it is a critical component of farm labour supply, will this negatively affect the ability to forecast land use change?

The potential importance of such questions will be explored in planned research. As a preliminary qualitative investigation the Huntly study points to voluntary labour as an important issue, yet to fully understand the processes involved and its potential implications requires both a refinement of the research approach and further quantification. Studies of agriculture in the UK almost inevitably focus on the existing farmer him/herself. We propose to begin this research by focusing on the perspectives of the children of farmers – both those who are potential successors and those who contribute to the voluntary labour supply without the objective of succession. Through learning how farmers' children perceive their contribution to the existing farm structure and the potential development of the farm, we hope to make advances in our understanding of the future development of Scottish agriculture.

"The work they're doing they only have to sit in a tractor and enjoy themselves – that's all it is. They're just enjoying themselves."

Acknowledgments.

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Nitrogen dynamics in grasses.

Barry Thornton

• Summary

New tissues of grasses can obtain the nitrogen they require for growth from two possible sources, current root uptake and mobilisation of stores. The ability to store, mobilise and subsequently reuse nitrogen can contribute to the competitive fitness of grasses. These processes are, therefore, likely to be an important factor in determining the species composition and productivity of grasslands. Using steady state ^{15}N labelling techniques, our research has shown that in intact grasses mobilisation from older leaves provides the majority of nitrogen for the initial growth of new leaves in spring. Mobilisation also provides nitrogen for leaf growth when a plant is defoliated for the first time, but it provides less nitrogen when the plant has been subjected to repeated defoliation.

In undefoliated grasses, roots do not normally act as a source of mobilised nitrogen for growing leaves but they do become a source following severe defoliation. We have shown that such mobilisation can occur independently of any leaf damage and down-regulation of nitrogen uptake. Also for the first time we have shown that only the older roots of a grass contribute in supplying mobilised nitrogen. The future challenge is to develop techniques to quantify the nitrogen dynamics of plants under field conditions.

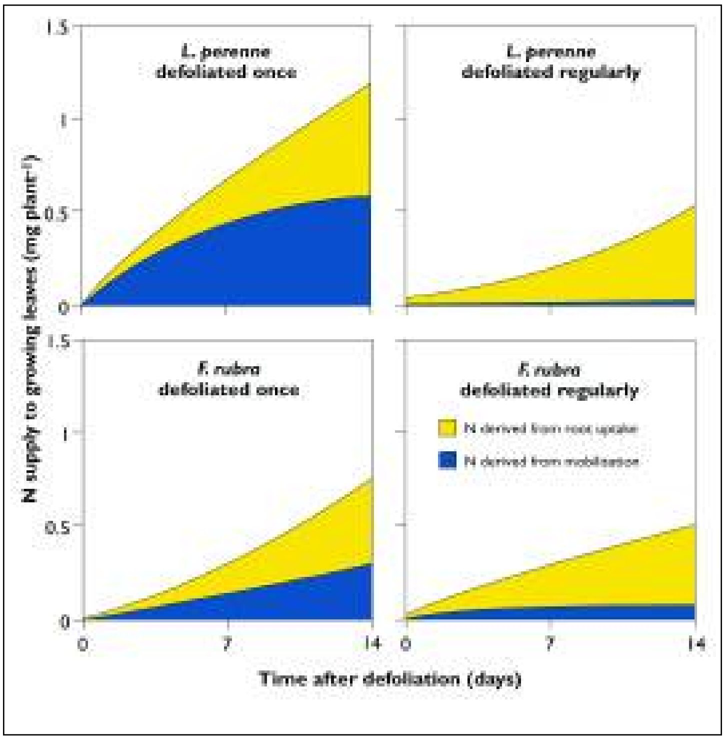

Figure 1: The nitrogen supplied to the growing leaves (mg plant^{-1}) of plants of Lolium perenne and Festuca rubra by root uptake (yellow) and mobilisation (blue) over a 14 day period following defoliation. Plants were subject to either a single or repeated defoliation.

• Context

Grasses form an important part of the landscape in many countries; for example they are the major vegetation component of 25% of the land cover of Scotland and form a minor component on an additional 8% (Land Cover of Scotland, 1988). No matter where in the world grasses are abundant, be it on the savannah plains in Africa or on a Scottish hillside, they are commonly subject to defoliation by grazing herbivores.

Within Europe nitrogen inputs to temporary and permanent grassland have been reduced as agriculture moves to more extensive management, whilst in many semi-natural ecosystems nitrogen is often the limiting nutrient for the growth of plants. Consequently many plants, including grasses, have developed mechanisms by which, following nitrogen acquisition, they can achieve efficient use of this nutrient. Indeed, the ability to store, mobilise and subsequently reuse nitrogen has been suggested as an important contributor to the competitive fitness of grasses especially under nitrogen-limited conditions (de Aldana and Berendse, 1997).

The dynamics of nitrogen within both intact and defoliated grasses is, therefore, an important factor in determining the plant species composition and productivity of both managed and semi-natural grassland systems. The Macaulay Institute, in collaboration with international partners, has used a range of techniques including steady state ^{15}N labelling to gain an understanding of the dynamics of nitrogen.

Steady state ^{15}N labelling.

Two stable isotopes of nitrogen exist, ^{14}N and ^{15}N. The natural abundance of the two isotopes is such that only 0.366 % of the nitrogen atoms are ^{15}N, the remaining 99.634 % being ^{14}N. In a typical steady state ^{15}N-labelling experiment, grasses are grown with all nitrogen supplied at natural abundance (^{14}N, unlabelled nitrogen), then at a specific time point, time zero, the nitrogen supply to the plants is switched to one enriched with ^{15}N (labelled nitrogen), or vice versa. Coupling this with a series of destructive plant harvests and subsequent analysis by isotope ratio mass spectrometry (IR-MS) allows the nitrogen dynamics of both intact and defoliated grass plants after time zero to be established. Mobilisation of stored nitrogen, already present in the grass at time zero, from "source" to "sink" compartments and the partitioning of nitrogen taken up by the roots after time zero can be determined (see Thornton et al., 2002).

Figure 2: Plants of a tropical grass, Panicum maximum, one day after being defoliated at a range of severity. Numbers indicate the proportion of leaf area removed.

N dynamics in intact grasses.

Using the steady state ^{15}N labelling technique described above, we have established the seasonal dynamics of a range of intact grasses. Molinia caerulea is a deciduous grass widespread throughout upland Scotland. The only organs of this grass in winter are the root system and swollen basal internodes with attached buds. New shoot growth in spring develops from the buds attached to the basal internodes. In spring the nitrogen required for the initial shoot growth is primarily supplied by mobilisation from the roots and the basal internodes. Later in the season root uptake from the soil becomes more important in supplying nitrogen to leaf growth. Later still in autumn, nitrogen is withdrawn from the senescing leaves back to the roots and basal internodes (Thornton and Bausenwein, 2000; Thornton and Millard, 1993). However, most grasses found in temperate regions are evergreen in nature, possessing some leaves at all times of the year. In these grasses mobilisation also provides the major source of nitrogen for leaf growth in spring. In intact plants of both Agrostis capillaris and Festuca rubra, two evergreen perennial grasses, nitrogen mobilised from older senescing leaves provides the majority of nitrogen for the initial growth of new leaves (Bausenwein et al., 2001). A feature of intact evergreen perennial grasses is that the roots generally do not act as a source of mobilised nitrogen for shoot growth (Bausenwein et al., 2001; Santos et al., 2002; Thornton et al., 2002).

N dynamics in defoliated grasses: the influence of shoot morphology.

As in intact plants, both current root uptake and mobilisation of stores are used to supply nitrogen to growing leaves in defoliated grasses. We have shown that following defoliation, the amount of growth that leaves achieved was positively related to their total nitrogen supply from both uptake and mobilisation. However, the degree to which each source was used was dependent on the previous defoliation history. In both Lolium perenne and F. rubra plants, which had previously been regularly defoliated, far less nitrogen was mobilised to the growing leaves than for plants defoliated for the first time (Figure 1) (Thornton and Millard, 1997). Two different scenarios can explain these results: (1) in regularly defoliated plants each previous defoliation had reduced the store of nitrogen potentially available to be mobilised, and (2) the shoots of regularly defoliated plants had become morphologically adapted such that when cut to a set height these plants were defoliated less severely, thereby inducing less nitrogen mobilisation than when plants were defoliated for the first time.

One means of determining which scenario is correct is to establish the relationship between the proportion of leaf removed by defoliation and the amount of nitrogen mobilised to the remaining growing leaves and to see how this relationship alters as the plant shoots are regularly defoliated and become morphologically adapted. If the first scenario is correct, the plants previously defoliated regularly and morphologically adapted will mobilise less nitrogen to leaves than plants defoliated for the first time, irrespective of the severity of defoliation.

In collaboration with colleagues at the University of São Paulo, Brazil, the relationship between proportion of leaf removal and nitrogen mobilisation was initially established in a tropical grass, Panicum maximum, with large leaves (Figure 2). As the proportion of leaf material removed increased, the ability of remaining expanded leaves to act as a source of nitrogen for growing leaves decreased (Figure 3). The total supply of mobilised nitrogen to the two youngest growing leaves was, however, maintained; this was mainly achieved through a change in root behaviour. In common with temperate grasses, roots of P. maximum did not act as a source of mobilised nitrogen in intact plants. However they switched from being a net sink to become a net source of mobilised nitrogen as the severity of plant defoliation increased (Figure 3). How this relationship between root functioning and defoliation severity alters as plant shoots become morphologically adapted to previous defoliation is currently being investigated with colleagues at INRA-Lusignan, France using two genotypes of L. perenne of contrasting leaf length.

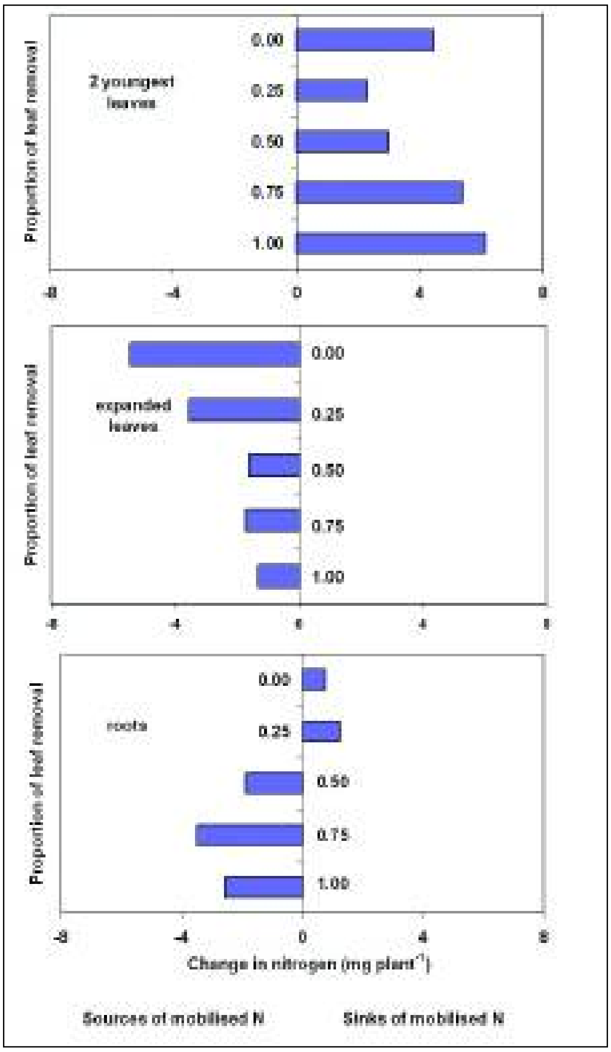

Figure 3: The change in mobilised nitrogen (mg N plant^{-1}) in the two youngest leaves, expanded leaves and roots of Panicum maximum plants over a seven day period following defoliation to various severity. A positive value (net gain in mobilised nitrogen) indicates the plant compartment was a sink of mobilised nitrogen, a negative value (net loss of mobilised nitrogen) indicates the compartment was a source of mobilised nitrogen.

