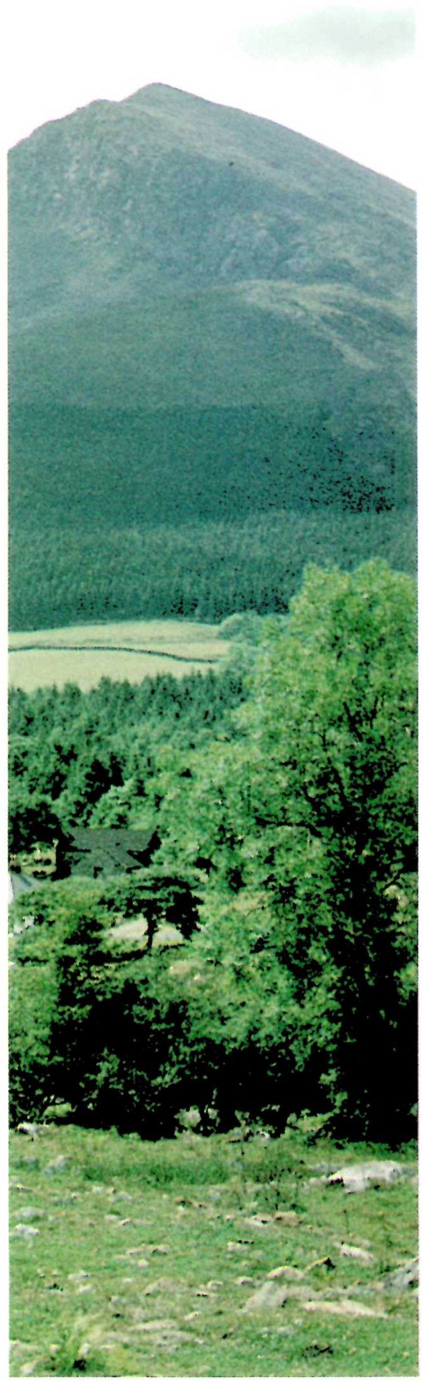
1988 – 1989

REPORT



Institute of Terrestrial Ecology

Natural Environment Research Council

Foreword

The Natural Environment Research Council produces an Annual Report summarising the activities across the organisation Such an Annual Report can only provide selected information on the scientific activities of individual Institutes It is therefore important for each Institute to produce its own Report which gives a full account of its research, its structure and its finances

The Institute of Terrestrial Ecology is part of the Terrestrial and Freshwater Sciences Directorate of NERC The Directorate's in-house capability also comprises the Institutes of Freshwater Ecology (formed in April 1989 from the staff and laboratories of the Freshwater Biological Association), Hydrology, and Virology and Environmental Microbiology (formerly the Institute of Virology but renamed in April 1989), the Unit of Comparative Plant Ecology (Sheffield University), the Water Resource Systems Research Unit (Newcastle University) and the Interdisciplinary Research Centre for Population Biology (Imperial College London)

The Institute of Terrestrial Ecology has a wide span of skills and disciplines and forms a core component of the Directorate As noted in the Directors' report, the year has been active and eventful In particular, it has been marked by the retirement of Dr Jack Dempster, its Director (South) I would like to take this opportunity to express my appreciation of his great contribution to the scientific reputation and management of ITE, and to welcome his successor Dr Mike Roberts with all good wishes for his future work with NERC

P B Tinker
Director of Terrestrial and Freshwater Sciences
Natural Environment Research Council

Front Cover Illustration Upland landscape near Beddgelert, North Wales (Photograph Ken Walton, ITE Bangor)

The Natural Environment Research Council

Report of the Institute of Terrestrial Ecology for 1988/89

Contents

Directors' statement

The year 1988/89 was marked by three developments which signify a turning point in the fortunes of the Institute of Terrestrial Ecology:

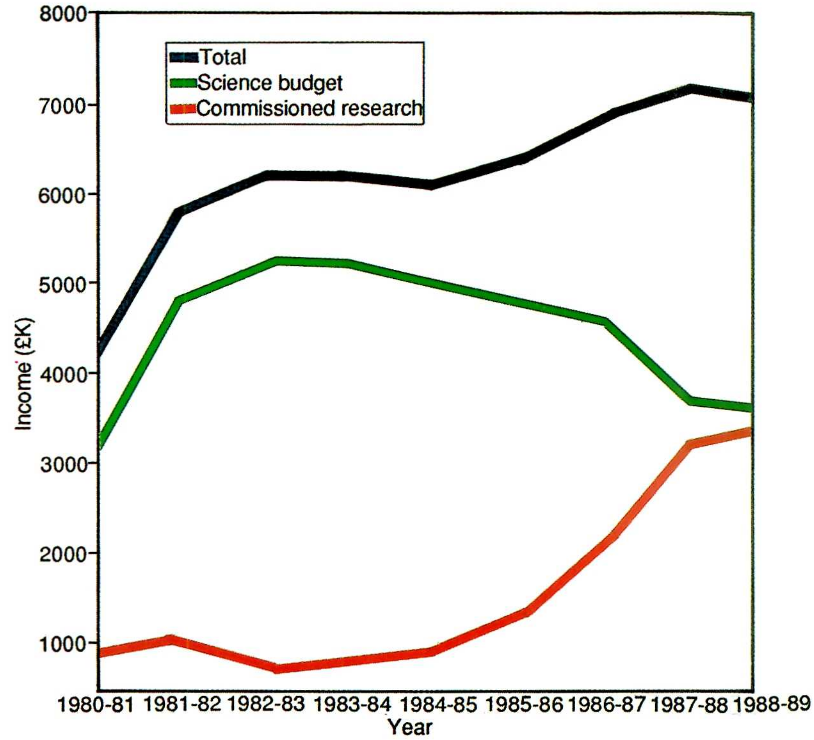
- increasing awareness of environmental issues – the 'green' movement
- increased demand for contract research
- re-organisation to meet the changing situation.

Environmental awareness

There has been a marked increase in awareness of environmental issues at all levels in society. This increased awareness has brought expertise in terrestrial ecology to the forefront in the quest for sustainable development and environmental protection. In particular, there has been a development in the awareness that man's actions can have ecological consequences on a regional and global scale, as well as at the local level.

The most widely publicised environmental issue is the 'greenhouse' effect, an issue which has been the focus of attention within research circles for many years, but for which evidence is now sufficiently strong for it to have captured the public and political imagination. The ITE research interest is in the factors which contribute to the increased concentrations of radiatively active gases (carbon dioxide, methane and others), the likely consequences of the increase in these gases, and the effects of the associated climatic changes. Although the global climatic predictions are reasonably precise, those at the GB scale are uncertain, especially in the combinations of temperature, rainfall and wind that are likely to change. Despite the lack of precision on the extent of climatic change, it is essential that the research on terrestrial causes and consequences is developed now – preventative measures in terms of sea defences and forest planting are better than remedial action after the event. Research on climatic change is discussed in the main report.

Environmental awareness has also been raised by problems in the North Sea, which are affecting birds as well as seals, by changes in land use and the susceptibility of rare species, by the continuing effects of acid deposition and Chernobyl and by the introduction of legislation on Environmental Impact Assessment (EIA). Responding to those issues is a major opportunity and challenge; the ability to respond depends on sustained high- quality science, based on detailed understanding of natural populations and processes.



most marked recent changes are the increased income from the Overseas Development Administration, reflecting tropical concerns, and from a variety of private sector commissions ('others'). The private sector interests range from EIA to product development, such as mycorrhizal inoculum for trees.

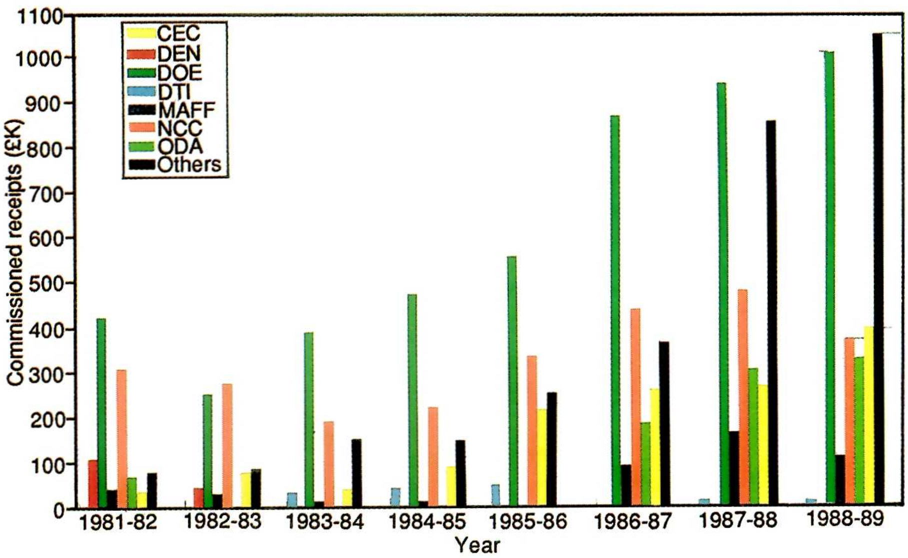
Demand for contract research

Demand for the Institute to carry out commissioned research projects continues to grow. Commissioned research now meets 47% of the Institute's income, and continues to offset the decline in Science Budget funds. As shown in the above graph, the ITE Science Budget funding was apparently static during the mid-1980s, but has declined sharply in the last five years. Income from commissioned research was less than 20–25% of total income up to 1985, but has risen sharply recently: a rise of more than 300% in five years. This increased income of about £2M results from the improved awareness mentioned above, combined with a vigorous marketing effort by the Institute staff. The sources of income, shown in the first graph overleaf, vary considerably, depending upon current issues, but the

However, despite the increases in demand for commissioned research, the general financial situation has forced a reduction in total numbers of staff by 25% since 1985 (see second graph overleaf).

Re-organisation

The re-organisation of the Institute into the Directorate of Terrestrial and Freshwater Sciences (TFS) in 1987 (along with the Institute of Hydrology, Institute of Virology, Freshwater Biological Association, and the Unit of Comparative Plant Ecology) and the subsequent restructuring of research work into Programme areas have produced a new focus. This re-organisation, along with the increasingly broad scientific base required by some contract work, has provided the stimulus for multidisciplinary research projects. Whilst the Institute of Terrestrial Ecology



continues to be managed as two components, (ITE(North) and ITE(South), each with its own Director), every effort has been made to operate as a cohesive unit in responding to environmental issues requiring a regional or national response.

The re-organisation of ITE and its research was subject to the appraisal of a Visiting Group which reported to the Natural Environment Research Council, and thence to the Institute, in 1988. The Group's general assessment of the scientific programme was '. . . that the science undertaken at ITE, together with that at UCPE, was a comprehensive reflection of the national research needs within terrestrial ecology and that there were no major gaps. The Institute has so far been able to maintain a breadth of expertise in basic research such that it can respond to the research and monitoring needs of major natural and man-made events'.

The Visiting Group emphasised the need to publish a greater number of papers in refereed science journals, and to concentrate more effort into larger units with a common scientific goal and increased emphasis on experimental approaches. This independent detailed review of present research and of proposed developments provides valuable guidance to management and research staff in the Institute. Various actions have been taken to follow up the recommendations, including the removal of areas of redundant science. Subsequently, the adjustment to larger groups or sections within each of the six Stations has provided a clearer focus and enhanced communication:

Monks Wood: conservation and management, agriculture/environment interactions, avian biology, ecotoxicology

Furzebrook: vertebrate ecology, ecological genetics, community ecology

Bangor: montane ecology, biogeochemistry, ecosystem responses to air pollution

Edinburgh: temperate tree biology, tropical forestry, atmospheric pollution

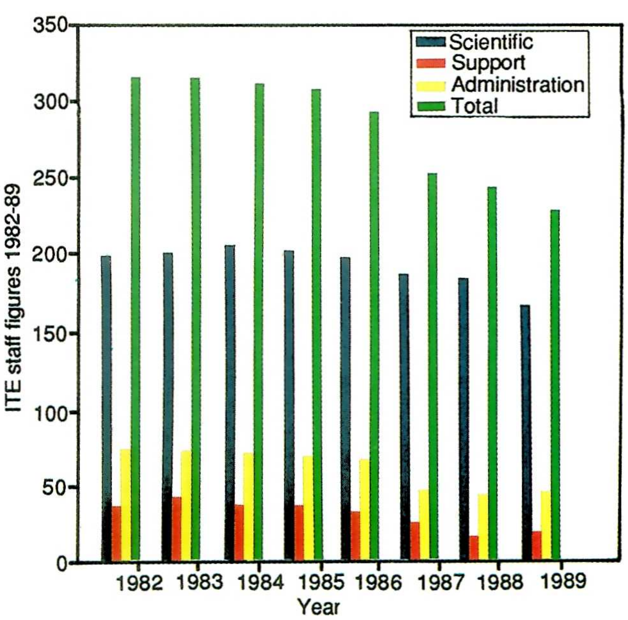
Merlewood: radioecology, soils and nutrient cycling, land use, forest ecology, chemical and stable isotope services

Banchory: vertebrate population dynamics, herbivore/plant interactions, human impact

A further major organisational change took place early in 1989, with the formation of an Environmental Information Centre (EIC) within the Institute. The EIC, located at Monks Wood Experimental Station, was officially opened by Lord Chorley in July 1989 (Plate 4). The four units within the Centre are concerned with data base management, remote sensing, geographical information systems, and biological recording. EIC will develop effective data base management and spatial analysis techniques within the Institute, and thereby promote research commissions in these general areas.

What of the future?

Council, through the Visiting Group, gave us clear general guidelines. Environmental awareness and concern should ensure reasonable opportunities to compete for commissioned and Science Budget funding, and the improved organisational structure with enhanced linkages with other institutes and universities can strengthen our



Figures on the three graphs revalued to 1988-89 prices using GDP indices research capabilities. What, then, are the areas of science that will provide the new foci? Three areas in which ITE is already involved are likely to show marked expansion:

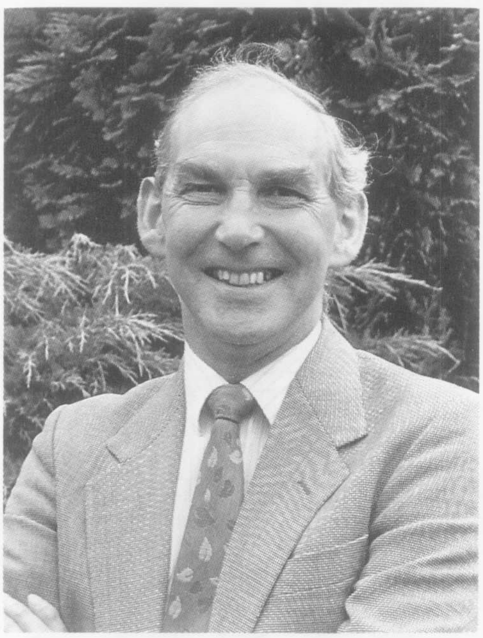
1. *Climatic change* and its effects are likely to be a central issue for some years to come. The subject is particularly relevant to ITE because of (i) its wide range of expertise, allowing integrated studies, (ii) its facilities, and (iii) its experience already developed in land/atmosphere interactions, and in collaboration with the other institutes and units of TFS.

2. The changing patterns of *land use* will continue to provide the stimulus for research on changing management practices and their effects. Set-aside, extensification, farm forestry, Environmentally Sensitive Areas, nitrate-sensitive areas, and other new schemes designed to control land use and its environmental consequences will require knowledge of ecological processes in determining the options for legislation and in assessing their effectiveness.

3. *Tropical regions* will be an increasing focal point for environmental and management research to meet the various needs of developing countries. ITE has developed a unique expertise in tree establishment, which is being applied in several countries. Plans are in hand to expand these activities, and to build on ITE's tropical experience in ecological processes and wildlife management.

Jack Dempster, the remaining member of the original Management Group, retired as Director ITE(S) in 1988. His contribution to ITE, through his extensive ecological knowledge, rigour and integrity, has been considerable. Fortunately, his talents will not be lost to ecology as he is redeveloping his abiding interest in population dynamics at Cambridge University. His place as Director ITE(S) has been filled by Dr T M Roberts, who has come from the Research Laboratories of the Central Electricity Generating Board, where he was Head of Terrestrial Ecology Research. His research experience includes the effects of air pollution on crops and trees, reclamation of derelict land, and environmental impact assessment, experience which is central to the research of ITE.

O W Heal
T M Roberts



Dr Heal

Dr Roberts

Forest science

The Forest Science Programme is concerned with strategic research on tree biology and forest soils, and on the ecology of forests and woodlands.

The tree biology research is focused on genetic improvement, stress physiology and growth modelling, and on the role of mycorrhizas in tree growth. A significant part of the research, financed partly by the Overseas Development Administration, involves tropical trees, and is exemplified by the work in Cameroon and Kenya reported first. The ecological aspects of woodlands include impacts on soils, and on the dynamics of populations of herbaceous plants and animals, as well as of the trees themselves. The results of two studies are described below.

Ecology of indigenous hardwood plantations in Cameroon

(This work was partly supported by funds from the Commission of the European Communities and the Overseas Development Administration)

The Institute of Terrestrial Ecology has been doing research on West African hardwoods for the last 15 years. Much of this research has been concerned with developing techniques of vegetative propagation which should increase plantation productivity by giving higher yields, better quality and shorter crop rotations. However, such gains will not be realised unless a sustainable and ecologically stable system of reforestation with indigenous trees is developed, and ITE's tropical forestry programme has recently been expanded to examine techniques for sustainable silviculture. Ecological studies of tropical forests have focused almost entirely on the natural forest ecosystem. Consequently, little is known about either the effects of different amounts of forest damage on the establishment, ecological stability and performance of such plantations, or, conversely, the effects of indigenous plantations of indigenous trees on the ecosystem. Damage to plantation sites arises from logging operations and the subsequent use of ecologically insensitive site preparation treatments. Throughout West Africa, very different forms of site preparation are used for local species like *Terminalia ivorensis*, *Triplochiton scleroxylon* and *Lovoa trichilioides*. These methods range from total forest clearance by bulldozer, to manual opening of the forest by machete. The former is very damaging to both the vegetation and the soils, while the latter retains most of the species diversity and does little, if any, damage to the soil.

Studies of some of the factors affected by the application of different methods of site treatment are in progress in the secondary, moist deciduous forest of Mbalmayo Forest Reserve in Cameroon (Plate 1). This research has been carried out in close collaboration with ONAREF (Office National de Regeneration des Forets) and with the University of Edinburgh. Three students from Cameroon, M Musoko, C P Ngeh and Z Tchoundjeu, have been responsible for much of the work.

Strategy

One-hectare research plots were established in 1987 and 1988, using three contrasting site preparation treatments:

1. total clearance by machine (bulldozer) (TC);
2. minimal clearance by hand (machete) (HC); and
3. partial clearance by machine (MC), with the retention of as many trees as possible and minimal damage to soil and ground flora.

In the first stage, the project has examined the changes that occur in the physical and chemical properties of the soil, and in the soil microflora (endomycorrhizal fungi), following the site preparation treatments. These changes have been compared with those in natural forest (uncleared) control plots (UC).

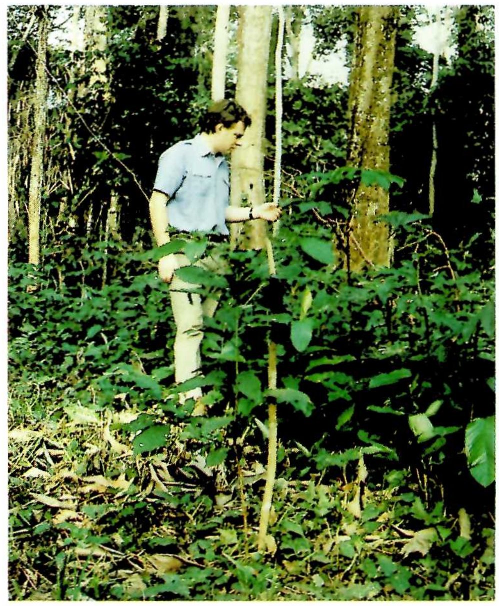


Plate 1. Assessing vegetation development on plots partially cleared by machine near Mbalmayo, Cameroon

The establishment of a temporal series of plots enables the study to be extended to an examination of vegetation succession, the insect population dynamics, and the effects of the different environments on physiological processes in the planted trees (Figure 1).

Three major sample sets were collected.

1. Prior to site preparation, samples were taken during the dry season (February) to provide a baseline for subsequent results.
2. A second sample was taken after site preparation, but just before planting.
3. The final sample was taken 12 months after planting.

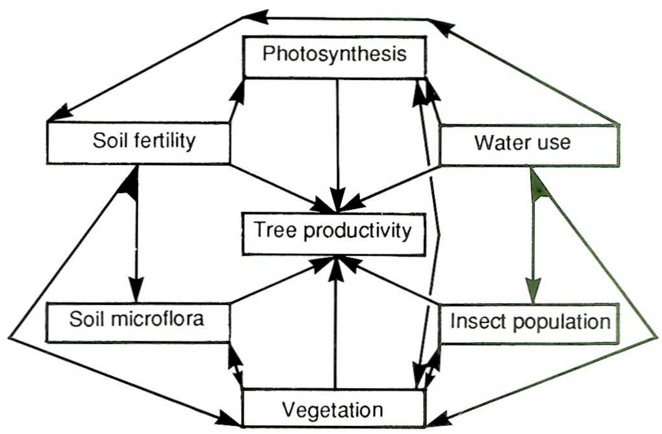


Figure 1. An ecosystem approach to the development of highly productive sustainable plantations of indigenous hardwoods in a moist deciduous forest in tropical Africa

Vegetation

An inventory of the area under study revealed that, on average, each hectare of the forest contains more than 160 trees with trunks larger than 20 cm diameter at breast height Over 200 species have been identified on the seven hectares studied so far

A major effect of site preparation, as yet unquantified, is the change in the vegetation Hand clearance retains most of the species diversity of the ground flora intact, while suppressing the growth of pioneer species and invasive weeds By contrast, total clearance removes the forest flora, which is quickly replaced by a small number of pioneer trees like *Musanga cecropioides* and *Trema guineensis*, and weeds like *Eupatorium odoratum* The mechanical partial clearance was intermediate in its effects

These changes in the vegetation are presumably related to changes in the physical environment, particularly the removal of shade, and to some extent soil disturbance After site preparation, light interception by the tree canopy (as measured by a quantum radiation sensor) was 98% in the natural forest control plots, and 80% and 70% in the plots which were partially cleared manually and mechanically There was, of course, no light interception under total clearance Consequently, air and soil temperatures were 4–5°C higher in the totally cleared plot than in the partially cleared plots

Such changes in vegetation and microclimate will, in turn, influence the population size, diversity and species dominance of the soil microflora, although higher soil temperatures may also play a part in the loss of viability of the fungal spores

Effects on soil microflora

The results, so far, indicate that Mbalmayo Forest is associated with about 26 endomycorrhizal fungi (many of which are as yet unidentified and may be new species), giving spore populations in the dry and wet seasons of about 310 and 150 spores per 100 ml of soil, respectively Samples collected in association with *T superba* trees had greater spore populations than those collected in open areas, and samples collected near the base of these trees also contained spores of a greater number of mycorrhizal species Generally, however, although more than 20 species occurred in all these samples, two species dominated and accounted for about 70% of the total spore population

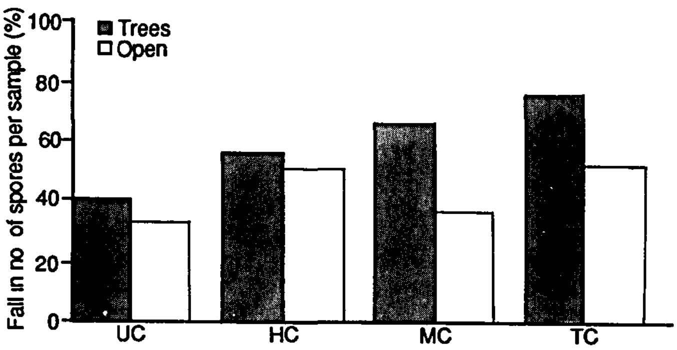


Figure 2 Effect of different methods of site preparation on the percentage reduction in numbers of mycorrhizal spores three months after site preparation Samples were taken along transects between trees and in the open (UC = uncleared control, HC = clearance by hand, MC = partial clearance by machine TC = total clearance by machine)

Spore populations declined following site preparation, this decline being greater the more damaging the system of site clearance, particularly in samples associated with *T superba* trees (Figure 2) The dominance of *Glomus aggregatum* and *Acaulospora scrobiculata* spores was reduced by both forms of mechanical clearance, just three months after site preparation, while *Acaulospora laevis* was virtually eliminated Twelve months after site preparation, these changes had advanced to the point where, with total clearance, two of the less common fungal species, C9 (*Glomus occultum*) and C22 (as yet unidentified), dominated the spore population, accounting for 61% of the total number of spores counted By contrast, under the partial clearance systems, this change in the dominant microflora did not occur The two fungi, C9 and C22, represented 20% and 25% of the spore numbers observed in the uncleared control and manually cleared samples, respectively Furthermore, of these two fungi, C9 in particular has been found to be strongly associated with the invasive weed *Eupatorium odoratum*