N dynamics in grasses: a special case.

Defoliation of grasses induces roots to become a net source of mobilised nitrogen. In order to assess whether the physical damage of leaf removal or a reduction in the photosynthetic capacity of the plant induced such mobilisation from roots, these two factors had to be separated from each other. We explored this by reducing the rate of the plants' photosynthesis by lowering the concentration of carbon dioxide in the atmosphere surrounding the plant. In this way no physical damage was done to the leaves. Intact plants of F. rubra placed into the carbon dioxide-reduced atmosphere did mobilise nitrogen from their roots to growing leaves (Figure 4) (Thornton et al., 2002). This suggests that the mobilisation of nitrogen from roots can occur independently of any leaf damage and hence the post-defoliation mobilisation of nitrogen from roots may be brought about due to reduction in the plants' rate of photosynthesis. Interestingly in this study, defoliating plants in ambient concentrations of carbon dioxide did not result in reduced uptake of nitrogen, though mobilisation of nitrogen from roots occurred (Figure 4). The induction of nitrogen mobilisation from roots can, therefore, occur independently from any down-regulation of nitrogen uptake.

Opening the root compartment

In all previous studies of mobilisation of nitrogen in grasses, the roots were considered as a single entity. Different age categories of leaves behave very differently with regard to nitrogen dynamics in grasses (Figures 3 and 4); we hypothesised that same could be true for roots. In collaboration with the Technical University of Munich, Germany, we were able to separate the root system of L. perenne into different age categories and observe the nitrogen dynamics in each category following defoliation. For the first time we were able to show that, following defoliation of L. perenne, only the older roots mobilised nitrogen to support the growth of leaves. Younger roots appeared to retain all the nitrogen present in their roots at the time of defoliation and may even have provided a net sink for mobilised nitrogen.

Future

The laboratory-based studies described above indicate the importance of mobilisation of stores in supplying nitrogen for leaf growth in both intact and defoliated grasses. The full ecological implications of this process will not be realised until mobilisation can be measured in plants growing in the field. Some factors involved in differences between "laboratory" and "field" plants, such as effects of pH and aluminium on mobilisation, can be addressed (Thornton, 1998). With colleagues at INRA-Caen, France and the University of Caen, France, we used the steady state ^{15}N-labelling technique to show that the nitrogen dynamics in defoliated L. perenne growing in the field were similar to previous laboratory studies (Louahlia et al., 2000). However the steady state ^{15}N-labelling technique requires a sudden switch between two known but different N enrichment sources for all nitrogen supplied to the plant. This is difficult to achieve for plants growing in the field where many different nitrogen pools exist. The future challenge is to develop techniques to accurately measure the nitrogen dynamics of plants under field conditions. One exciting approach to achieving this is through the application of proteomics. Establishing which proteins within the different age categories of roots and leaves alter in response to defoliation and comparing this between "laboratory" and "field" plants could potentially meet the challenge. Only when accurate field measurements of mobilisation exist can its importance in the competitive fitness of grasses and hence on species composition be assessed under natural conditions.

The future challenge is to develop techniques to accurately measure the nitrogen dynamics of plants under field conditions

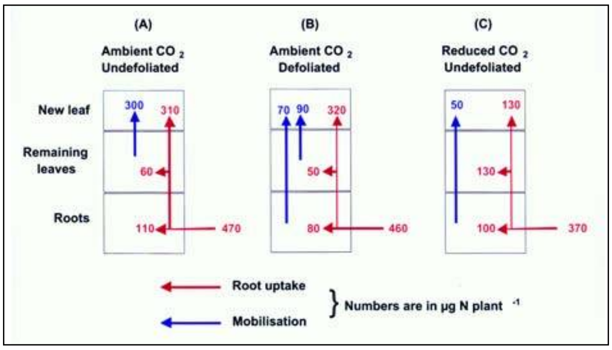

Figure 4: The fluxes of nitrogen derived from root uptake (red arrows) and mobilisation (blue arrows) in plants of Festuca rubra over a seven day period. Plants were either: (A) undefoliated in ambient concentrations of carbon dioxide, (B) defoliated in ambient concentrations of carbon dioxide or (C) undefoliated in reduced concentrations of carbon dioxide. Numbers at tip of arrows indicate the amount of nitrogen moved over the seven day period in μg N plant^{-1}. The base of the arrows indicates the site from where the nitrogen originated.

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Diet selection learning in ruminants

Alan J Duncan

• Summary

Free-ranging herbivores encounter a range of potential food plants, some of which are toxic, and some of which are nutritious. The success with which animals make appropriate choices about what to eat will influence their growth and reproductive success. The role of diet learning by herbivores in determining diet selection has aroused much research interest in recent years. The prevailing view is that animals learn about the nutrient and toxin content of their food by making associations between the physiological effects of particular foods, and their flavour. Recent research at the Macaulay Institute has explored the relevance of this mechanism to free-living herbivores foraging in botanically diverse habitats. We have found that the ability of goats to learn about the positive and negative effects of different plants when multiple species are simultaneously available is more limited than previously thought. Furthermore, in situations where animals have to balance ingestion of foods with positive and negative effects solely by associating effects with flavour, the negative effects appear to dominate, perhaps because avoiding toxicity is a crucial goal for browsing herbivores. Finally, the diet selection response to simulated seasonal change in diet quality and toxicity appears to be sufficiently flexible to cope with changing toxicity but less sensitive to changing nutrient rewards. Further work in this area will focus on the temporal resolution of positive and negative physiological effects of different test foods and how this influences diet choice.

• Context

The habitats used by free-ranging herbivores generally contain a diversity of plants that can be regarded as potential food. For example, even an apparently uniform habitat, such as a heather moorland, represents a plant community with varying amounts of heather (Calluna vulgaris), blaeberry (Vaccinium myrtilus) and various hill grasses such as Agrostis and Festuca species. Each plant species varies in nutrient quality, particularly plants ingested by browsing herbivores, but also in an array of plant secondary metabolites that may have toxic effects. The diet selection process is therefore not simple. Herbivores must make a series of decisions about which plants and plant parts to consume and the outcome of these decisions will influence their growth, reproduction and survival.

Conditioned aversions and preferences

How do herbivores assess the quality and potential toxicity of plants and come to appropriate decisions about what to eat? One theory which has gained prominence in the last 15 years is that animals use conditioned aversions and preference to adjust their choice of food (Launchbaugh et al, 2001). These ideas emerged from the psychological literature with early work being conducted in rats. Rats are omnivorous animals, do not have a vomit reflex and tend to consume single food meals. There are therefore strong pressures for them to be able to assess toxicity and avoid toxic foods. Early work showed that rats avoided flavoured water when the flavour had previously been associated with nausea. The conditioned taste aversion was still effective when a delay was introduced in the conditioning phase so that the flavour and nausea were separated by periods of several hours (Garcia et al, 1966). Later work showed that flavours could also come to be associated with positive stimuli such as nutrient infusions to elicit conditioned preferences for flavours (Garcia et al, 1974). The ideas developed in this early work stimulated interest in the possibility that similar processes might operate in large herbivores. Many experiments have since been reported showing that ruminants are able to form associations between flavours and feelings of nausea or the alleviation of hunger (Provenza, 1995).

Can ruminants use conditioned responses in botanically diverse habitats?

It is clear that large herbivores can make associations between flavours and physiological effects in the same way as rats. However, rats and ruminants have very different feeding styles and questions remain over how useful such mechanisms might be in the complex habitats used by free-ranging herbivores (see Figure 1). Rats tend to consume single-food meals while ruminants may include multiple components within a single meal. Rats rely on their diet for essential nutrients such as B-vitamins and essential amino acids making them sensitive to these nutrients in their environment. In ruminants the rumen microbial population synthesises many essential nutrients from raw ingredients. Rats are mono-gastric animals and nutrients and toxins are rapidly absorbed in comparison with the slower fermentative digestion found in ruminants. Finally, the food plants of ruminants are not static in their nutrient and toxin composition like those of rats, but change with the growth of plants and with the seasons. Is the observed ability of ruminants to make associations between food flavours and physiological effects in simple situations useful to the animal foraging in botanically complex environments? At the Macaulay Institute, we set out to assess this question in a series of experiments using goats as a model browsing herbivore. In all the experiments,

RATS	RUMINANTS
Single food meals	Multi-food meals
Reliant on diet for essential nutrients	Less reliant on diet for essential nutrients
Foods rapidly digested	Slowly digestible foods
Food quality stable over time	Temporally dynamic foods

Figure 1. Conditioned food aversions – applicable to large herbivores as well as rats?

goats were offered cut branches of different conifer species indoors and during feeding they were dosed with stimuli simulating the negative consequences of consuming plant secondary metabolites or the positive consequences of consuming nutrient-rich plants. Following this learning phase the animals were offered all the conifer species in a choice test to see how they had learned about the foods during the learning phase.

Single versus multiple food options

To test the efficiency with which large herbivores learn about post-ingestive consequences when offered multiple food components, we set up two learning scenarios. In the first, separate conifer species were offered on separate days to goats and following a period of feeding, goats were dosed with a positive stimulus, sodium propionate, a negative stimulus, lithium chloride or a neutral stimulus, sodium chloride, in proportion to the quantity of the browse species consumed. Following exposure to three different conifer species on consecutive days, goats were offered a choice of all three and their preference measured to see whether they had learned about the post-ingestive effects of consuming each food type. This scenario was compared with a more realistic scenario in which the same three test conifer species were offered to goats, but on this occasion, they were all presented simultaneously and the goats allowed to choose their own feeding strategy. Again the positive, negative and neutral stimuli were given post-feeding in relation to the quantity of each of the browse species consumed (see Figure 2). Results showed that goats learned quickly about post-ingestive effects when a feeding strategy was imposed upon them but that, when allowed to devise their own feeding strategy, their choices showed much less evidence of learning (Duncan & Young, 2002).

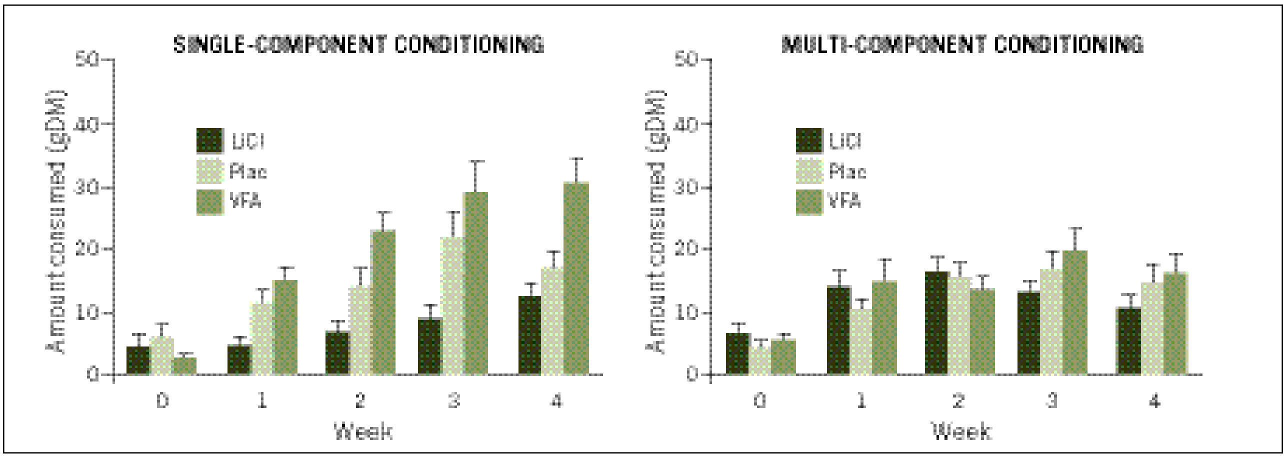
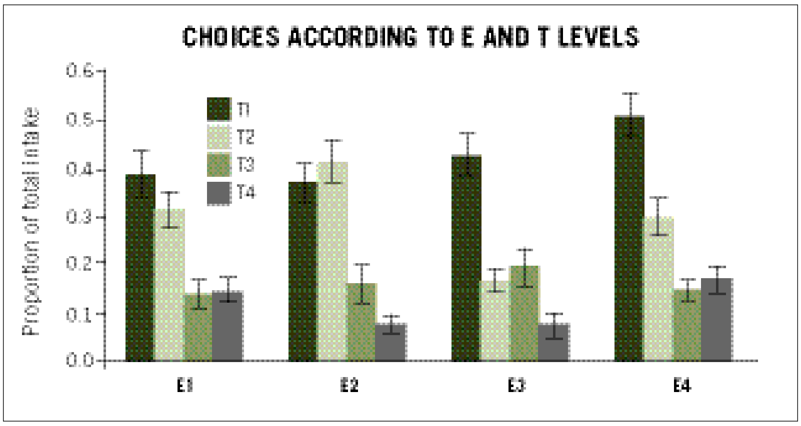


Figure 2. Comparison of the ability of goats to associate foods with positive and negative stimuli when the foods are offered singly during the learning phase and when multiple food options are offered. Positive (VFA), negative (LiCl) or neutral (Plac) stimuli were orally administered to goats during consumption of different conifer species during the learning phase. The graphs depict subsequent diet choice following a series of learning periods. (Duncan & Young, 2002).

Figure 3. Food choice by goats during preference tests when each of a series of conifer species offered during the learning phase was associated with varying intensities of a positive (E1 to E4) and a negative stimulus (T1 to T4) (Ginane et al, 2002).



Positive and negative consequences from the same food

The food plants of browsing herbivores consist of a mixture of positive and negative components. As well as macro-nutrients, such as nitrogen and energy, many browse plants contain plant secondary compounds. The browsing herbivore must, therefore, learn about the positive and negative consequences of consuming individual plants and make diet selection decisions based on the trade-off between them. One can envisage various diet choice solutions that herbivores might use when faced with this dilemma. To begin to test the way in which herbivores sample foods and adjust their choice based on the trade-off between positive and negative consequences, we offered 24 goats different conifer species on four separate days per week. During consumption of test foods, a mixture of sodium propionate (positive stimulus) and lithium chloride (negative stimulus) was orally administered to goats to simulate different post-ingestive consequences. Four levels of the positive stimulus and four levels of the negative stimulus were tested and the treatments were spread across animals so that the dose-response curve of the positive and the negative stimulus and their interaction was fully tested. Food choice was measured on day five of each week to assess the extent of learning and the change in preference in response to post-ingestive effects. As can be seen in Figure 3, results of the experiment showed that goats ranked test foods according to their negative consequences with preference declining as the strength of the negative stimulus increased (Ginane et al. , In press) There was no evidence for the positive stimulus influencing preference. It may be that diet choice is more sensitive to toxic signals than to nutrient signals because of the greater risk of making poor choices.

Seasonal change in diet quality and toxicity

For browsing herbivores, the food options on offer are not static in the post-ingestive effects they exert. The chemical composition of browse species and their nutritive value changes with season and with the phenology of the plant. Sampling of food plants could be a means to ensure accurate information about the consequences of consuming food plants in the face of their changing quality. If long-delay learning is important in large herbivores then one would expect the learning process to be sufficiently flexible to accommodate the changing quality of the food resource. We tested this, again using goats offered conifer species. Systematic temporal changes in nutrient

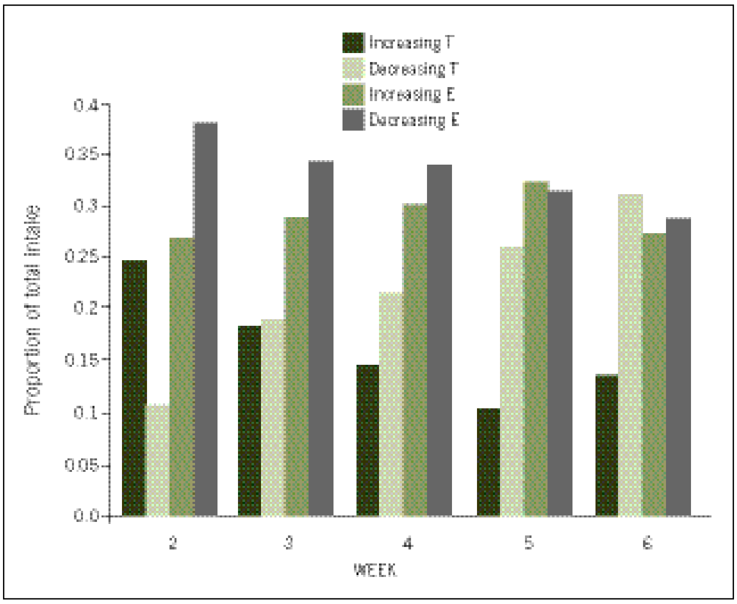


Figure 4. Changes in preference with time in response to simulated seasonal change in nutrient rewards (Increasing E or Decreasing E) or secondary compound exposure levels (Increasing T or Decreasing T). Different conifer species were offered to goats during a learning phase during which positive (E) or negative (T) stimuli were orally dosed. The levels of positive or negative stimuli administered changed systematically each week. (Duncan et al, 2003).

rewards and toxic consequences of consuming each food type were studied. The experiment lasted six weeks and four treatments were tested in each of 24 goats. The treatments consisted of increasing or decreasing amounts of both a positive (sodium propionate) and a negative (lithium chloride) stimulus associated with consuming each food type. Results of the experiment (Figure 4) showed that goats were able to closely monitor changing negative consequences and adjust their diet selection appropriately although they were less sensitive to a changing positive stimulus.

Conclusions

We tend to take for granted, the ability of wild and free-ranging domestic herbivores to avoid toxic plants and focus on nutritious ones. However, we have seen that the task they face is not a straightforward one. Each potential food plant offers nutrients but also presents risks. Animals must trade-off these different currencies in selecting a diet. Our work suggests that avoidance of toxicity may represent a more dominant foraging goal than subtle adjustment of preference to maximise nutrient intake. The quality and toxicity of plants also changes with time, so animals must have the means to adjust their diet selection decisions to cope with the changing resource. The results of our research have shown that the conditioned responses of ruminant animals to positive and negative stimuli are sufficiently flexible to accommodate temporal change in toxicity but are less sensitive to changing nutrient rewards. It may be that more proximate cues are used by animals to determine likely nutrient rewards. Finally, the propensity of ruminants to continually sample their foods means that each meal generally consists of multiple components. Allowing our experimental animals to adopt their own sampling regime reduced the accuracy of their diet selection decisions. This finding has implications for the ability of herbivores to learn about their foods in habitats with different scales of patchiness. We would expect learning to be more successful when large patches of one type of vegetation exist so that the length of feeding bouts on a single species would be extended. The question of the temporal resolution of nutrient and secondary compound delivery in ruminants and its influence on the success with which physiological effects can be successfully associated, by animals, with individual foods will be the focus of the next phase of research in this area.

We tend to take for granted, the ability of wild and free-ranging domestic herbivores to avoid toxic plants

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KNOWLEDGE TRANSFER & EXPLOITATION

The Institute ensures that the scientific knowledge that it gathers is transferred to those who will use it. Our work in this area includes the development of a 'toolbox' on agroforestry for land managers, an explanation of the implications of reducing livestock density and advice to the Scottish Executive on water abstraction.

Silvopastoral Agroforestry Toolbox

Alan Sibbald

• Summary

An internet and CD-based toolbox has been developed by the Institute to provide information to land managers and their advisors about the potential benefits of silvopastoral systems as an alternative to separate woodland or sheep production systems. It is based on information generated through the UK Agroforestry Forum and contains information on the practical issues involved in the establishment of trees and management of systems where trees are grown for timber on the same land as that used for sheep production. The economics of silvopastoral systems are described together with information on what grants and subsidies are available from government. The toolbox was developed in conjunction with land managers who had experience of silvopastoral systems and those who were interested but had no previous experience of them.

> farmers and land managers will be most interested in the financial performance of these systems

• Context

Silvopastoral systems are a specific branch of agroforestry systems in which, in the UK, trees are planted at wide spacing into permanent pastures. They have been used widely in many other parts of the world but in the UK it has only recently been shown that such systems can provide a number of benefits. With proper management trees can be grown to produce timber with little or no reduction in agricultural production from the same area of land for at least twenty years. This compares with more conventional farm forestry in which land is taken out of agricultural production to provide the forestry area. The total economic return from the land is, therefore, potentially greater from silvopastoral systems. Such systems can also provide more shelter from the weather for livestock and pastures and provide new opportunities for increasing the diversity of insects and birds in particular. They also provide attractive landscapes that have almost been lost from the UK.