Effects on soil physical and chemical properties

Like the microflora, the major changes in the physical and chemical properties of the soil can also be attributed to changes in the physical environment and the vegetation Mechanical clearance, which also caused soil compaction, removed much of the litter standing crop, while manual clearance resulted in a litter increase of over 100% These organic inputs would have been even higher if the large stems and logs left on the site had been included To this direct effect of clearance can be added the effects on subsequent litterfall (Figure 3) Between nine and 12 months after clearance, litterfall in the partially cleared sites was about 50% that of the natural forest, while with total clearance it was only about 10% Not only was there less litterfall on the totally cleared plots, but there was also a substantial reduction in the nutrient content of the fallen litter The amounts (g m^{-2}) of nitrogen, phosphorus, potassium, calcium and magnesium in the litter collected in the totally cleared plot were, respectively, 17%, 15%, 6%, 9% and 13% that from the manually cleared plot Furthermore, the decomposition rate of the litter from the completely cleared plot was slower than that from the other treatments, resulting in approximately a doubling of the time taken to break down the litter completely

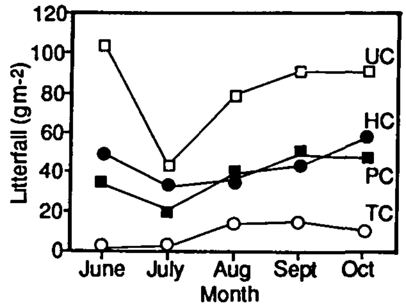


Figure 3 Seasonal variation (1988) in the mean total monthly litterfall in differently prepared planting sites (key as in Figure 2)

Against the above background of organic nutrient cycling, there was a contrasting situation regarding inorganic nutrients Both the plots cleared either totally or partially by bulldozer developed high soil nutrient concentrations during the dry season, presumably reflecting the favourable conditions (high light and temperatures) in these plots for soil weathering In the following wet season, leaching losses were high in the totally cleared plot The deep litter layer of the manual plot, however, greatly reduced the amount of light reaching the soil

The method of site preparation had profound effects on the young *T ivorensis* trees, which were planted at 5 m x 5 m spacing Establishment was worst in the completely cleared plot, where there was nearly 20% mortality, compared with 7–10% in the other plots (Figure 4) With

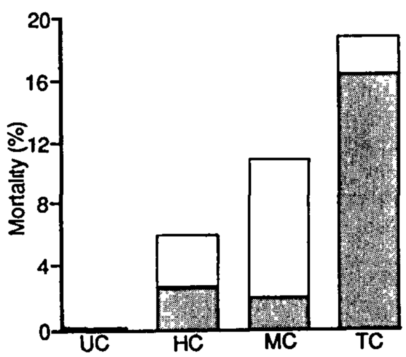


Figure 4 Tree mortality since planting recorded in February (shaded histogram) and July (unshaded) 1988 (key as in Figure 2)

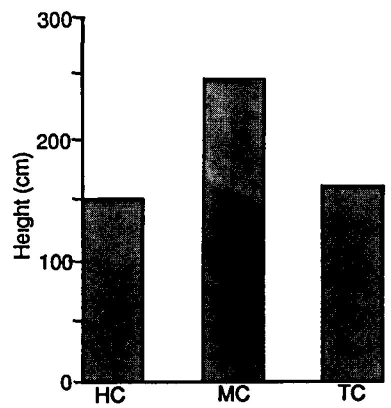


Figure 5 Effects of site preparation treatment on the height of planted *Terminalia ivorensis* trees one year after planting (key as in Figure 2)

complete clearance, some of the mortality was attributable to waterlogging during the wet season and some to drought during the dry season Once established, however, the trees on the fully cleared site grew well, although they required more frequent weeding and maintenance than on the other plots (Figure 5) Growth rates (height and diameter) were, however, fastest in the plot partially cleared by bulldozer It is probable that light levels were limiting in the manually prepared plot This hypothesis is being tested in more recently established plots

Conclusions

Site preparation has profound effects on the soil microflora and nutrient cycle, and on the successful establishment of plantation trees The minimisation of damage with the retention of both the tree and ground flora can have major beneficial effects on the maintenance of a stable ecosystem While the growth of the planted trees on the totally cleared site was good, it is unlikely that this system of silviculture will be sustainable It is clear that the trees on this site were dependent on the nutrient capital of the soil, rather than on recycled organic inputs Furthermore, the impoverished and completely changed soil microflora may have serious later effects on sustainable growth, such as have been reported for *T ivorensis* plantations in Ghana and the Ivory Coast where, on poor soils, the crop died after 8–10 years' growth In addition to these soil-based criteria for sustainability, the reduced species diversity of the vegetation following total clearance may lead to increased risks of pest problems in the planted trees These problems could result from interferences to both the life cycles and food chains of the pathogens, parasites and predators of the potential pests It is clear, therefore, that profitable reforestation must incorporate sustainable silviculture practice, and that commercial interests are compatible with environmental objectives for tropical forest conservation

R R B Leakey

Tree establishment in semi-arid areas of Kenya

(This work was supported by funds from the Overseas Development Administration)

'Tree planting has reached the proportions of a national crusade in Kenya' (Harrison 1987) In a contribution to this effort, the Overseas Development Administration is funding work to investigate methods of improving tree establishment and growth in semi-arid areas, and a team from ITE Edinburgh is collaborating with the National Museums of Kenya (where nursery and glasshouse facilities have been established) and Nairobi University The project focuses on locally important multi-purpose tree species appropriate for agroforestry, and incorporates a novel approach for solving the problems of their establishment and improving the subsequent performance of both the trees and their associated intercrops Studies on root microsymbionts (endomycorrhizal fungi and rhizobial bacteria), which are beneficial to plant growth, are being combined with studies on the vegetative propagation of trees and the selection of superior clones In addition to this work which exploits biological variation, the effects of incorporating a water-holding polymer into the rooting medium and planting hole are also being assessed, the polymer having already been shown to improve establishment in the Sudan by retaining moisture

It is well established that, under normal conditions, root microsymbionts are essential for plant growth The endomycorrhizal fungi (the dominant mycorrhizal fungi of the tropics), like their ectomycorrhizal counterparts, improve the uptake of water and nutrients from the soil They also have a number of other beneficial functions Rhizobial bacteria fix atmospheric nitrogen, making it available for use by its host plant Such symbionts usually occur naturally in soil and are available to infect plants, but they may be in short supply in degraded or disturbed sites and may also be deficient in tree nurseries The effectiveness of these fungi and bacteria varies greatly, and is linked with their ability to tolerate site conditions and to interact with the host plant This factor can be exploited, and selections can be made of those microsymbionts which are well adapted both to site conditions and

Plate 2 Collecting soil samples for assessing endomycorrhizal spore populations near Marimanti, Kenya

to interact with the host plant. This factor can be exploited, and selections can be made of those microsymbionts which are well adapted both to site conditions and the host, so increasing overall productivity. ITE is investigating whether such selections are beneficial for tree establishment on semi-arid sites in Kenya and, because both trees and annual crops may be endomycorrhizal with the same species of fungi, also whether inoculation of trees with selected endomycorrhizal fungi will benefit interplanted cross-infected crops, such as millet or cowpea. The benefit may result from an enhancement of the processes of nutrient cycling and the provision of a favourable environment for the intercrop growth of healthy trees. It may also result from an accumulation of populations of beneficial inocula in the soil. The trees may provide a sustained resource of viable inoculum for the intercrops which would otherwise be reduced or lost between harvesting one crop and growing the next.

In addition to the variability in effectiveness of the symbionts, there is the great genetic diversity in trees – the conditions under which they thrive, their growth rates, and their form. The attributes of superior individual trees may be exploited through clonal selection, and experimentation with vegetative propagation and stockplant handling will identify how these superior trees can be made widely available. Integrating microsymbiont selection with tree selection has great potential for all types of forestry, especially on difficult sites, as in Kenya.

The introduction of exotic trees for forestry in many parts of the world has provided numerous examples of the need to introduce appropriate ectomycorrhizal fungi, but problems with the endomycorrhizal flora have been little appreciated. Recent work in the humid tropics in Cameroon suggests that indigenous populations of endomycorrhizal spores, both total numbers and numbers of species, are strongly influenced by site disturbance (pp 4–6). Evidence from a number of other sources suggests that the infection of plants by endomycorrhizal fungi may be reduced by site treatments, such as fallowing, or disturbance, because of adverse effects on inoculum potential. Hence, the establishment of trees on degraded land may be hindered by an inadequate endomycorrhizal flora which, in the absence of inoculation, only recovers slowly, as endomycorrhizal spores are produced below-ground and are not readily dispersed.

Experiments on native and exotic trees

Four tree species have been selected for initial studies: *Acacia tortilis*, *Terminalia brownii* and *T. prunioides*, all indigenous to Kenya, and *Prosopis juliflora*, a widely planted exotic. The *Acacia* and *Prosopis* species are both nitrogen-fixing. *A. tortilis* is widely used for making charcoal and its pods and leaves are good animal fodder; it favours alkaline soils. *P. juliflora* is primarily used for firewood, it makes good charcoal and is a valuable source of fodder; it is both salt- and drought-tolerant. *T. brownii* is a good source of termite-resistant timber, and is used as a medicinal plant. *T. prunioides*, like *T. brownii*, is a valuable timber tree.

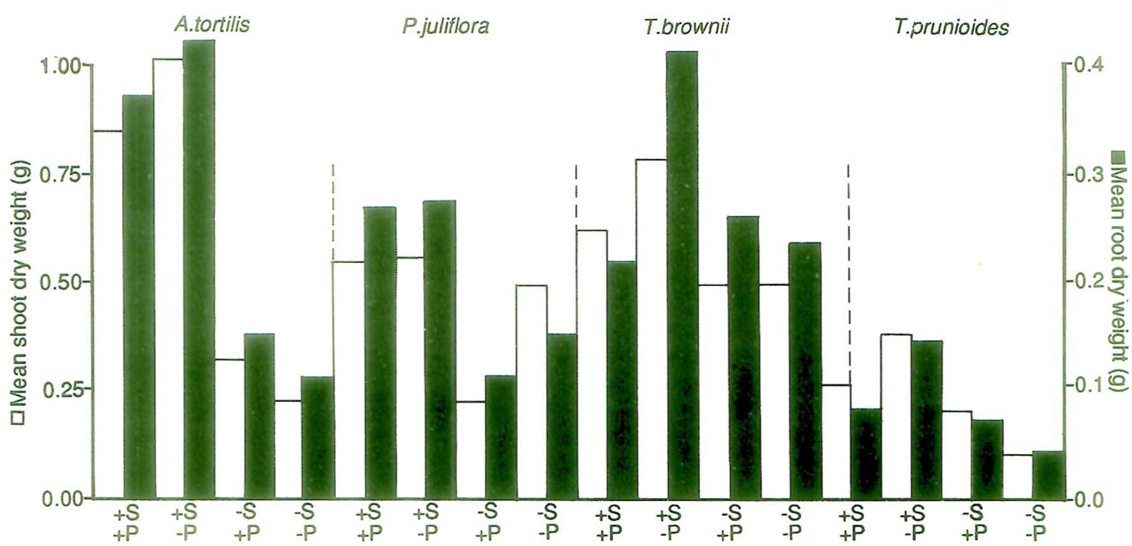


Figure 6. Mean shoot and root dry weights of plants with and without symbiont (+S,-S) and with and without polymer (+P, -P) at Olorgasailie and Marimanti at planting time

A range of endomycorrhizal inoculants has been collected locally for testing, together with rhizobia of various origins The use of predominantly local tree species and inoculants should ensure optimum suitability for the prevailing site conditions

Microsymbiont studies are continuing in glasshouse, nursery and field experiments Tree seedlings are being used at present, while studies which combine tree clones and selected microsymbionts will commence later this year Trees are treated in the nursery with mixed endomycorrhizal inocula, originating from plants of the same species but bulked up on the roots of maize and cowpea Where appropriate, they are also inoculated with *Rhizobium* and polymer is mixed with the rooting medium

Trees produced in this manner have been planted out in experiments at two contrasting semi-arid field sites, Marimanti (Plate 2) and Olorgasailie, which have average annual rainfalls of 847 mm and 476 mm respectively The former of these two sites is climatically the more favourable for growth, and also has a less alkaline soil although a hard-pan is present Factorial experimental designs have been used at each site, testing the effects of inoculation and use of polymer on the growth and survival of each tree species Plants were grown in the nursery in Nairobi, and were then transferred to field nurseries at their respective sites to acclimatise to higher temperatures and reduced water regimes for a few weeks before planting

The effects of the experimental treatments upon plant growth became apparent in the Nairobi nursery prior to planting Inoculation tended to improve both shoot and root growth, while the effects of polymer were variable, overall, inoculated plants performed best without polymer (Figure 6) A number of other growth parameters was assessed at the time of harvest, including the extent of mycorrhizal infection on the root system A strong correlation was found between infection and other growth parameters including plant height and root dry weight, in that large plants had a greater proportion of their root systems mycorrhizal than small plants (Figure 7) Since planting, the treatments have affected growth and survival differently at the two sites At Olorgasailie, significant differences in survival were found between the factorial combinations of symbiont and polymer for all species except for *P juliflora*, whereas, at Marimanti, they were found for all species except for *T brownii* Where symbiont effects were significant, plant survival was increased by an average of 19% Polymer had no significant effects upon survival of any species at Marimanti and, unexpectedly, reduced survival of the two *Terminalia* species at Olorgasailie, by 23% Although strong treatment effects have been found, these data should be treated with some caution, as the weather in Nairobi and at the field sites has been unusually cold and wet The symbionts and polymer have not, therefore, been tested under the conditions for which they were intended

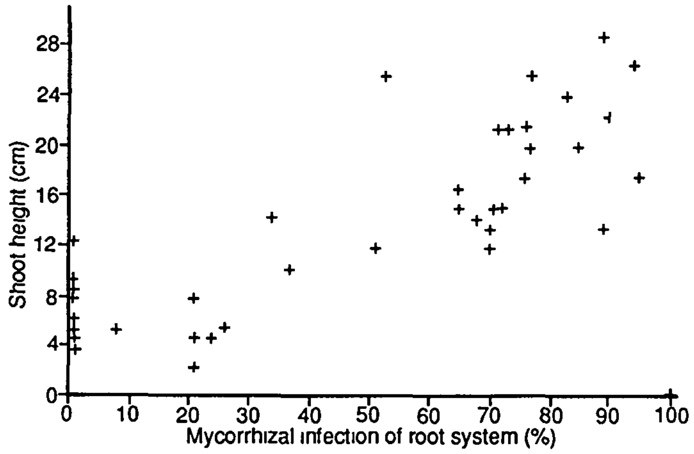


Figure 7 Growth of *Acacia tortilis* before planting at Marimanti relationship between shoot height and mycorrhizal infection (correlation significant at $P<0.001$)

Vegetative propagation experiments are in progress to determine the optimum conditions for rooting cuttings of the experimental tree species Soil conditions of the stockplant, length of cutting and its location on the stockplant are among the variables being tested *P juliflora* has been the easiest species to root, and an important experiment has compared the rooting ability of its cuttings when placed in a non-mist propagator, an open-mist propagator, or an enclosed-mist propagator Large differences in rooting ability and mortality were observed, with rooting being best and mortality lowest in the non-mist propagator (Figure 8)

Future options for improved planting

Progress made on this project has been promising Preliminary experiments have shown that inoculation with symbionts can improve both the growth and survival of trees, that some symbiont/host combinations are more effective than others, and that polymer either has no effect upon survival or reduces it Cuttings have been successfully rooted in the vegetative propagation experiments, and it is encouraging to note that the

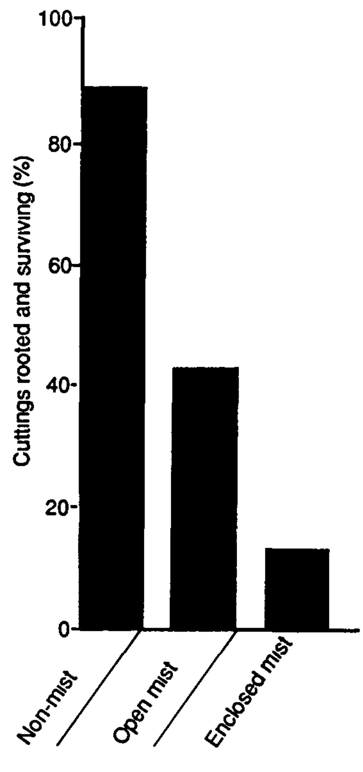


Figure 8 Vegetative propagation experiments effects of different environments on the rooting of *Prosopis juliflora* cuttings

most successful rooting has been in the low-technology non-mist propagator which is highly appropriate for developing countries It is possible that the full potential of the experimental treatments has not yet been shown because the unusually wet weather may have influenced the outcome of the field trials described Further experiments are in progress, and are planned to optimise host/symbiont combinations, to incorporate intercrops, and to develop a technology which is applicable at the village level

J Wilson

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Changes in species composition of a mixed deciduous woodland

The longevity of trees, compared with other organisms, often limits experimental and observational studies of forest development to providing 'snapshots' in the life of the forest This limitation is especially relevant when the interest is in successional changes involving several generations of trees Computer models which incorporate both theory and real data allow the dynamics of forest development to be simulated over selected, and if required long, periods of time and can be used to give guidance for management, whether for wood production or species conservation The models must, of course, be carefully tested before they can be used with confidence

The likely changes in the biomass and species composition of a mixed deciduous woodland have been explored at ITE's Merlewood Research Station by Harrison and Ineson (1987), using a computer model FORTNITE (Aber & Melillo 1983) which was originally developed by American research workers This model gave predictions of changes over a period of 100 years in Meathop Wood, Cumbria, a site which was studied intensively during the International Biological Programme and whose history is reasonably well known The FORTNITE model is focused particularly on the constraints to growth imposed by nutrient availability, which is related closely to decomposition of the annual litter input

Simpler models are available which use less explicit consideration of nutrient availability by setting an upper limit for total biomass and simultaneously reducing the growth rates of all tree species as this limit is approached These simpler models have the advantage that they do not require information on litter inputs, decomposition rates and nitrogen mineralisation, which are rarely available except at research sites, and the models therefore appear to have wider applicability One such model, FORET (Shugart & West 1977), developed for use in the deciduous forests of the Appalachians, concentrates on the growth of trees and their interactions with climate, light availability and crowding, and is being examined using data from Meathop Wood

The FORET model

The model consists mainly of four parts, each within its own subroutine

1 Subroutine BIRTH The decision as to whether new individuals are introduced into the simulated forest sample plot uses a series of 'switches', which are logical variables carrying either true or false values The ecological requirements of the species are specified in the first set of 'switches' A second set of 'switches', calculated by the simulator for each year, describes conditions on the sample plot following the previous year's simulation By comparing these two sets of 'switches' the model deduces whether new seedlings of each species have the potential to appear Random processes then determine how many individuals, if any, of each species will appear

2 Subroutine SPROUT If a tree of a pre-specified diameter dies and it is of a species which normally sprouts, a random selection is made of which species and how many sprouts will be allowed to grow

3 Subroutine GROW The growth of trees is based on an empirical growth equation which relates growth to tree size, shading by overtopping trees, and crowding from other trees in the sample plot Other factors, such as the climate at the site and the ability of each species to tolerate shade, are also taken into account

4 Subroutine KILL Trees are killed on the basis that only 1% of them will reach their expected maximum age and that a proportion of those which have grown very little in the previous year will die

A FORET simulation

A simulation covering 600 years, and using as a starting point data on tree diameters collected in 1967, is shown in Figure 9 for the main tree species, oak (*Quercus petraea*), ash (*Fraxinus*

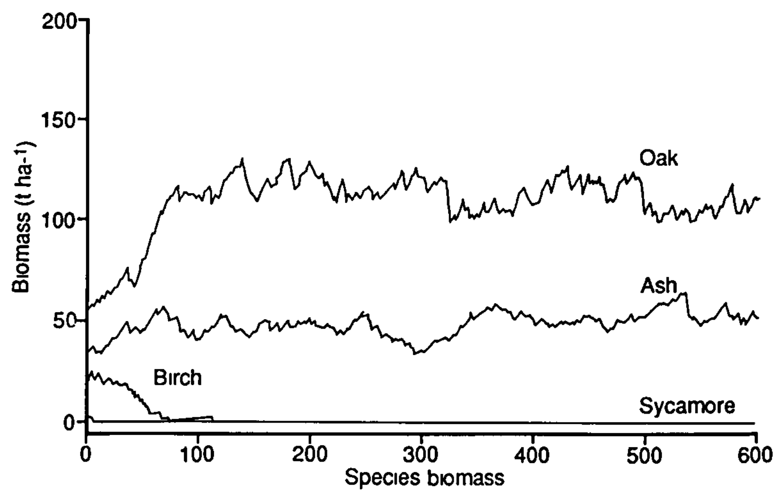

Figure 9 Biomass predictions of the main tree species in Meathop Wood over a 600 year period made by the FORET model

excelsior*), birch (*Betula pubescens* and *B. pendula*), and sycamore (*Acer pseudoplatanus*). By the middle of the next century, it is predicted that both oak and ash will reach a fairly constant biomass, but birch will have almost totally disappeared. Sycamore, which made only a small contribution to total biomass in 1967, is predicted to play no part in the stand after the first 20 years.

Actual changes in Meathop Wood

How well the predictions relate to reality can be judged by comparing them with actual measurements made in Meathop Wood in 1988. Meathop Wood is mainly composed of deciduous species – oak, ash, birch and sycamore, with an understorey of hazel (*Corylus avellana*) and several other infrequently occurring shrubs (Plate 3). The wood has been cut periodically over a long period under the coppice-with-standards system, and it is believed that the present stand results from regeneration following a number of fellings, the oldest trees pre-dating a felling in 1892 and many others resulting from the most recent coppicing in 1939. Apart from the occasional intrusion of sheep and scientists, the wood has been allowed to develop naturally since 1939.

Plate 3. A mixed deciduous woodland canopy of oak, ash, birch and sycamore at Meathop Wood, Cumbria

The number of stems of different species on two occasions, 1967 and 1988, provides one indication of changes occurring in the stand (Table 1). The three main species, oak, ash and birch, showed net losses, whilst the number of sycamore stems, still a relatively minor component, almost doubled.

The net change in numbers is made up from the difference between net recruitment, ie ingrowth occurring during the period and surviving to 1988, and mortality of stems recorded in 1967 which failed to survive to 1988. The most striking changes were in birch and sycamore, where opposite trends were occurring. Ingrowth of birch stems was negligible, whilst 52% of the original

Table 1. Number of stems ha^{-1} recorded in 1967 and 1988, in Meathop Wood

Tree species	1967	1988	Stems ha^{-1} Netr[1]	Mort[2]	Surv[3]
Oak	332	263	18	87	74
Ash	266	210	30	86	68
Birch	124	64	5	65	48
Sycamore	25	45	26	6	76

[1] Net recruitment, ie ingrowth surviving to 1988
[2] Trees recorded in 1967 failing to survive to 1988
[3] % 1967 stems surviving to 1988

Table 2. Basal area of the main species measured in 1967 and 1988, in Meathop Wood

Tree species	1967 Ba ha^{-1} (m^2)	1967 % total	1988 Ba ha^{-1} (m^2)	1988 % total	% change in basal area
Oak	7.9	45	11.6	47	+54
Ash	5.9	34	8.0	33	+32
Birch	3.1	18	3.5	14	+5
Sycamore	0.7	4	1.0	4	+5
Total	17.5		24.2		