Research over the last 15 years through the UK Agroforestry Forum, a consortium of Institutes and Universities in England, Scotland, Wales and Northern Ireland, has provided a wealth of knowledge, understanding and experience. This is based on a long-term network experiment at six sites and the development of on-farm silvopastoral systems in Northern Ireland. For this work to be translated into practice requires incentives currently available to farmers for conventional forestry and agriculture to be extended to silvopastoral systems and for farmers to have an appreciation of their financial and environmental benefits and the practical issues in managing such systems. To meet this latter objective, easy-to-access information must be produced to raise the awareness of land managers of its potential. An internet and CD-based Silvopastoral Agroforestry Toolbox has been developed by the Institute to assist in raising the awareness of the opportunities among farmers.

Content of the Toolbox

The Toolbox contains visual information on what silvopastoral systems will look like as they develop over their lifetime before felling after 40 to 80 years depending on the site and tree species. The management of these systems is explained under the three headings of pasture management, livestock management and tree management. Under pasture management sward management and reseeding ar e described. Sward management is very similar to that for conventional sheep production with the management of sward height to maximise herbage production and to maintain high digestibility of grazed herbage. Reseeding of the sward is advocated before planting, as once the trees are planted it will not be possible to reseed the pasture easily. The impact of the trees on herbage growth highlights the herbage production benefits that arise in spring and autumn on account of the warmer microclimate created by the trees and the slightly reduced herbage growth during the early and late summer due to reduced light intensity. It also points out that in dry summers, herbage growth can be increased over that of conventional pastures by the higher levels of soil moisture found due to the sheltering effects of the trees. The livestock welfare benefits of the presence of trees are explained under livestock management.

Because many farmers and land managers lack experience of tree management, considerable information is given about the species of trees that can be used for different objectives and sites. The quality of purchased planting stock is described in detail and sources from which the trees can be purchased are provided. There is also information on tree establishment and post-establishment management. Under tree establishment the pros and cons of bare-rooted trees or transplants and the timing of planting of the two approaches are considered. The procedure for planting and erecting the tree guards is explained in detail as this is a crucial part of the success of a good silvopastoral system. Planting density and pattern, and herbicide treatment around the young trees, are also described. Under post-establishment management, emphasis is placed on the importance of achieving good timber quality through routine maintenance and pruning. Pruning methods, including early formative pruning, and timing of pruning are explained in detail with diagrams.

As well as dealing with these practical issues of management, farmers and land managers will be most interested in the financial performance of these systems. The establishment costs, the potential income from timber and the output from sheep production are described. There is also a detailed description of the grants and subsidies that are currently available under the various Woodland Grant Schemes that operate in the UK. There are sections on the biodiversity and landscape benefits and how these can be used to obtain grants from the diverse range of stewardship schemes that currently operate.

The Toolbox also contains a section on frequently asked questions and on links to web sites where more detailed information either from organisations or individuals who have considerable experience of silvopastoral systems can be obtained. There are also lists of addresses and contact details of nurseries which sell seedling trees and other equipment necessary for the management of silvopastoral systems and saw-millers who will buy relatively small quantities of high quality timber.

Knowledge transfer

The Toolbox was developed using a focus group of farmers with experience of starting up silvopastoral systems and from another focus group of farmers who were interested but who had no previous knowledge of these systems. In this way valuable experience of users could be tapped into but the needs of the ultimate end-users were also listened to carefully. The material for the Toolbox was developed by Alan Sibbald who has had 20 years of experience of silvopastoral systems both in the UK and overseas. He was Secretary of the UK Agroforestry Forum from its inception in 1986 until 2002. He was also able to call upon the expertise of the members of the UK Agroforestry Forum that contains most, if not all, of the expertise on such systems in the UK.

The uptake of any agricultural system in Europe depends on the demand for the products and the degree of support provided by governments implementing the Common Agricultural Policy. Silvopastoralism is no different from other enterprises. Currently the profitability of sheep systems is relatively high but timber prices are low. Support payments for enhancement of the environment are likely to increase. The degree of government support differs between areas of the UK but where support is relatively high the uptake of silvopastoral agroforestry systems has been encouraging. By accessing information of the kind given in the Toolbox land managers are in a position where they can make an informed decision about the value of Silvopastoral Agroforestry systems to their farming enterprise.

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Copies of the Toolbox on CD are available free of charge from the Institute, contact Jane Lund (j.lund@macaulay.ac.uk). The Toolbox is also available on the internet (www.macaulay.ac.uk/agfor_toolbox)

Implications of pasture extensification

Carol A Marriott

• Summary

A study on the extensification of management of sheep-grazed pastures demonstrated that sown herbage species remain in grazed sown upland pastures that are managed more extensively. Although lamb output on an area basis is less when compared to more intensively managed systems, individual ewe and lamb performance may be increased because sheep have an opportunity to select higher quality herbage from the heterogeneous sward. The small changes in species composition over ten years suggest that medium-term increases in plant diversity in such upland sheep systems are unlikely to result from simply removing fertilizer and reducing grazing intensity.

• Context

Extensification is the process of reducing the stocking density of pastures and usually involves an associated reduction in the amount of fertilizer used. It is an integral part of European Union rural policies that have been formulated to address the declines in grassland biodiversity and the loss of landscapes and habitats in Europe. In the upland and marginal areas of the UK, the grazing systems on permanent pastures sown with perennial ryegrass and white clover have typically been relatively intensively managed for several decades, often relying on inorganic fertilizers to maintain high levels of animal production. We have studied the effect of a change to more extensive systems of production on species composition, vegetation structure and animal output in an experiment set up in 1990/91 at three sites across Scotland (Barthram et al., 2002; Marriott et al., 2002). Treatments were an unfertilized and ungrazed control, pastures receiving no fertilizer and managed to different sward heights (4cm or 8cm) throughout the year, and a more intensive treatment (4cmF) receiving fertilizer (an annual total of 140 kg/ha N and 20 kg/ha each of P_2O_5 and K_2O) and maintained at a mean sward height of 4 cm. The sward heights on the treatments were maintained by adjusting sheep numbers in response to weekly measurements of sward surface height. Scottish Blackface ewes, with their single lambs from May until weaning in mid-Au gust, were used.

> the rapid changes in vegetation structure will be beneficial to other aspects of biodiversity

Species composition of pastures

Within two years there were dramatic changes in the species composition of the ungrazed treatment (picture 1). The sown species, perennial ryegrass and white clover, virtually disappeared at all sites and the vegetation became dominated by tall herbs and coarse grasses. The species composition that developed differed between the sites, depending on initial species composition, previous management history and the surrounding vegetation.

In contrast there were comparatively small changes in the grazed treatments. Over ten years there were no major shifts in species dominance, and the number of species that were lost or colonized was small. The sown species retained a high presence in the grazed treatments. Perennial ryegrass made a higher contribution to the species composition of the 4cmF treatment (57.4%) and the 8cm treatment (55.6%) than to the 4cm treatment (44.7%). There was more white clover in the unfertilized 8cm treatment (10.5%) than the fertilized 4 cm treatment (8.1%), and the greatest amount was in the unfertilized 4cm treatment (20.3%). Although fertilizer applications had ceased on the unfertilized treatments, nitrogen inputs from N_2 fixation by white clover and nutrient redistribution via excretal return partly made up for this. Thus the sown species appear not to have experienced nutrient limitations which would affect their competitive ability in the unfertilized treatments. This may explain why the proportion of sown species remained high.

None of the treatments showed a large increase in species richness. The seed bank was generally richer in species and had a higher abundance of herbs than the vegetation, but it did not contain species typical of species-rich grasslands. The lack of desired species in seed banks and limited seed dispersal are now recognized as important biotic constraints to the restoration of many species-rich grassland and heathland communities throughout Europe.

Sward structure

Although changes in species composition at a field scale may take a long time to occur, changes in responses of sward structure to reductions in grazing pressure are rapid and some can be seen within

Picture 1 Grazed sward on left, ungrazed sward on right.

Picture 2 Intensively managed treatment (4cmF) at top, extensively managed treatment (8cm) in foreground to illustrate the differences in the amount of green and dead material in autumn.

a growing season. The proportion of dead vegetation in the standing biomass was greatest on the 8cm treatment (picture 2) and, averaged over all treatments, it was least in May and greatest in November. There were large changes in the distribution of plant parts in the canopy as vegetation increased in height and flowers developed. In addition there was more dead material and greater heterogeneity in heights across the 8cm grazed treatment (Figure 1) due to the greater opportunity for sheep to select their diet. Plant competition and species composition are influenced by sward height and litter accumulation through effects on the light profiles in the canopy and inhibition of seed germination and establishment. Thus it can be expected that taller growing species would eventually increase in the 8cm swards and there may be a lower number of species than in the 4cm swards. Changes in the spatial distribution patterns of species can also develop. The taller and more structurally diverse swards in more extensive systems play a key role in providing opportunities for changes in foraging behaviour and diet selection of grazers, as well as for an increased diversity of invertebrates and birds.

Stocking density

The fertilized treatment (4cmF) carried the greatest number of sheep (3746 grazing days/ha/yr) while the unfertilized treatments maintained at 4cm and 8cm carried 73% and 43% respectively of this number. The differences between the treatments appeared within the first year and, apart from some year-to-year variation, the number of sheep carried, output per ha, ewe live weight and condition score have been sustained over ten years. Average values are shown in Table 1.

Individual animal performance

Ewes and lambs had the highest individual response (greater condition scores and live weights) on the 8cm treatment (Table 1). The overall quality of diet on offer was lowest on this treatment because of the greater amounts of stem and dead material. However, the lower stocking density provides an opportunity for individuals to select the higher quality components. This, together with the greater potential bite depth (the main driver of rate of intake), will have led to the high levels of performance. The ewes and lambs usually had a higher performance on the unfertilized 4cm treatment than on the 4cmF treatment. Potential bite depth will have been similar in both treatments but the greater white clover content in the unfertilized treatment was probably responsible for the higher performance.

Production per hectare

The greatest live weight of lamb per hectare was produced by the treatment with the highest stocking rate, i.e. the 4cmF treatment. The 4cm treatment produced just over three-quarters of this amount and the 8cm treatment about half of this amount (Table 1). Ignoring

Table 1. The effects of the grazing treatments on animal performance during the period from mid-May until weaning in late-August, averaged over two sites and 10 years, with the standard error of difference (s.e.d.).

	LAMBS			EWES	
Treatment	Live weight at weaning (kg/lamb)	Live weight gain (g/day)	Live weight at weaning (kg/ha)	Live weight gain (g/day)	Live weight at weaning (kg/ha)
4cmF	29.9	190	629	-15.5	2.59
4cm	31.6	212	485	+5.4	2.61
8cm	33.9	238	346	+42.3	2.75
s.e.d.	1.1	10	31	12.9	0.06

† 4cmF, receiving fertilizer (an annual total of 140 kg/ha N and 20 kg/ha each of P_2O_5 and K_2O) and maintained at a mean sward height of 4cm; 4cm, receiving no fertilizer and managed to 4cm throughout the year; 8cm, receiving no fertilizer and managed to 8cm throughout the year

agricultural support and assuming a lamb value of £0.80/kg (2000 prices), the value of the lamb produced at weaning by the 4cmF treatment was £498/ha, by the 4cm treatment was £384/ha and by the 8cm treatment was £274/ha. These returns highlight the benefit in lamb output per hectare of applying fertilizer at the price of £50/ha in 2000. However there is some evidence that extensive systems can produce a greater gross margin than intensive systems when all the costs of production are taken into account (Thériez et al., 1997).