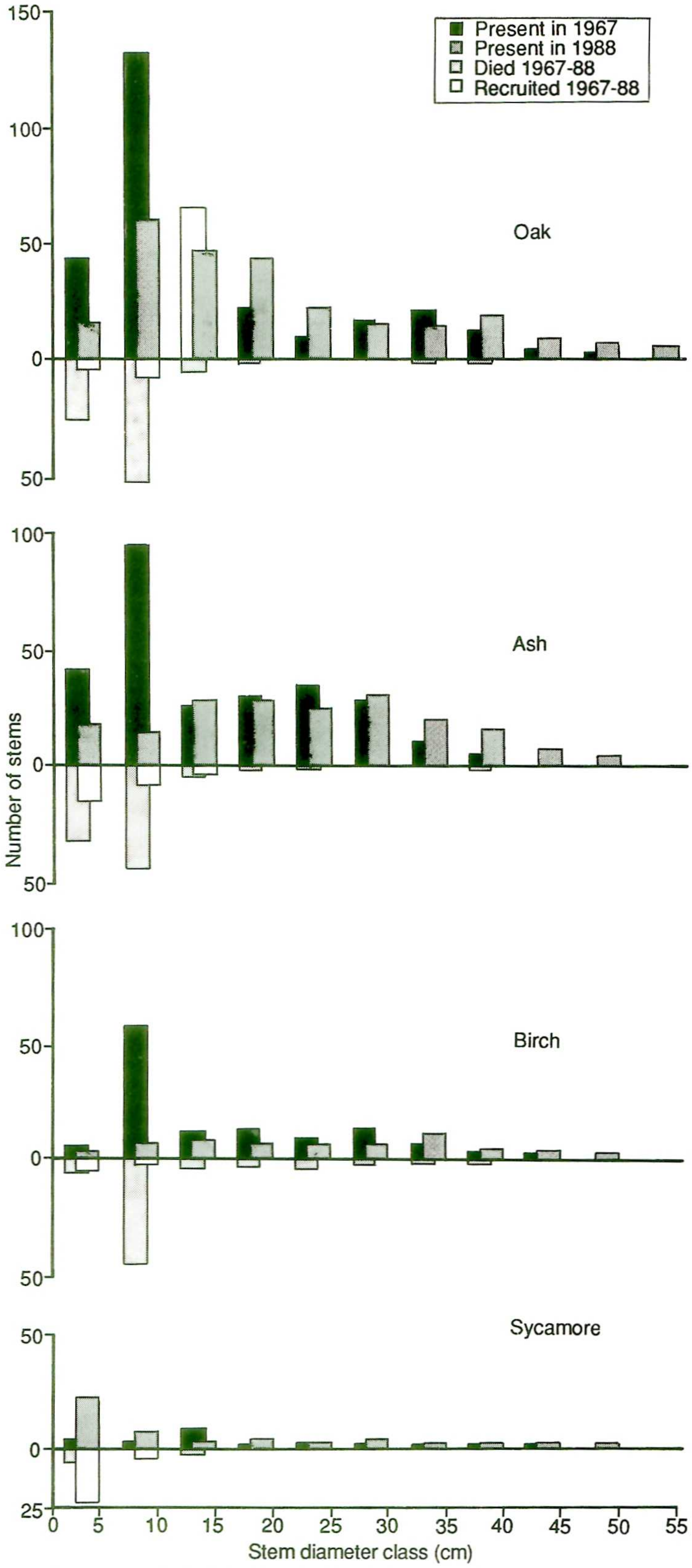

Figure 10. Frequency distributions of tree stem and diameter in Meathop Wood, measured in 1967 and 1988, and of stems dying and recruited

stems died; net recruitment of sycamore stems more than doubled the original number, whilst 24% of the original stems died. Fewer birch stems died than either oak or ash but, as a percentage of the 1967 numbers, birch mortality was by far the greatest.

Frequency distributions of diameter size classes are shown in Figure 10. The marked skewness and kurtosis shown by oak and ash in 1967 and the bimodal tendency, which reflected the two major age classes resulting from fellings in 1892 and 1939, had all been reduced by 1988. This reduction was caused by high mortality in the smaller size classes and the progression to higher diameter classes as a result of growth. The pattern for birch was similar, except that a greater proportion of trees in the 6–10 cm class died without replacement and more, larger trees also died.

Table 2 shows the basal areas, which are closely related to volume and biomass, of the four species in 1967 and 1988. Total biomass increased by 6.8 m^2, or 38%, and the relative dominance of the species changed. Change in basal areas for a species, expressed as a percentage of the total basal area growth for all the species, is a measure of this relative dominance, and it is evident that oak and sycamore improved their position at the expense of ash and, particularly, of birch.

The changing competitive relationship is further indicated by estimates of the compound rate of change in basal area of the four species:

$$X_2 = X_1 e^{r(t_2 - t_1)}$$

where X_2 = basal area of a species in 1988,
X_1 = basal area of a species in 1967,
t_2 = 1988,
t_1 = 1967, and
r = compound rate of change

The equation can be solved for r and results in the following compound rate of change:

oak	r = 1.84
ash	r = 1.53
birch	r = 0.61
sycamore	r = 1.93

which again demonstrates the relative decline of birch and the improved position of oak and sycamore.

It is clear that this simulation accords reasonably with the facts, as far as birch is concerned This pioneer species is relatively short-lived and, whilst it is able to regenerate following clearfelling or heavy coppicing, as in 1892 and 1939, the smaller gaps created naturally by the deaths of trees may be inadequate to allow regeneration Predictions about the future role of sycamore seem more doubtful, although it is still only a minor contributor to the stand, its aggressive nature is well known and it could be expected to play an increasing role in the wood It is obvious that some of the assumptions made in the model need to be re-examined more critically, as do some of the parameter values used, for instance to control the growth rates of different species, to establish whether and at what rate a species may regenerate from seed or by vegetative means, and to determine the expected maximum age of a species at the site Nevertheless, predictions which differ from known facts help to identify areas where knowledge needs to be strengthened or improved

J M Sykes

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Biogeochemistry of afforestation in upland Wales

(This work was partly supported by funds from the Department of the Environment and the Welsh Office)

Much of upland Wales is underlain by slowly weathering bedrock of lower Palaeozoic age, containing small amounts of base cations such as calcium and magnesium The soils developed from these rocks are acid, and contain large quantities of readily exchangeable aluminium Naturally, acid peats and peaty topsoils are widespread, resulting from a combination of high rainfall and relatively low temperatures limiting the decomposition of organic matter These upland areas are, therefore, naturally acidic and susceptible to further acidification by acidic deposition and certain land management practices (Figure 11)

In the rural uplands of Wales, rainfall has a low solute content and is moderately acidic (pH *c*4 7) Sea-derived sodium, chloride and magnesium are the major constituents, and concentrations of non-sea sulphate and nitrate are amongst the lowest in the UK However, the high annual rainfall leads to relatively high rates of solute deposition, especially in north Wales

Large-scale afforestation with exotic conifer species in the UK has been concentrated, for the last 40 years, in the uplands The streams and rivers of these areas are important as plentiful supplies of pure water and as sports fisheries Recently, much concern has been expressed over the possible environmental effects of widespread conifer afforestation on upland stream ecosystems In Wales, ITE has been studying these problems in collaboration with the Institute of Hydrology, the Forestry Commission and the Welsh Water Authority at three main sites Beddgelert forest, Plynlimon and Llyn Brianne (Figure 11) The research has focused on how afforestation has changed soil and stream water chemistry in the uplands, and studies of the processes controlling nutrient cycling have led to the development of forest management options to minimise effects on water quality

Interactions between the forest canopy and the atmosphere

The development of the forest canopy in the moist windy uplands increases the amount of water lost by evaporation (interception loss), thus reducing the amount of rainfall which reaches the ground At Plynlimon and Beddgelert, this loss amounts to approximately 24% of the incoming precipitation Any solutes contained within the evaporated precipitation stay on the needles to be washed off by the remaining water as it passes to the ground as throughfall and stemflow

The tree canopy also acts as an efficient filter of the atmosphere, capturing aerosols, mist and cloud droplets The latter usually contain very high concentrations of solutes, representing an input additional to the evaporative/ concentration effects already mentioned Dry deposition of gases on to and into leaves also occurs For nitrogen gases, dry deposition will be greater to the forest canopy, whereas sulphur dioxide deposition will be similar for both forest and grassy vegetation (Fowler, Cape & Unsworth 1989)

The combined effect of these processes is to increase the concentration of most solutes reaching the ground in throughfall beneath, for example, Sitka spruce *(Picea sitchensis)*, compared with the pre-existing mat-grass/fescue (*Nardus/ Festuca*) vegetation or an open raingauge (Table 3) This comparison is an oversimplification, however, as the age and species of tree will obviously influence the concentration of solutes in throughfall (Table 3) Independent of deposition, canopy leaching of nutrients, such as potassium, which have been cycled by the vegetation, will further supplement solute concentrations in throughfall compared with an open rain collector

Soils and soil water chemistry

Afforestation has increased the concentration of most ions in the soil solution compared with soils under grassland, with the largest increases observed for aluminium, sulphate, chloride and organic anions (Table 4) Ion exchange, driven by the increased anion concentrations, may be the proximal source of aluminium, although some increase in weathering must also

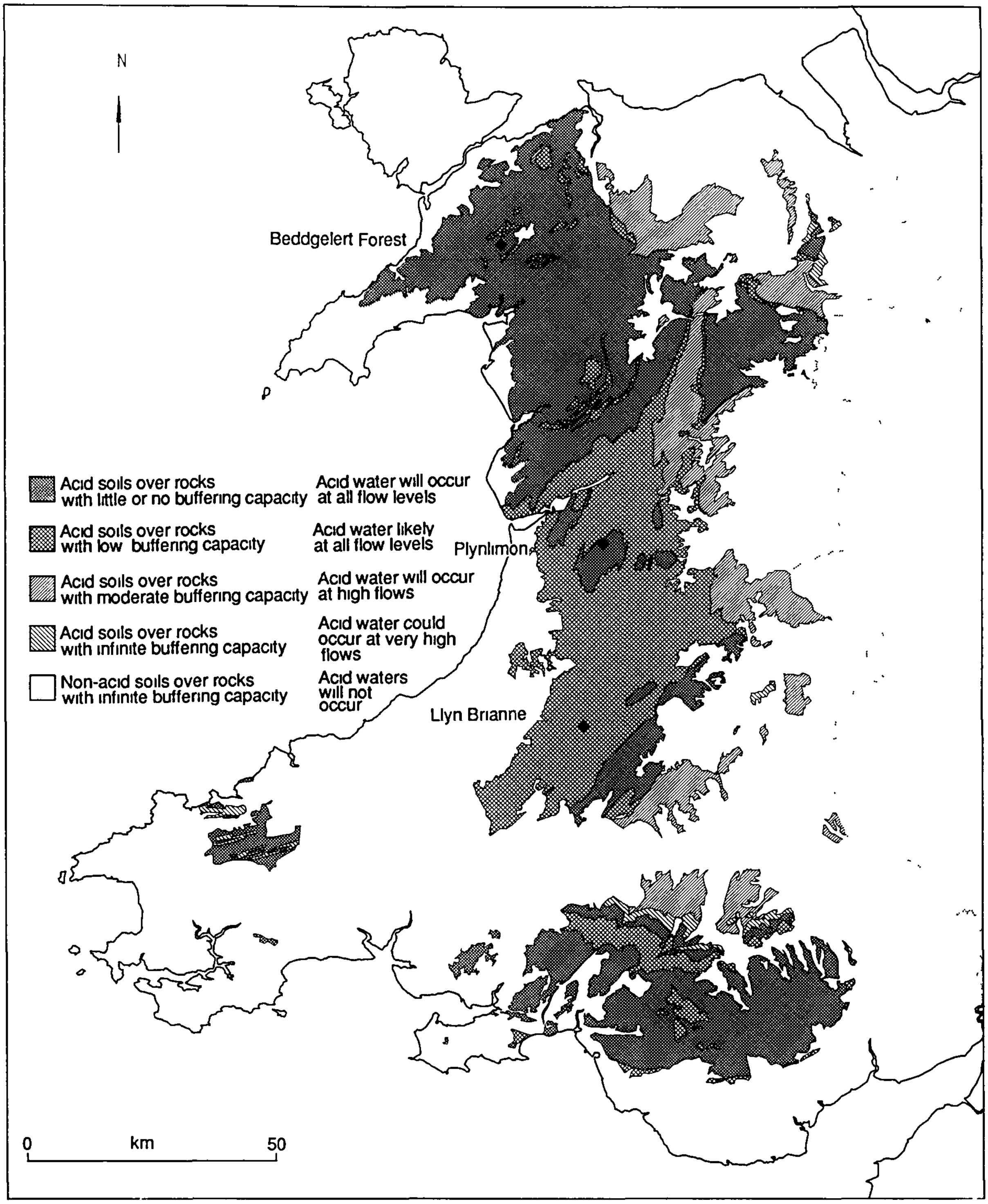

Figure 11 Location of ITE study sites in Wales shown in relation to the predicted occurrence of acid waters in Wales (Hornung *et al* 1989)

Table 3 Volume weighted mean solute concentrations (μeq l⁻¹, except pH) in bulk precipitation and throughfall at Plynlimon and Beddgelert

	pH	K	NO_3	SO_4	Cl
Plynlimon					
Precipitation	4 6	2	12	51	105
Mat-grass/fescue	4 6	38	4	53	124
Sitka spruce (P 1949)	4 5	43	10	107	152
Japanese larch (P 1949)	4 0	31	9	136	156
Beddgelert					
Precipitation	4 5	2	15	50	113
Sitka spruce (P 1979)	4 4	38	32	112	296
Sitka spruce (P 1971)	4 4	43	24	131	237
Sitka spruce (P 1951)	3 9	26	38	137	276
Sitka spruce (P 1936)	4 0	28	49	144	389

Table 4 Arithmetic mean solute concentrations ($\mu eq\ l^{-1}$) in soil waters at Plynlimon

	Horizon	Al	SO_4	Cl	Organic anions*
Grassland	Oh	29	68	124	50
	Eag	55	87	209	30
	Bs	44	71	184	35
	C	66	77	202	27
Forest	Oh	46	108	135	88
	Eag	132	159	233	139
	Bs	162	206	327	56
	C	169	186	281	65

* Difference between sum of cations and sum of anions

have taken place (Neal *et al* 1989). The greater soil water anion concentrations in the forest reflect the increased concentrations in throughfall. In contrast to many Scottish forests, there is active nitrification in Welsh forest soils, particularly in the older crops, which leads to significant concentrations of nitrate in the soil solution. Soil water sulphate concentrations may be further enhanced by increased mineralisation of organic sulphur compounds in the drier forest soils. In addition, as the plantation develops, needle litter accumulates on the forest floor. This layer is commonly more acid than the surface horizons of the underlying, pre-existing soil, and provides a source of organic acidity.

Tree species and age also influence soil solution chemistry. At Llyn Brianne, aluminium concentrations were greater in soils below larch (*Larix* spp.) compared with Sitka spruce of similar age and on similar soils (Figure 12). Soil water sulphate and chloride concentrations were little different between the two species, although concentrations of nitrate were significantly higher below the larch. Of particular interest is the observation that soil water aluminium concentrations beneath 25-year-old Sitka spruce are more than double those beneath pre-canopy closure 12-year-old Sitka spruce (Figure 12). Indeed, aluminium, sulphate and chloride concentrations beneath the younger spruce are very similar to those beneath moor-grass *(Molinia)*, a major change in solute chemistry may, therefore, take place over a forest rotation.

Many semi-natural upland grassland ecosystems are in a state of equilibrium, such that there is no net accumulation or loss of biomass. In these systems, nutrient uptake by vegetation is balanced by decomposition and mineralisation. Even where the grassland supports low-intensity grazing, losses of major nutrients from the system remain low (Reynolds, Hornung & Stevens 1987). As the forest grows, trees accumulate nutrients in the biomass, leading to a large net removal of nutrients from the site at harvesting. For soils with a low base cation content, this removal may represent a major depletion of the element store (Stevens *et al* 1988).

In addition to changes in soil water chemistry, the hydrology of the soil is altered during ground preparation and forest growth. In many older forests, areas with poorly drained and/or iron-pan soils were ploughed and drainage ditches were dug to stream margins. The main effect was to allow direct and rapid transport of soil-derived water, which is acid and aluminium-rich, to the main stream channel during storms. This process was assisted by the development of drying cracks and root channels within the soil resulting from the increased interception losses and root development with tree growth. Indeed, under stormflow conditions, forest ditches may themselves act as sources of aluminium to the main stream channel (Reynolds & Hughes 1989).

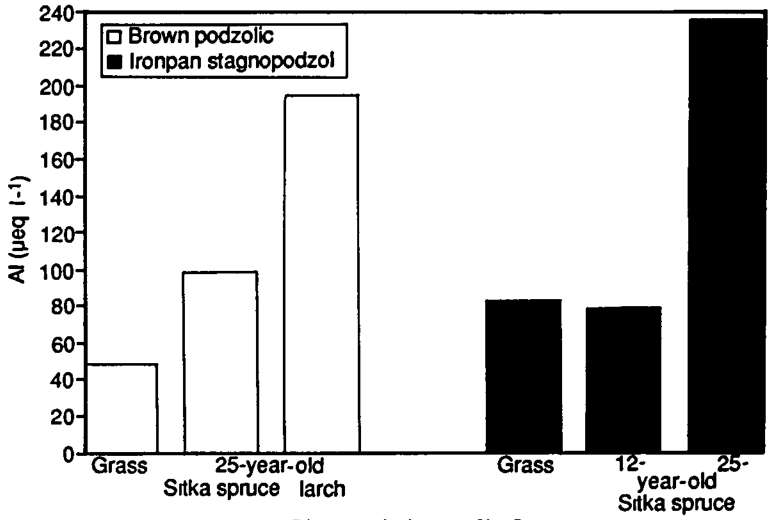

Figure 12. Aluminium concentrations in B-horizon soil solutions at Llyn Brianne

Table 5 Mean stream water solute concentrations ($\mu eq\ l^{-1}$, except pH and Si = $\mu mol\ l^{-1}$) at Plynlimon and Beddgelert. Plynlimon data are discharge-weighted, Beddgelert data are simple arithmetic means

	pH	Na	K	Ca	Mg	Al	NO_3	SO_4	Cl	Si*
Plynlimon										
Grassland										
Cyff	5.43	147	4	70	70	<6	13	94	161	36
Gwy	4.89	143	3	36	54	9	15	72	155	35
Forest										
Hafren	4.69	185	3	44	66	33	28	100	199	58
Hore	4.83	202	3	72	72	33	23	114	218	54
Beddgelert										
Grassland	4.91	157	3	40	49	19	12	81	178	21
60% forest	4.74	257	6	80	74	43	43	119	279	36
80% forest	4.70	283	5	105	82	75	54	162	319	38

Stream water chemistry

Streams draining catchments underlain by lower Palaeozoic mudstones and shales are naturally acidic and poorly buffered at all flow levels At Plynlimon and Beddgelert, the acidity and concentrations of sodium, magnesium, aluminium, chloride and sulphate are greater in streams draining mature forest catchments than those draining moorland on similar soils and geology (Table 5) These differences are greatest at high flows, when aluminium concentrations in forest streams can be up to five times those draining adjacent moorland Such differences in chemistry have been observed elsewhere in Wales, and have been linked to alterations in freshwater invertebrate populations and fish stocks

The observed differences in stream chemistry are related to the effects of afforestation on soils and soil water chemistry discussed previously However, small-scale variations in geology, such as calcite veins within the bedrock, can generate sufficient bicarbonate in baseflow waters to buffer stream acidity during storms, which ameliorates, to some extent, the effects of afforestation on water quality

Management options

As a consequence of the reported changes in stream water quality, there is considerable pressure to limit further afforestation in much of upland Wales Any real extension of forestry in these areas would seem to depend upon the development of modified techniques of forest management and/or ameliorative measures to limit or prevent the adverse impacts on water quality

Given that a major factor in determining the effects of afforestation on water quality is the interaction between the conifer canopy and the atmosphere, any changes in canopy structure which affects solute deposition may be beneficial In the first year following thinning at Llyn Brianne, sulphate deposition was reduced to 50 kg ha^{-1} yr^{-1} beneath the thinned trees, compared with 90 kg ha^{-1} yr^{-1} below an unthinned stand The long-term result of thinning, following re-establishment of a closed canopy, is not known Also at Llyn Brianne, liming of stream source areas has effectively reduced the stream water acidity and aluminium content in forest catchments The duration of the improvement in water quality is not yet known, and the lime additions can have a deleterious effect on wetland plant communities Therefore, ITE is continuing to investigate the processes responsible for the differences between forest and moorland soil and stream water chemistry In particular, the research is focusing on how forest age and structure might affect the capture of substances from the atmosphere, the weathering of soil minerals, and the forest nitrogen cycle

P A Stevens, B Reynolds and M Hornung

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Land use, agriculture and the environment

Since early 1989, this Programme has been an amalgamation of the former Programmes 2 (Land use) and 3 (Agriculture and the environment). The amalgamation gives formal recognition to the relevance of all forms of land use to environmental issues, and acknowledgement of the predominant role which agriculture takes in determining Britain's rural environment. Key concepts in the Programme are that current use is only one option of several which are possible, and that objectives, systems and methods of land use must be clearly defined and differentiated. In many ways, Programme 2 is a central area of ITE's research, and one which emphasises the variety of different scales at which ecological investigations can be made. Land use studies are sometimes perceived as constituting mainly 'broad brush' research, but an essential feature of this Programme is the way in which ecological studies, many of them site-related, integrate with broad survey, monitoring and environmental mapping. This mix of projects and subprojects has produced a comprehensive programme of work which is both soundly based in science and relevant to the needs of specific customers and to decision-makers generally.

The Environmental Information Centre is a good example of the application of high technology to ecological problems, particularly those requiring a geographical approach. The CORINE project and LANDSAT classification are typical examples of the Centre's work. The survey of land use on the Lleyn peninsula illustrates the speed at which change can occur in areas which are apparently under little pressure, and indicates the value of repeated survey. Two investigations of the interactions of land use in the uplands of Britain with natural succession, both involving trees and land management, are reminders of the dynamic nature of ecological communities, and emphasise the ecological processes which are influenced by land use.

Plate 4 Lord Chorley formally opens the ITE Environmental Information Centre on 5 July 1989, accompanied by Professor John Knill Chairman of NERC

The ITE Environmental Information Centre

(This work was partly supported by funds from the Nature Conservancy Council and the Commission of the European Communities)

At the beginning of 1989, NERC announced the formation of an Environmental Information Centre (EIC) within ITE. The EIC, located at the Monks Wood Experimental Station, was officially opened by Lord Chorley in July 1989 (Plate 4). The Centre brings together existing activities in the fields of biological recording, remote sensing and geographical information systems (GIS). It is a unique source of expertise in the computerised acquisition and management of ecological data, and it is responsible for some of the most extensive holdings of data on the terrestrial environment in Britain.

The EIC has two functions. First, it operates in a service capacity, with an Institute-wide responsibility to develop and promote the use of data bases and methods of spatial analysis in support of ITE's scientific research programmes. Second, EIC functions as a 'shop window' for data holdings and expertise throughout the Institute and seeks to participate in research commissions in the general areas of environmental assessment and land use planning. Recent and probable future changes in the landscape and natural environment, brought about by changes in land use and climate, provide further stimulus to the application of this technology for environmental survey and monitoring and for the predictive modelling of the ecological consequences of such changes.

There are four units within the Centre, concerned with:

1. spatial data management
2. biological recording
3. remote sensing
4. applications development and promotion

These units work in close co-operation, sharing a common data resource and adopting a common methodological approach.

The scientific programme of the Centre has four broad themes:

1. documentation of the Institute's data holdings through the compilation of a computerised inventory, and introduction of standards for the storage and exchange of data to facilitate their exploitation by a wide community of users;

2. construction and maintenance of a core data base covering key aspects of the natural environment of Great Britain (eg landform and topography, soils and geology, climate, vegetation and wildlife, and human factors such as settlements, roads and administrative areas);

3. development and promotion of remote sensing and geographic information systems in the context of specific projects, research commissions and demonstrator packages;

4. research in underpinning methods, particularly in the fields of remote sensing and GIS.

This programme is ambitious, and it would be wasteful of resources for EIC to attempt it unaided. In many aspects of the programme, EIC will operate as a link to units in ITE and elsewhere who hold relevant components of the data base. Co-operative ties with groups such as the ITE Land Use Survey Team at Merlewood, and with the ESRC Rural Areas Data Base at the University of Essex are particularly important, and appropriate technical and administrative arrangements are being established for joint access to data and methodological expertise.

In April 1989, the EIC was joined at Monks Wood by staff from the NERC Remote Sensing Applications Development Unit (RSADU). RSADU was created as part of the NERC response to the formation of the British National Space Centre. Their move to Monks Wood is intended to encourage synergistic interaction between the RSADU technologists and the applications scientists in the Institute.

Spatial data management

Given that ecology is concerned with inter-relationships between living organisms and the physical environment, it follows that much of the information associated with ecological research has strong spatial associations. A large proportion of ITE data holdings are stored and accessed by spatial keys, such as National Grid references; much relevant information is acquired or presented in the form of maps.

The developing technology of geographic information systems (GIS) is, therefore, of fundamental importance to EIC and one of its constituent units is concerned with the application of this technology to the handling of ecological data sets (Plate 5). EIC staff were associated with some of the earliest examples in the UK of the use of digital cartographic data in terrestrial ecology and land resource management. More recently, the ITE Digital Cartographic Service (now part of EIC) has demonstrated the use of digital cartography and spatial data overlay techniques in a number of pilot projects (Brown & Norris 1988). A further example of EIC involvement in GIS is its role in the design and implementation of an environmental information system for the European Community – CORINE (Wyatt, Briggs & Mounsey 1988). The contribution of EIC to the CORINE programme is described in greater detail elsewhere in this Report (pp 20–22).