Conclusions

This study has demonstrated that sown species remain in grazed sown upland pastures that were more extensively managed. While lamb output on an area basis is less in extensive systems, individual ewe and lamb performance may be increased compared to more intensively managed systems because sheep can select higher quality herbage from the heterogeneous sward. However, the sustainability of lamb output depends on a number of factors including the species composition of the sward, site fertility and level of utilization. The small changes in species composition over ten years suggest that medium-term increases in plant diversity in such upland sheep systems are unlikely to result from simply removing fertilizer and reducing grazing intensity. The presence of a diverse range of vegetation types within the local area may increase the colonization by new plant species to above the level seen in our study. Otherwise, interventionist measures, such as sowing seeds or introducing grazers from plant communities containing seeds of desirable species, will be required in order to create species–rich swards. However, irrespective of any changes in species composition, the rapid changes in vegetation structure will be beneficial to other aspects of biodiversity. In light of the slow changes in plant species composition following extensification, appropriate indicators that take this into account should be used when assessing the success of environmental policies.

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Quantifying Surface Water Abstractions in Scotland

Sarah Dunn

• Summary

In response to the requirements of the EU Water Framework Directive new legislation for abstraction control in Scotland is currently being prepared. Knowledge of current abstraction practices is important to guide policy development but is limited in its extent and fragmented in nature. Consequently, the Scottish Executive commissioned a collaborative project between the Macaulay Institute and CJC Consulting to quantify the importance of abstractions for medium- and high-volume water users in Scotland. The project combined a quantitative assessment of the abstractions in relation to available water resources with an economic assessment of their value for a range of businesses. The results of the assessment demonstrate the significance of different types of abstraction across Scotland, as well as highlighting the need for a control mechanism that is place- and time-specific.

• Context

One requirement of the EU Water Framework Directive is that all member states must have in place methods of control over the abstraction of fresh surface water and groundwater. Generally, Scotland is viewed as a nation with plentiful water resources and, consequently, current legislation controlling abstraction of water is relatively relaxed. Although specific statutes govern abstraction of water for specific purposes, such as public water supply, there are no controls in place for many industrial and agricultural abstractions. New legislation is now being drawn up to create a system of abstraction licensing. In order to inform the development of the new policy there was a need to quantify the current situation in Scotland with respect to the volumes of abstraction that occur at present. An assessment of the importance of these abstractions, both economically and in terms of their environmental impact, was also seen as valuable to help guide the development of appropriate policy for abstraction control.

Abstraction Volumes

Because there has been no control over the majority of abstractions, there is no common database for Scotland that quantifies abstractions, either in terms of location or volume. One objective of this project was to integrate as much data as possible from different sectors that were identified as being high- and medium-volume water users. This included sectors such as public and private water supplies, agriculture (principally growing of vegetables and soft fruit), aquaculture, and whisky, paper and bottled water manufacturers. Figure 1 summarises the abstraction data collated for public water supplies, distilleries and boreholes. Estimates of agricultural abstractions for potato irrigation were also available from a previous study. Although the data do not give a complete overview of abstractions in Scotland, they demonstrate the comparative significance of abstractions by different sectors and highlight their geographical locations. The study excluded abstractions and transfers

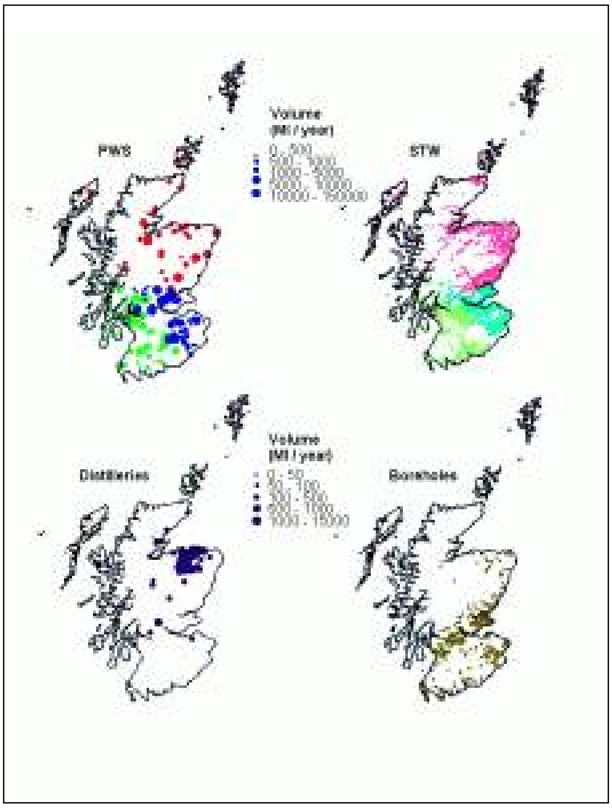

Figure 1 Locations and volumes of public water supply abstractions, sewage treatment works returns, distillery abstractions (incomplete dataset) and borehole abstractions

of water by the hydro-electric industry which affect very large areas of the Highlands of Scotland.

Catchment Analysis

The requirement for abstraction controls is driven by the objective of achieving good ecological status of rivers and, central to this, is the need to minimise disturbance of the natural system. The amount by which particular activities will need to be regulated will depend on a number of factors, such as: how many other abstractors there are in the locality, the seasonality of abstractions, and the climatic and hydrological characteristics of the location. A broad-scale assessment of the significance of the abstractions was carried out by linking the available abstraction data to a simple hydrological model, integrated in a Geographic Information System. In this way the abstractions could be quantified relative to the natural annual water balance.

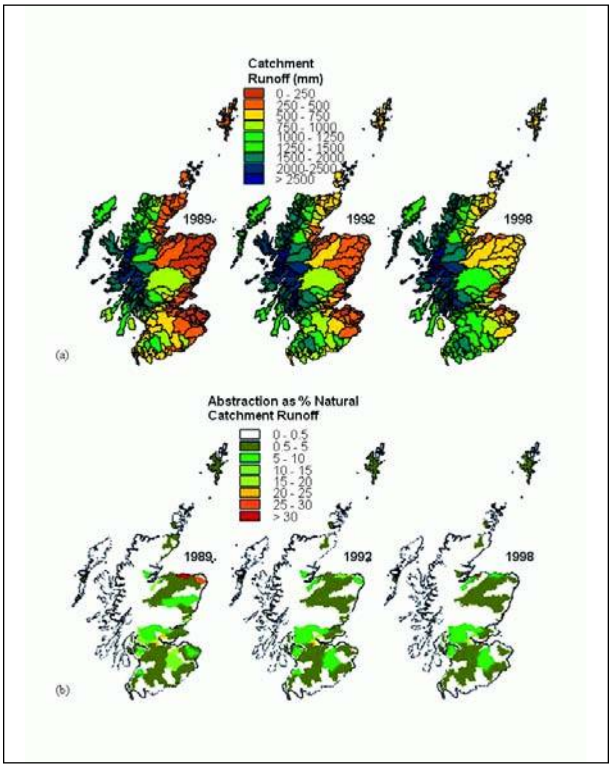

Figure 2 Catchment averaged (a) runoff and (b) abstraction as % of runoff for 1989, 1992 and 1998

Figure 2 illustrates some results from this analysis. In Figure 2(a) the mean catchment run-off is shown for three example historic years; 1989, which was very dry, 1992, which had average rainfall, and 1998, which was very wet. Figure 2(b) shows the percentage of this runoff that was abstracted for either public water supply, distilleries, from private boreholes, or for irrigation. The highest rates of abstraction from catchments occur in different locations, depending on the year. This reflects the influence of climatic variability in determining the significance of abstractions in different locations. The east of Scotland is particularly sensitive to abstractions during dry years, because natural run-off volumes tend to become very low compared with the rest of the country. Public water supply abstractions are most commonly the reason of high abstraction rates, but some areas in the north-east of Scotland are significantly affected by distillery abstractions, and in dry years, irrigation can also be an important issue in the east of Scotland.

Spatial and Temporal Sensitivity

The catchment scale analysis gives an overview of abstractions in different parts of the country. However, the sensitivity of any particular abstraction is also very dependent on its location within a catchment. If an abstraction is made from a large river, then its relative impact on flows at that point is likely to be low. The same abstraction from a small stream may constitute a high proportion of the flow and cause a locally significant modification to the flow regime. It is, therefore, important that individual abstractions are assessed in the context of their spatial location, and this can only be performed on a case-by-case basis.

A number of example businesses were selected as case studies to examine how different possible levels of abstraction control would impact on their current practices. The results for one distillery business, abstracting water from a small headwater catchment of 7.4km^2, illustrate the issue of spatial scale. Here, assuming the volume of abstractions was limited by volume to a maximum of 10% of the mean monthly stream flow, legislation could have very different impacts depending on its scale of implementation. If the controls were applied specifically to the area upstream of the business, a 50% reduction in abstraction would be

The issue of temporal variability in abstractions is also extremely important

necessary to satisfy such a control. However, if the control is applied at a spatial scale of 10km^2, there would only be a 29% reduction, and at 20 km^2, only a 4% reduction. Clearly, if legislation is implemented at a larger scale, it will be far less effective in controlling low flows in small tributary streams, which may be ecologically just as important as the larger rivers.

The issue of temporal variability in abstractions is also extremely important. In most cases, abstractions are likely to be relatively small when compared to the total annual run-off in a stream. However, if the abstraction is continuous throughout the year, then during the summer months it will constitute a much higher proportion of the flow and may have a much more significant impact. For seasonal abstractions, such

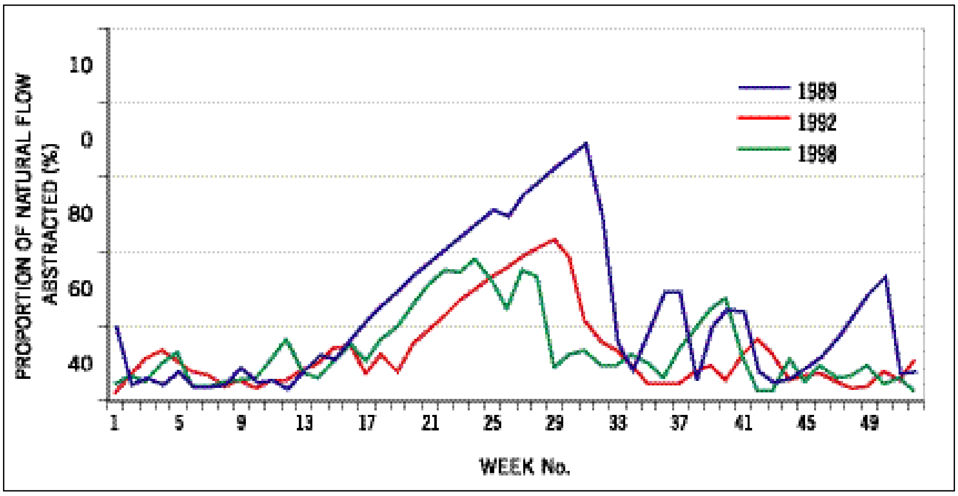

Figure 3 Abstraction as % total natural flow in the River Forth for 1989, 1992 and 1998

as irrigation, this is particularly important, as the abstractions are likely to be concentrated over the summer months when stream flows are already low. Figure 3 illustrates this issue for the River Forth. The total abstraction for the catchment is estimated to be around 8% of the total natural flow. However, during the summer the abstraction that occurs at any time may rise to 38% of the natural flow in a wet year, such as 1998, or up to 68% of the flow in a dry year, such as 1989.