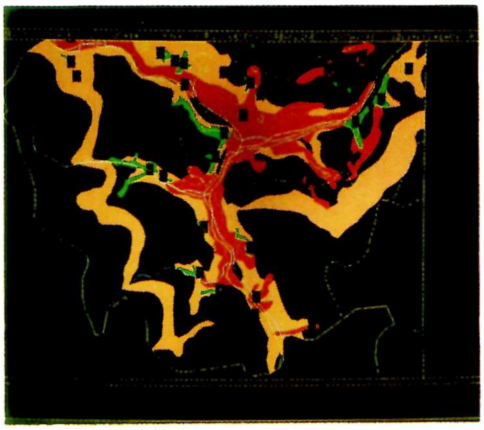

Plate 5 Use of a geographic information system for assessing land capability: amber areas indicate sites in Calderdale with high potential for reforestation

EIC aims to extend the scope and sophistication of such applications through two parallel activities. The first is the compilation of a comprehensive national digital data base on the terrestrial environment at a small to medium scale, to enable the retrieval of information on geographical, as well as ecological criteria, for national and regional appraisal. The data base will consist of topographic and thematic data in the form of map overlays and statistics, drawn as far as possible from existing digital sources. The second programme will develop more detailed demonstrations, selected on the basis of a current scientific or customer interest. These demonstrations will provide case studies of specific GIS applications as examples to potential users and customers, and will allow EIC staff to evaluate new products and techniques. Relevant work is developing rapidly at a number of ITE Research Stations, and links are being forged between the EIC and appropriate staff elsewhere in the Institute.

Remote sensing

ITE staff were among the earliest and most enthusiastic users of NERC facilities for digital image processing. Even before the advent of digital remote sensing, aerial photography was already an important technique for ecological survey and monitoring. Remote sensing in ITE evolved at a number of sites where there was strong scientific motivation for its use. The formation of EIC has provided the opportunity to concentrate expertise in remote sensing and digital image processing at one site, recognising that the objective is to provide the means for ecologists to treat these techniques as routine tools in the pursuit of their science.

The remote sensing programme in EIC builds on existing applications. In particular, projects are concerned with:

- image classification and interpretation for land cover mapping and the detection of change (Jones & Wyatt 1988); this work is described separately in a following article (pp 23–25);

- the use of remote sensing with supplementary data in integrated environmental information systems, with particular interest in their potential for predictive modelling (Plate 6) (Jones, Settle & Wyatt 1988);

- applications of remote sensing to the management of land resources in arid lands (Stewart *et al.* 1989).

The programme seeks to advance the methodology of image interpretation, and to implement these methods in case studies and in the compilation of an information base on UK land cover for use in ecological research and land management applications. In these respects, the remote sensing programme will parallel and complement the GIS development programme. Each will draw on common test sites, and will be designed to be responsive to the needs of a common user community.

Biological recording

Fundamental to much of the work of ITE is a knowledge of the geographical distribution of biological species, of habitats and of ecosystems. The ITE Biological Records Centre (BRC) pioneered the mapping of national

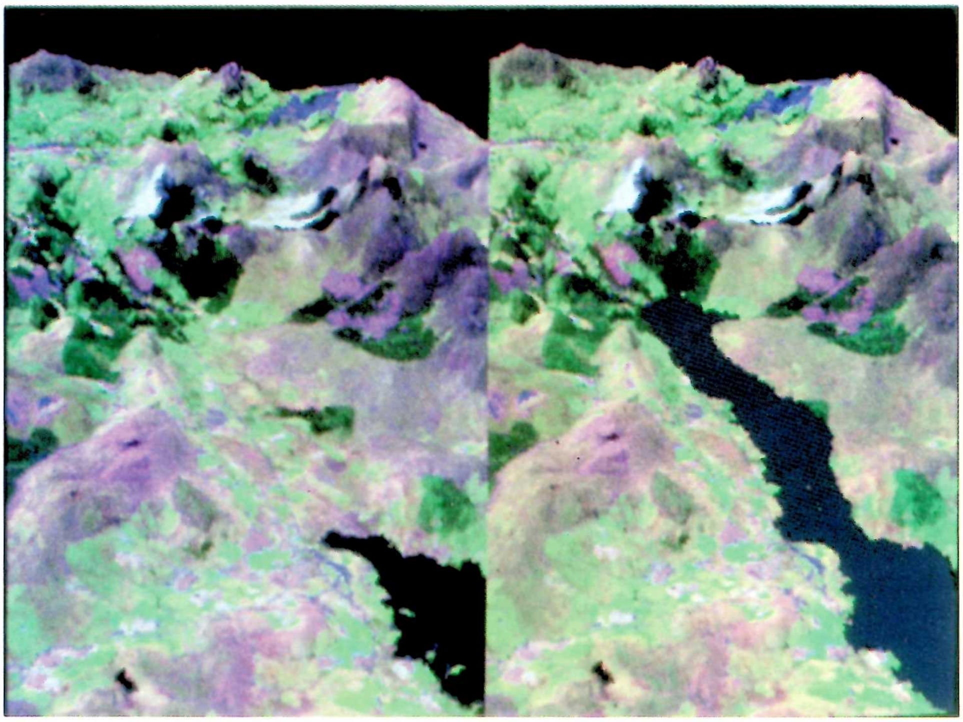

Plate 6. Simulation studies using remote sensing and digital elevation data: visualisation of landscape effects of reservoir development in Snowdonia

species distributions from a computer data base. This year, BRC celebrates its 25th anniversary; its incorporation within the Environmental Information Centre offers new opportunities to explore causal links between environmental conditions and the presence of biological organisms, and to undertake predictive modelling of the ecological consequences of changes in environmental conditions.

BRC forms the largest and most important national computerised data base on the occurrence of plants and animals in the British Isles. The Centre obtains its data from specialists working as volunteers and from a variety of other sources, including research and survey by ITE, and the data can be presented in the form of maps (Figure 13) and statistical summaries describing the geographical distributions of over 9000 plants, vertebrates and invertebrates. These maps may be produced in response to individual search requests; the data base is also used to produce camera-ready copy for the publication of atlases of biological distributions (Harding 1989). In the long term, it is the data base itself rather than any single map product which has the greater value for ecological research and for applications in environmental assessment and modelling. Species occurrences are being recorded with increasing spatial precision and with greater supporting detail describing the environmental context. The data base, especially site-relatable data, is already being used in environmental assessment and for site and species protection. Given the existence of other thematic information on, for example, soil type, geology, meteorological conditions and land use, it is intended to draw on expertise in the use of GIS technology elsewhere in EIC to allow more sophisticated interpretation of this unique data base.

Underpinning methods and systems

The effective use of data drawn from a wide range of disparate sources demands two prerequisites; first, it is necessary to know of the existence of a relevant item of data and its key characteristics; second, some measure of standardisation needs to be introduced to the storage of such data – both at the level of its physical storage and in its logical structure. EIC has been instrumental in drawing up a computerised inventory of data holdings in ITE and related organisations. This inventory is being refined and is scheduled for publication later in 1989. A further aspect of the work programme of the Centre is the development of guidelines and common formats for collecting, holding and exchanging spatially referenced environmental data. These guidelines will form the standards for data management within EIC and, hopefully, in ITE as a whole.

The Centre makes use of the complete repertoire of computational facilities provided by NERC, including software packages such as the ORACLE relational data base management system, statistical and graphics packages, and GIS. A powerful microVAX cluster at the Monks Wood site, linked to the NERC mainframes, provides general computing facilities and is linked to specialised workstations for digital cartography and image analysis.

B K Wyatt

Plate 7. The blue-tailed damselfly (*Ischnura elegans*) is one of the commonest species, and is more tolerant of polluted waters than any other British dragonfly. Its distribution is shown in Figure 13

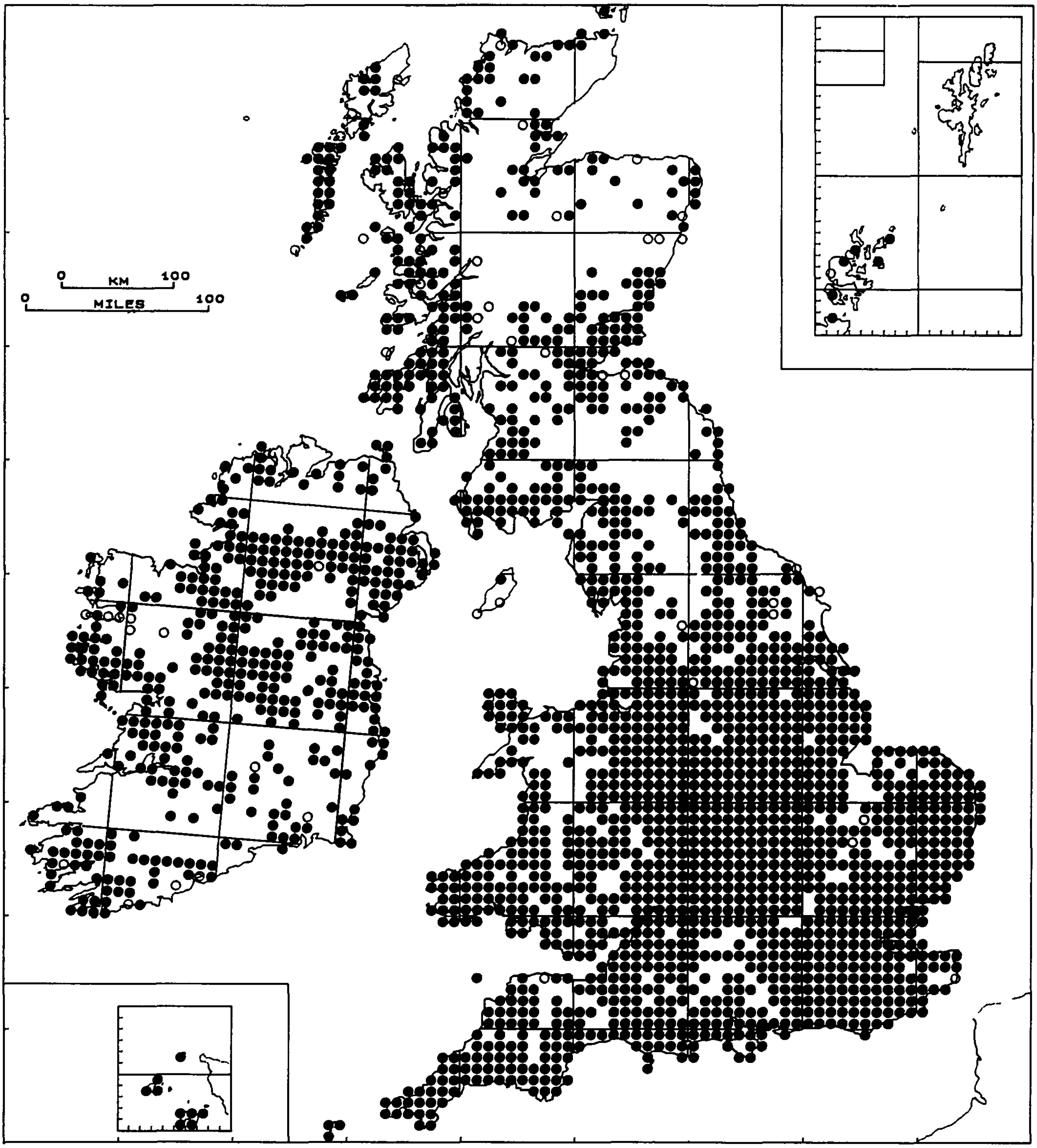

Figure 13 Distribution map of the blue tailed damselfly pictured in Plate 7

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Co-ordinated environmental information in the European Community

(This work was supported by funds from the Commission of the European Communities)

An important feature of environment policy in the European Community since 1973 has been the inclusion of measures to protect and conserve the biosphere Examples include the Directive on the Conservation of Wild Birds (European Commission 1979), the Directive on the Implementation in the Community of the Convention on International Trade in Endangered Species (CITES) (European Commission 1982), and recent discussions leading towards a Directive to protect important Community habitats

None of these measures can be properly implemented, neither can their effects be monitored, without the existence of a reliable and accessible information system which documents the state of the environment of the Community It was the creation of such a system which gave rise to CORINE (Co-ORdinated INformation on the Environment), an experimental programme of the Environment Directorate (DG XI) of the Commission of the European Communities (European Commission 1985) The immediate objectives of the programme were, within the period 1985–89, to

- acquire appropriate data covering the whole of the European Community,
- establish a computerised environmental data base, making use of Geographic Information System (GIS) techniques,
- develop the means to improve the availability and consistency of existing data at national and international levels

Within this programme, a number of broad thematic topics were identified biotopes (ecological sites) of major Community importance, atmospheric emissions, land use, land quality, soil erosion, water quality, water resources, seismic risks and coastal problems