Implications

Despite a generally healthy situation with respect to the availability of water resources in Scotland, abstractions from surface and ground waters are significant and have resulted in substantial modification to the natural flow regime of many rivers. If new legislation for abstraction control is to be effective in its objective of helping to improve the ecological status of surface waters then there is a need to account for the impact of abstractions at a range of spatial and temporal scales. Water budgeting at a catchment scale is unlikely to be effective in preventing over-abstraction from small watercourses, and the use of simple annual abstraction licenses will not prevent over-abstraction during dry periods.

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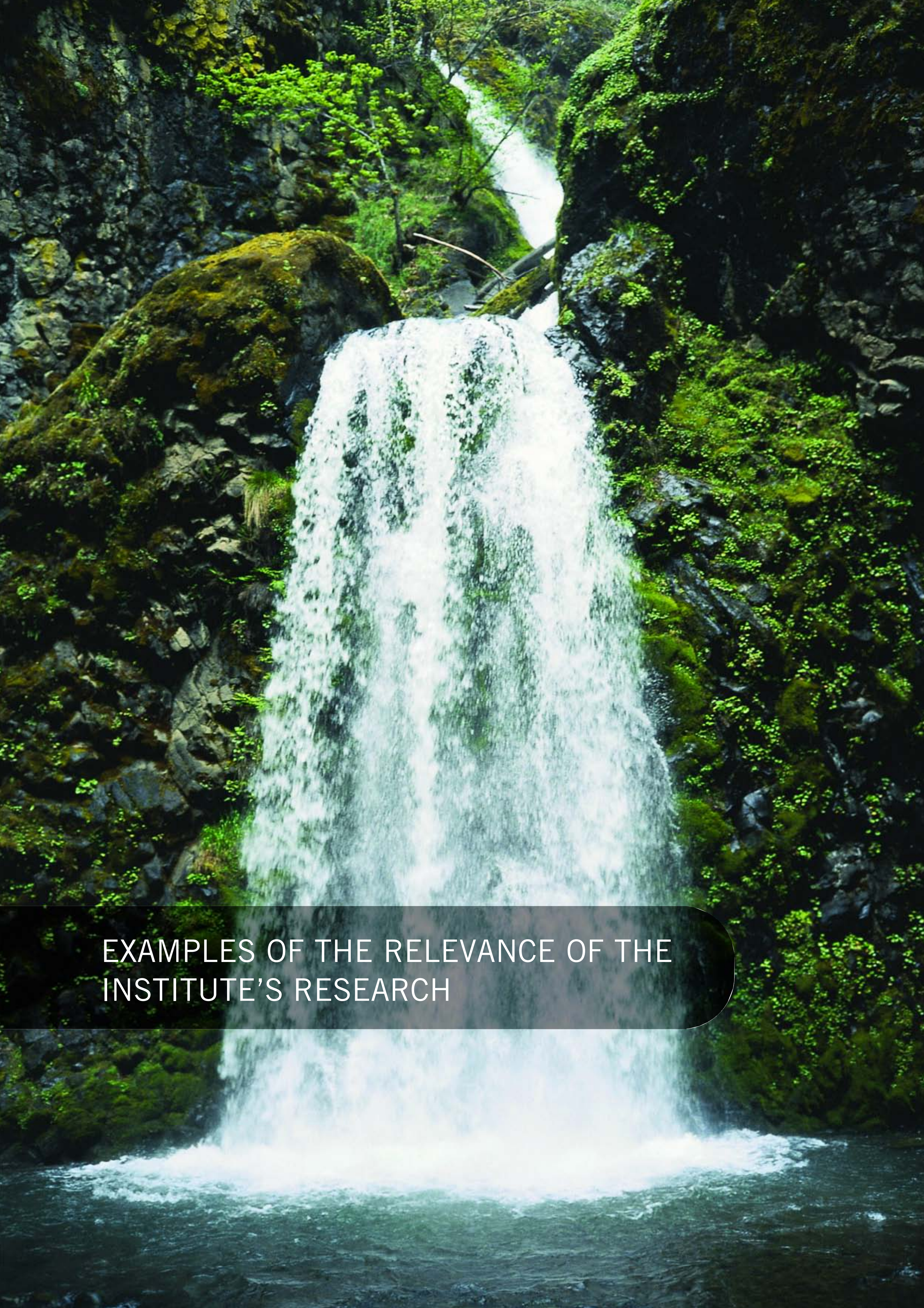

EXAMPLES OF THE RELEVANCE OF THE INSTITUTE'S RESEARCH

Examples of how the Institute's work was used by others in 2002 are our contribution to remediation of contaminated land, the development of a model to assess the risk of nitrogen pollution in Scotland and applying our knowledge of livestock management to Kazakhstan.

Investigation and remediation of chromium contaminated sites

Edward Paterson

• Summary

The development and use of an integrated approach to studying sites contaminated with chromium-containing wastes has shown how a combination of chemical analysis, mineralogical characterisation and chemical modelling can provide new insights into the processes occurring on site. In addition, the model developed can also be used to provide a software environment in which proposed remediation treatments can be tested.

• Context

Scotland was in the vanguard of the Industrial Revolution and many generations of Scots have grown up in cities and towns that have been significantly affected by industrial activities. The Institute has a range of generic skills in surface chemistry, mineralogy and computer modelling that can be directed towards urban environments. The combination of these skills with those of partner organisations, University of Edinburgh and Dames & Moore (now URS Corp), can be seen in our contribution to a recently completed project aimed at an integrated assessment and modelling of soil contaminant behaviour, transport and impact at chromium-contaminated sites.

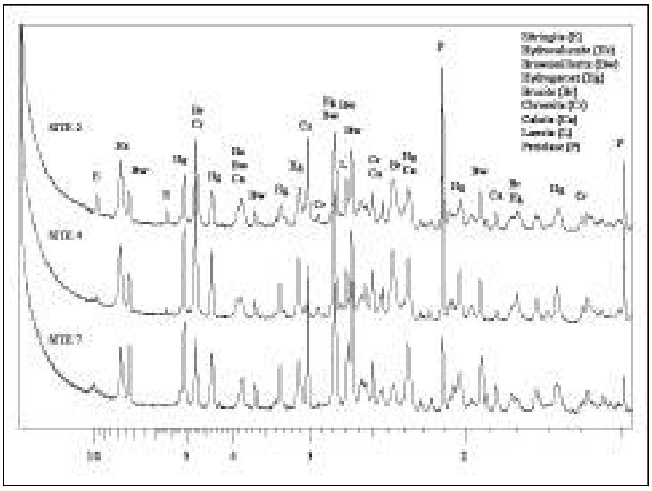

Figure 1 X-ray powder diffraction patterns of samples from three sites. Attribution of the main peaks to various minerals present is indicated. (reproduced with permission from Elsevier, Science of the Total Environment, 305, 198-210 (2003))

Background

From its establishment in 1830 until its closure in 1968, Whites Chemical Works (Plate 1a) in Shawfield, Glasgow, was involved in the production of chromium salts using the 'high-lime process' which involved high temperature treatment of chromite ore with alkali reagents. Over 2.5m tonnes of waste, called chromite ore processing residue (COPR), were generated from these activities and this material has subsequently been used for infilling quarries and low-lying areas in and around Glasgow and also for the construction of various earthworks such as terracing surrounding sports fields (Plate 2b). These sites are now recognised as heavily contaminated by chromium (Farmer et al., 1999). In nature, chromium exists in two main forms with valencies of +3, Cr(III), and +6, Cr(VI). The former is cationic, non-toxic and relatively immobile in soils because of adsorption by the soil matrix whereas the latter is anionic, highly toxic to a range of organisms including man and is relatively mobile.

Chromium-containing phases in COPR

The COPR collected from a number of sites showed very high pH values and concentrations of both Cr(III) and Cr(IV), well above the limits formerly used to define contaminated sites as given by the Inter-departmental Committee for the Redevelopment of Contaminated

Land. In addition, pore water recovered from the sites showed Cr(VI) concentrations three orders of magnitude in excess of the Environmental Quality Standard for Cr(VI) in drinking waters (Farmer et al., 2002). In addition, data are available from the Scottish Environment Protection Agency showing that Cr(VI) is leaching from these sites into both ground- and surface-waters. While these chemical analyses identify COPR as a serious hazard, Part IIA of the Environment Act (1995) requires that a source – pathway – receptor linkage be established in order to define a contaminated site. Chemical analysis alone is no longer sufficient and process-based knowledge is now critical to understanding the behaviour of pollutants on sites and, indeed, for informing remediation.

Plate 1a Aerial view of the site of White's Chemical Works at Shawfield, Glasgow, which was in operation from 1830 - 1968

Cr(VI) salts are generally very soluble and the fact that many of the sites studied in this project continue to leach Cr(VI) after fifty or more years of exposure suggest that mechanisms other than simple dissolution of chromate salts are operating. In order to test this, a detailed examination of the COPR was carried out using mineralogical techniques because previous work (Lumsdon et al., 2001) has shown how this can provide data on solid-state speciation of wastes. X-ray diffractometry showed that the COPR consists of a mixture of materials with a complex trace (Figure 1). However, using techniques developed at the Institute, we have identified and quantified several components that may contain chromium as part of their structure. Attention was focused on four minerals, chromite, hydrogarnet, hydrocalumite and brownmillerite and, using scanning electron microscopy, these components were detected in aggregates of COPR. In addition, energy dispersive X-ray microanalysis enabled the composition of each phase to be determined (Hillier et al., 2003). Thus, a series of potential sources of Cr(VI) have been identified based on the stoichiometry and known structures of these mineral phases.

Behaviour of chromium

In order to synthesise our knowledge of processes taking place on site we have used the ORCHESTRA modelling tool developed at the Institute (Meeussen, 2003). In addition, computer modelling can provide a very powerful method for synthesising knowledge and interacting with end-users. The ORCHESTRA-CHROMIUM model has been set up as a series of mineral dissolution reactions using thermodynamic data from the literature. In order to test the model predictions we have compared the predicted composition of COPR with that obtained by quantitative X-ray powder diffractometry (Table 1). The good agreement confirms that the assumption of thermodynamic equilibrium is justified in most cases and also gives some confidence to the prediction of pH- buffering behaviour at high pH and the release of Cr(VI) from mineral dissolution (Geelhoed et al., 2002).

Finally, we have tested various remediation options in laboratory conditions. Many of the methods suggested previously have been based on the reduction of the mobile, toxic Cr(VI) to much less mobile, non-toxic Cr(III) by Fe(II) solutions. We have simulated this by leaching a column of COPR with ferrous chloride solution but the results were disappointing in that there was no difference between the leaching of Cr(VI) in the presence and absence of Fe(II). This can be explained by the very pH causing precipitation of Fe(II) hydroxide species before redox takes place. However, when we tested a

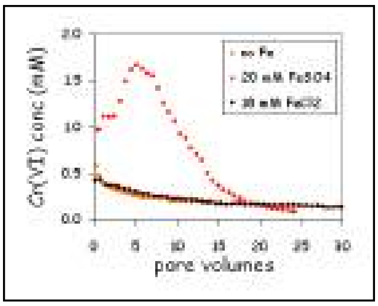

Figure 2 Leaching of Cr(VI) from column of chromite ore processing residue on infiltration with indicated solutions

Plate 2b Terracing around the football pitch has been built from chromite ore processing residue

%	modelled	measured
hydrocalumite	6.6	5.8
hydrogarnet	19.8	20.5
brownmillerite	12.3	13.7
calcite	5.1	5.5
chromite	2.0	5.0
periclase	unstable	6.6
brucite	27.4	8.4

Table 1 Comparison of modelled and measured contents of minerals in chromite ore processing residue

ferrous sulphate solution, as a source of Fe(II), a large pulse of Cr(VI) was released (Figure 2). This immediately raises the question of why different Fe(II) salts should have such a different impact. Again the combination of chemistry and mineralogy provides the answer. One of the components present in COPR is a mineral known as hydrocalumite, which is known to have anion exchange properties. Energy dispersive X-ray microanalysis (EDX) of hydrocalumite before and after sulphate treatment showed evidence for anion exchange of chromate for sulphate (Figure 3). Clearly, this is an important result in informing remediation options.

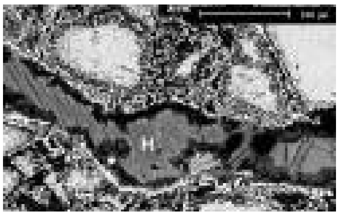

Figure 3a SEM backscatter image showing pore filled by hydrocalumite (H)

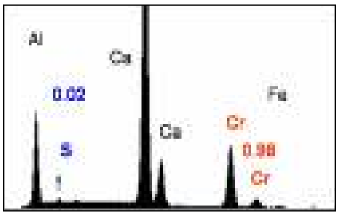

Figure 3c SEM/EDX analysis of hydrocalumite before ion-exchange

Figure 3b SEM secondary electron image showing morphology of hydrocalumite (H)

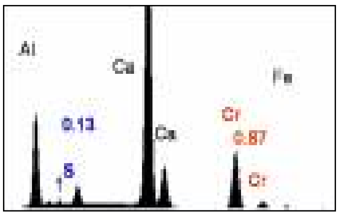

Figure 3d SEM/EDX analysis of hydrocalumite after ion-exchange

Figure 3 SEM and EDX analysis of hydrocalumite before and after exchange with sulphate $[Ca_2 Al(OH)_6]_2(CrO_4/SO4).6\ H_2O$ *(Reproduced with permission from Geelhoed et al., Environmental Science and Technology, In press)*

Conclusions

The skills and knowledge available in the Institute have been shown to be able to be deployed in one contaminated land situation but the generic approach adopted can be employed in a number of different environments. Integration of these skills with those in collaborating organisations has enabled high quality science to be deployed directly to meet the needs of a range of end-users.

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A Nitrogen Risk Assessment Model for Scotland

Allan Lilly

• Summary

In response to the EU Nitrates Directive (91/676/EEC), a Nitrogen Risk Assessment Model for Scotland (NIRAMS) has been developed to predict nitrate concentrations in rivers and streams draining from agricultural land in Scotland. The model is designed to predict nitrate concentrations in ungauged catchments, to fill gaps in monitoring data and provide guidance in relation to policy development. It uses national datasets of land use, soils and climate and runs within a Geographical Information System. The model calculates a water balance and the residual nitrate remaining in the soil at the end of the growing season. A transport component calculates the leaching and transport of nitrate at the catchment scale. Comparisons of the simulation results with measured data show that the model is capable of predicting mean levels of stream nitrate concentrations as well as any seasonal variation. The model will also be of value in exploring the effects of changes in land use and farming practices on the levels of nitrate in Scottish waters.

• Context

Nitrogen is a vital component of plant and animal proteins. Although the atmosphere comprises almost 80 per cent nitrogen, plants cannot use this nitrogen directly. In natural ecosystems, atmospheric nitrogen is converted to usable forms, such as ammonia and nitrate, by micro-organisms and, in modern agriculture, organic and inorganic forms of nitrogen in fertilizers increase the yields of crops, vegetables and grass. Unfortunately, nitrate is highly soluble and any remaining in the soil after the crop has ceased to grow, or has been harvested, is liable to leach into streams and rivers. As the use of nitrogen fertilisers has increased, the amount of nitrate available for leaching has also increased. It has been estimated that between 50 and 70 per cent of nitrate in water comes from agricultural sources with the remainder from sewage discharge, recreational ground and gardens.

While the use of nitrogen fertilisers brings great benefits to food production, there has been concern that the excess nitrate that leaches from the soil can have a detrimental effect on natural ecosystems. An increase in nitrate levels (eutrophication) has been associated with increased algal growth, a reduction in dissolved oxygen and loss of biodiversity although other nutrients may also be responsible for increased algal growth. It is thought that increased levels of nitrate leached may also have effects on the ecosystems of shallow coastal waters.

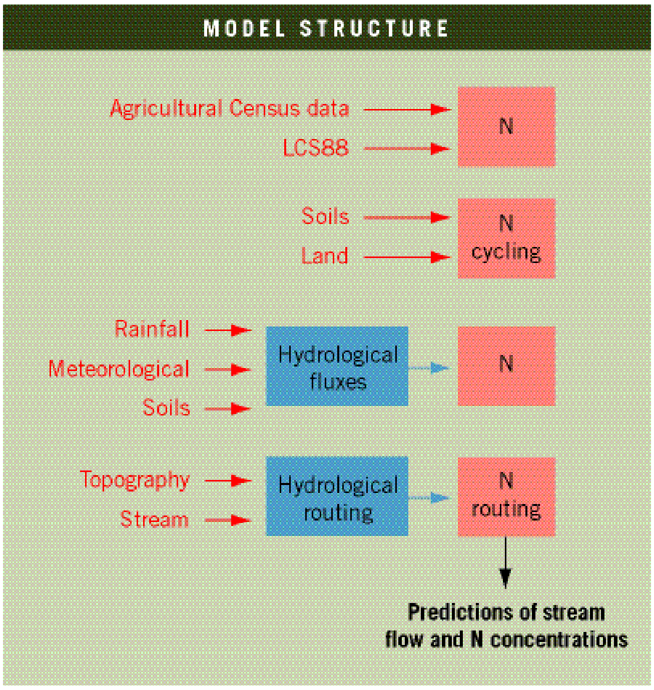


Figure 1. Structure of NIRAMs

In 1991, the European Community issued the Nitrates Directive (91/676/EEC) in an attempt to protect aquatic ecosystems and sources of potable water from the effects of nitrate lost from agricultural land. The Directive stated that waters that exceeded, or were likely to exceed, a nitrate concentration of 50 milligrams per litre should be identified and their catchments designated as Nitrate Vulnerable Zones (NVZs). Measures should then be taken to reduce the amount of nitrate leaching through agricultural practices within these catchments.

Although sampling from surface water is relatively easy and carefully sited monitoring points can yield information for large catchments, there are still many catchments where measurement is not possible, including sub-catchments and coastal 'gap' catchments where first- or second-order streams drain directly to the sea. Although a monitoring programme allows trends in water quality to be determined, there is limited scope for predicting how the water quality will change in response to changes in land use or farming practice. Thus, a model to predict concentrations and fluxes of surface and groundwater nitrates draining from agricultural land across the whole of Scotland was developed at the Macaulay Institute. The model, NIRAMS (Nitrogen Risk Assessment Model for Scotland) was based around existing national scale data sets, including soils, climate, land use and management, and runs within a Geographic Information system.

The model

Figure 1 shows the model structure. Land use and crop management are key determinants of the amount of nitrogen inputs to the land and water in agricultural areas. They also determine the spatial distribution of inputs in a catchment and the patterns of land use influence the way in which organic manures are spread on the land. The NIRAMS model made use of two important land use data sets, the Land Cover of Scotland (LCS88) data set (MLURI, 1993), which provides information on the spatial distribution of land cover types but does not specify which particular crops are grown on arable land and the Agricultural and Horticultural Census data collected annually by the Scottish Executive for each Parish administrative unit in Scotland. This latter data set provides a detailed summary of the areas of individual crop types and numbers of livestock within each Parish but does not indicate where the crops are grown or where cattle are grazed. By combining these two data sets, information on the crop composition of the cultivated land as well as livestock densities can be identified.

A simple input-output balance is used to estimate the nitrogen that will be available for leaching over the winter months. The amount of nitrogen available is determined from existing published data as well as from new experimental data and the predictions of the NIRAMS model. As actual leaching is dependent on hydrological conditions, NIRAMS also has a water balance component based on weekly rainfall and evapotranspiration rates and the water retention capacity of soil. The water balance model also separates drainage fluxes into three components: overland flow, sub-surface flow and groundwater flow. The relative proportions of each are dependent on the soil wetness and the soil hydrology.

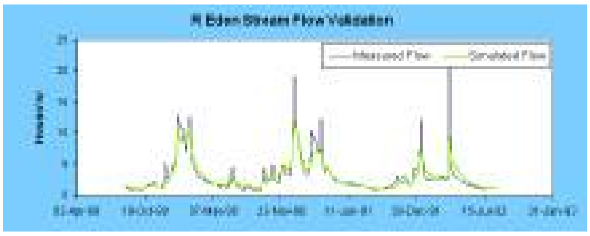


Figure 2 Comparison between measured and simulated stream flows

The nitrogen transport component of NIRAMS predicts the routing of flows from any point on the land surface to the stream. The routing is carried out using a digital elevation model where the topography of each 50m grid square is characterised. Overland flows are combined with sub-surface flows for routing purposes and are considered as a fast response flow as the majority of the sub-surface water reaches the stream via some form of preferential pathway, such as agricultural drainage systems. Nitrogen that has been leached from the soil by infiltrating water is transported in solution via different hydrological pathways to ground and surface waters. The principal objective of the NIRAMS model is to predict stream nitrate concentrations for any location in Scotland. In order to achieve this, the model is run within the ArcView Geographical Information System. A user can select any point on the stream network and the NIRAMS transport model is then applied to the upstream catchment.

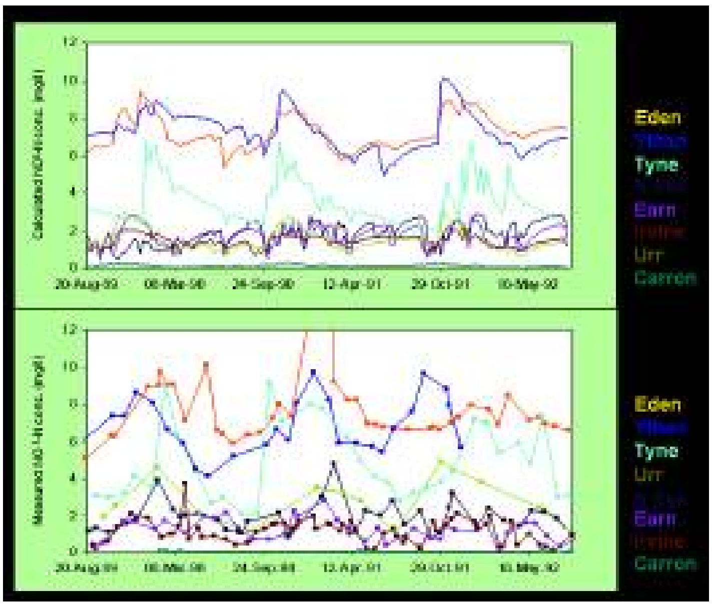
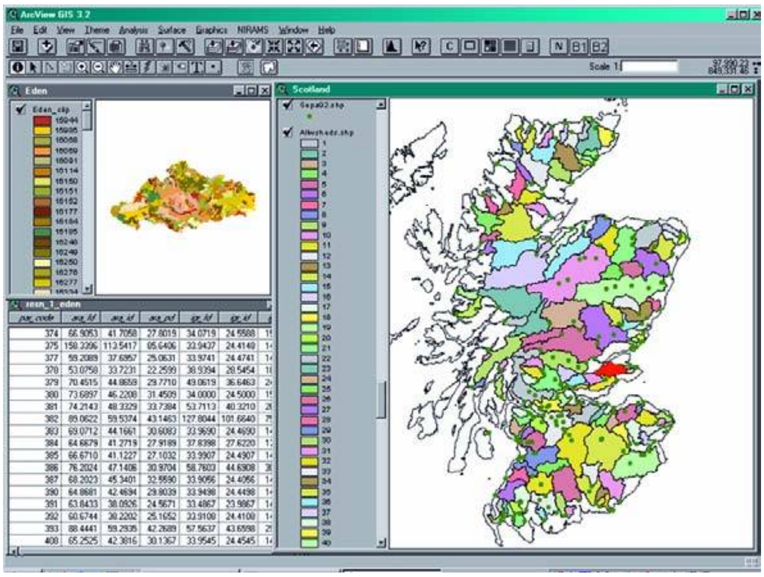


Figure 3 Comparison of Predicted Stream Nitrate with Measured Data for 8 Catchments

Model testing and outputs

The NIRAMS model has been tested by application to eight catchments that have a wide range in soil, climate and land use conditions. Simulations were carried out for a five-year period using historic land use and rainfall data from 1989–1994. The model successfully simulated stream flow, both in terms of the shape of the hydrograph and the water budgets (Figure 2). The predictions of stream nitrate concentrations matched the observed data in terms of their mean values and time-series plots demonstrate that the model is capable of reproducing the broad seasonal trends in variation of stream nitrate concentrations (Figure 3). The model can be applied to ungauged catchments or coastal gap areas with the confidence that an acceptable simulation will be achieved. These applications are of value for general screening purposes and can help focus more detailed monitoring or modelling studies in appropriate areas. The modelling success also demonstrates that large-scale nitrogen modelling can be carried out with simplification of N cycle processes providing that the key transport processes are adequately represented. The model currently predicts nitrate levels from historical data but its structure means that the effects on stream nitrate levels of land use changes can be explored, offering an important tool for managing future nitrate levels in Scottish waters.



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Livestock Production and Rural Development in Kazakhstan

Iain A Wright

• Summary

Following the break-up of the Soviet Union, pastoral agriculture in Kazakhstan has undergone major change with a massive reduction in the number of sheep and people gaining a livelihood from agriculture. New flock management systems have begun to develop and the Institute has undertaken research in collaboration with local research institutes to characterise these new systems and the issues that are likely to arise in identifying options for rural sustainability. Three types of farming system have been developed based on private owners with small flocks, private farmers and cooperatives. Large-scale private farmers are operating the most profitable systems and these are likely to increase in importance. However such an approach will only be successful, if land tenure issues can be resolved.

• Context

The past decade has been traumatic for the people of Central Asia following the break-up of the Soviet Union. In rural areas agriculture collapsed, leading to widespread poverty and a breakdown of many of the social services. There has been a transfer of assets from the state to the private sector with the emergence of new forms of livestock management. The farm structures and economic and social environments under which livestock are now kept are totally different from the past. There is a need to understand the ways in which those who manage livestock are responding to these changes so that a) research and development programmes can be designed to provide appropriate support and b) policies can be developed which assist the development of the livestock sector and rural areas. This article describes some of the research carried out by the Macaulay Institute, in collaboration with local research institutes, on the role of livestock in the rural economy of Kazakhstan.

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Privatisation of agriculture in Kazakhstan

When the Soviet Union broke up, Kazakhstan emerged as a separate state in 1991 and in 1994 legislation reorganised the agricultural sector. While land remained in state ownership, the state and collective farms were transformed into cooperatives based on the principle that employees each receive a share. They therefore had a notional entitlement to right of access and use of the land.

At the same time, the state withdrew from both the provision of subsidised inputs and the buying of produce. This sudden withdrawal of state support had a massive impact on the livestock sector. The newly formed cooperatives could not afford to buy inputs and there was no marketing system to take the place of the former state-controlled system. Livestock numbers, especially those of sheep, the main species, fell dramatically by two thirds from 35 to 9 million in a few years (Behnke, 2003). Many cooperatives collapsed and rural areas reverted to a barter economy.

Most cooperatives that remained ceased to follow the seasonal migratory system of sheep management, whereby sheep spent the winter grazing shrub vegetation in sand dune areas in winter, the spring and summer in steppe or semi-desert areas and the summer in mountain pastures.

Individuals who chose to become private farmers were allocated an identifiable area of land, typically 50-200 ha (usually with a well, a house and often a barn) as well as livestock. Usually their livestock numbers far exceeded what can be carried on their land, but they grazed freely on the cooperative land, since the massive reduction in numbers of livestock post-1994 has meant that the pressure on this land is much reduced.

Households that received less than about 50 sheep at privatisation and that had no other source of income did not have a viable flock.

The flock was not large enough to be self sustaining after slaughtering to provide meat for household consumption and selling or bartering for essential household items (Wright et al., 2003). By the late 1990s many of these households were down to their last few animals and by the turn of the century most households had either left the rural areas and migrated to urban centres in search of employment or were relying on cash remittances from family members working elsewhere.

New farmers emerge

By the late 1990s three main categories of livestock owners and management systems were emerging:

1. private owners with small flocks,
2. private farmers, and
3. cooperatives.

Small-scale private owners

In rural areas, most households own a small flock of sheep (up to about forty) and sometimes one or two cows. Often the livestock do not represent the household's main source of income, but provide meat for household consumption and a few animals for sale. Flocks are kept indoors in household barns in winter, usually grazing pastures during the day. Sheep are usually fed hay, while some owners also feed concentrates and or/straw. In summer, sheep are shepherded around the village on natural pasture, which can lead to considerable grazing pressure on land within 5-10km of the village.

Private farmers

Private farmers are those with an income mainly derived from farming. They usually have more than 60 or 70 sheep and typically have 150-300 or even more. They are often technical staff from the former collectives with a sound knowledge of livestock management. It is common for these farmers to have an area of land 10 to 60 km from villages, often based around a barn that was used seasonally by the former collectives. These barns are rented or bought from the cooperatives and are usually associated with a house. This arrangement is found in the dry steppe, semi-desert, foothills and lower mountain pastures (Kerven , 2003). These units, being away from the village, have the advantage of having access to forage supplies not utilised by village-based stock. Depending on the ecological zone, some private farmers are starting to move their animals seasonally to take advantage of the vegetation resources in different ecological zones.

Cooperatives

Prior to privatisation, each state or collective farm had land in different ecological zones, and livestock were moved to a different zone in each season. These farms had large numbers of sheep (25,000 to 65,000) with a well-planned management regime. Since privatisation, the numbers of livestock owned by cooperatives have fallen dramatically. Most cooperatives studied now have only 1,000 to 4,000 sheep and are in severe financial difficulties. Most no longer follow the traditional seasonal migration, because the massive reduction in livestock numbers has reduced grazing pressure on the steppe and semi-desert areas and often they no longer have the resources and ability to move livestock to other areas. Most cooperatives now keep their sheep on the steppe and semi-desert all year round, moving them to different pastures at different times of year.

A Kazak shepherd tends his sheep

Current sheep management systems

The different types of flock owners tend to be developing separate management systems and, recently, we have studied the effects of these management systems on the biological and economic performance of flocks. Flock owners who are based in the villages have the highest cost of bought-in fodder for winter but, despite this, their sheep lose the most live weight (Table 1, Kerven et al., 2003). By moving away from the heavily grazed areas around the villages, the cost of winter feeding can be reduced by about half and the liveweight loss over winter is also reduced. This is due to the much lower grazing pressure in the areas more distant from the villages. However, the lowest winter feed costs are incurred by those farmers who have

Table 1. Sheep live-weight change over winter and cost of bought fodder per sheep for different management systems.

	MANAGEMENT SYSTEM		
	Based in village	Based outside village	Move seasonally
Live-weight change over winter (kg)	-10.8	-5.5	+3.7
Fodder costs (US$/sheep/year)	0.78	0.31	0.24

returned to the traditional seasonal migratory patterns. Despite having the lowest feed costs in winter, their sheep actually gain live weight during winter (Table 1). It is only the larger flock owners who have the assets, e.g. a truck to transport animals and either enough family labour or large enough flocks to justify hired labour, to be able to adopt this management regime.

These results clearly show the benefits of a migratory system for efficient livestock management. At present only a few large-scale private farmers can operate such a system. There is little grazing pressure on the vegetation resources away from the villages and they can graze their animals more or less where they want, even although they have no formal or legal rights to do so. If such a system is to be sustainable in the long term, and, in particular, if animal numbers increase to the extent that there is competition for the grazing resources, then land tenure legislation needs to be developed in such a way as to allow migratory systems to continue. The results of research that the Institute is undertaking on this subject will contribute to the debate on the formulation of future land tenure legislation.

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