The data needed to support these analytical activities are extremely diverse For example, the task of protecting and enhancing the ecological resources of the Community demands the systematic assessment of their status and future trends This assessment requires that, for sites of Community importance, information is recorded on their distribution and on detailed characteristics, including their location and extent, the nature of habitats and wildlife species represented, their vulnerability to damage, pressures from human activities, ownership and protection status

ITE has been involved in the programme since early in its conception It is now represented in membership of the CORINE planning steering committee and the land cover project group, and as principal contractor to DGXI for the biotopes project (Wyatt 1989) Such involvement recognises the expertise of ITE's Environmental Information Centre in such disciplines as geographic information systems, the application of remote sensing, and biological recording

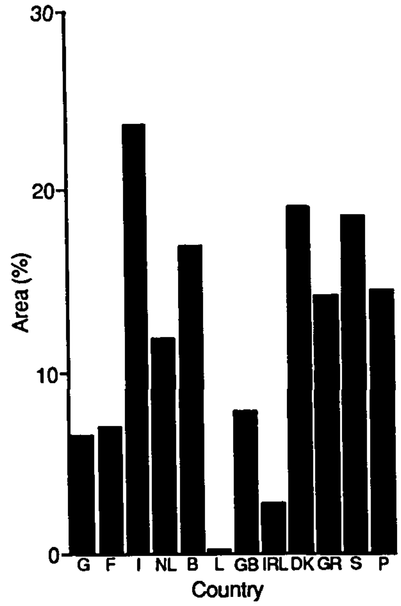

Figure 14 Percentage of the land surface of each European Community Member State covered by sites recorded in the CORINE biotopes project

Compilation of the biotopes data by experts in each of the Member States has inevitably proceeded at differing paces Over 12% of the Community's land surface is now covered by the biotopes in the CORINE data base, although the percentage varies widely between Member States (Figure 14) There is also wide variation in the percentage of biotopes which enjoy some form of statutory designation, eg National Park, or, in the UK, Site of Special Scientific Interest (Figure 15)

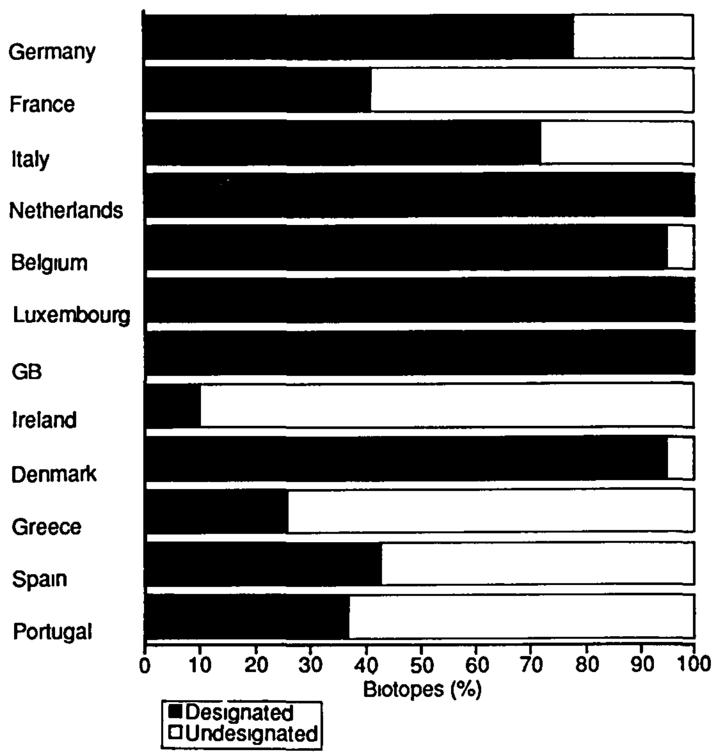

Figure 15 Percentage of CORINE biotopes in each Member State which have some form of statutory designation

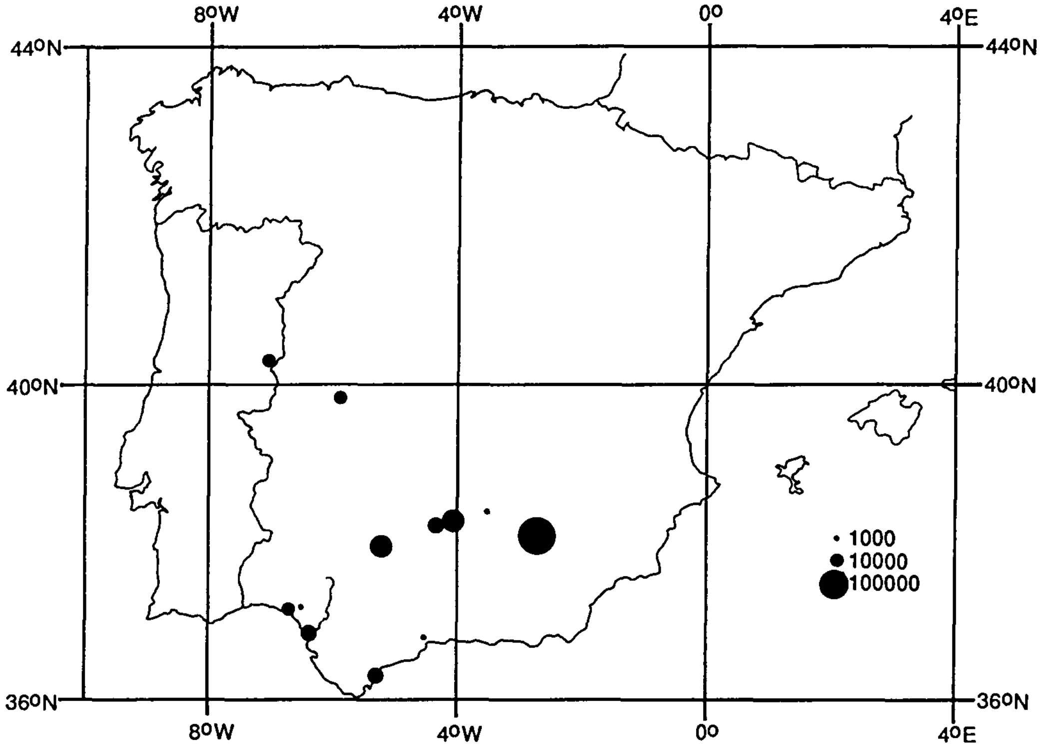

Figure 16 Biotopes where the Pardel lynx (*Lynx pardina*) an endangered species has been recorded. Areas of circles represent biotope areas in hectares as shown in the key

Applications

The CORINE data base is intended primarily as a source of information for users in various Directorates General of the European Commission – principally in the Environment Directorate However, the procedures for data harmonisation which are an integral part of CORINE are of much more general utility One important feature of CORINE has been the development of a pan-European system of habitat recording, and ITE is investigating the relationship between this and the British National Vegetation Classification, and also the feasibility of automatic classification of habitats to the CORINE system using key indicator species

The biotopes data base is unique in the breadth of its geographical and subject coverage and is attracting attention as a valuable source of information on the environment in the Community for both management and scientific applications Commensurate with the wide range of information recorded in the biotopes files is the range of individual applications A few examples of the use of the data base are sufficient to suggest its versatility and its potential value for the assessment and management of natural resources

The proposed Habitat Directive of the European Community – the data held in the biotopes data base have enabled the legislators to assess the potential extent of sites to be designated as a result of the inclusion of certain endangered or vulnerable species in the annexes to the Directive (Figure 16) The habitats to be designated are likely to be described using the CORINE habitat classification, and, again, biotopes data have been used to indicate the locations of these habitats

Implementation of the EC Directive on the Conservation of Wild Birds – this Directive (European Commission 1979) calls on Member States to notify the Commission of Special Protection Areas, wetlands of international importance, and other areas subject to comparable protection measures (Figure 17) Using the CORINE biotopes inventory, it is possible to identify sites of importance to vulnerable bird species in each Member State, and then to draw up statistics indicating the extent to which these measures have been implemented and how complete is the protection that they offer

Environmental models areas of importance for nature conservation threatened by change in sea level – there is considerable world interest in the possibility of climate change and its consequences Recently, a research team from London University, under contract to the World Wide Fund for Nature (WWF), has been studying the effects of increases in mean global temperatures (the 'greenhouse' effect) on natural systems One possible effect is a rise in mean sea level, and the WWF project assumed a scenario which gave a rise of 2–3 m Many important low-lying coastal ecosystems would be affected in such a scenario The CORINE biotopes inventory was the only readily available source of information on important habitats at a European level, and the biotopes retrieval system was used to locate coastal sites in which a significant proportion of their surface lies below 3 m In the Community as a whole, more than 700 sites were identified, dispersed throughout the coastlines of its Member States, though with a particularly high density of threatened sites in the Low Countries of northern Europe (Figure 18)

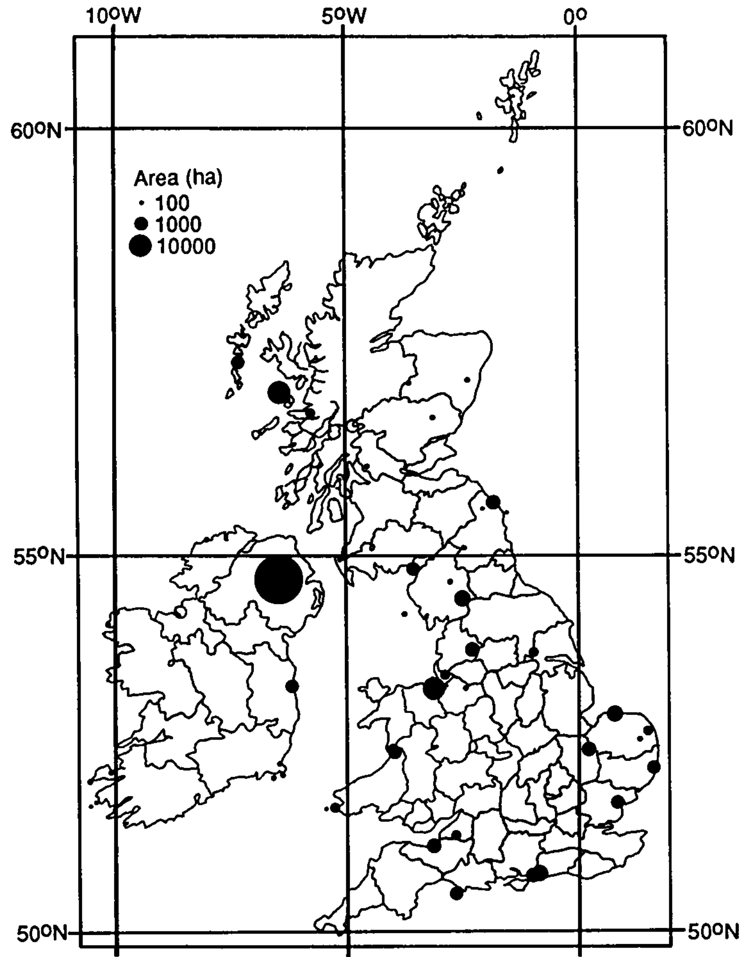

Figure 17 Location and extent of Special Protection Areas in Great Britain and Ireland under the European Community Bird Directive

Future developments

The present intention is to achieve, by the end of 1989, a complete GIS including information on each of the thematic areas listed above, together with the underlying topographical structure, political boundaries, and climatic information. In the case of the biotopes inventory of all Community sites which satisfy the criteria of Community importance for nature conservation, the complete files will be transferred to the main CORINE data bases, and it will become possible using GIS techniques to undertake much more sophisticated analyses of the data than are currently possible. For example, logical overlay of the location of biotopes on other environmental data sets will permit assessment of potential conflicts with human activities (residential areas, industry, transport routes, tourist centres, etc). Information on recent change in land cover (derived from satellite imagery) can be used to determine possible threats to biotopes.

The existence of a sophisticated capability for spatial data processing should facilitate the development of ecological models to optimise the use of scarce resources for nature conservation (eg by determining those sites which are most important along the routes of migrating birds, or by defining the form and extent of 'buffer zones' around areas in need of protection). The technology will be further enhanced when the boundaries of the larger biotopes have been digitised, as part of planned future work.

Finally, if the CORINE data base is to be a useful tool for environmental monitoring and assessment purposes, it is vital that those elements of the data which are subject to change are updated regularly. For example, the status of most biological sites is constantly changing as natural populations fluctuate from year to year, and human influences are ever more pervasive. Therefore, it is particularly important to give attention to the mechanisms by which the information held in the data base might be reviewed and updated at least every five years.

D Moss and B K Wyatt

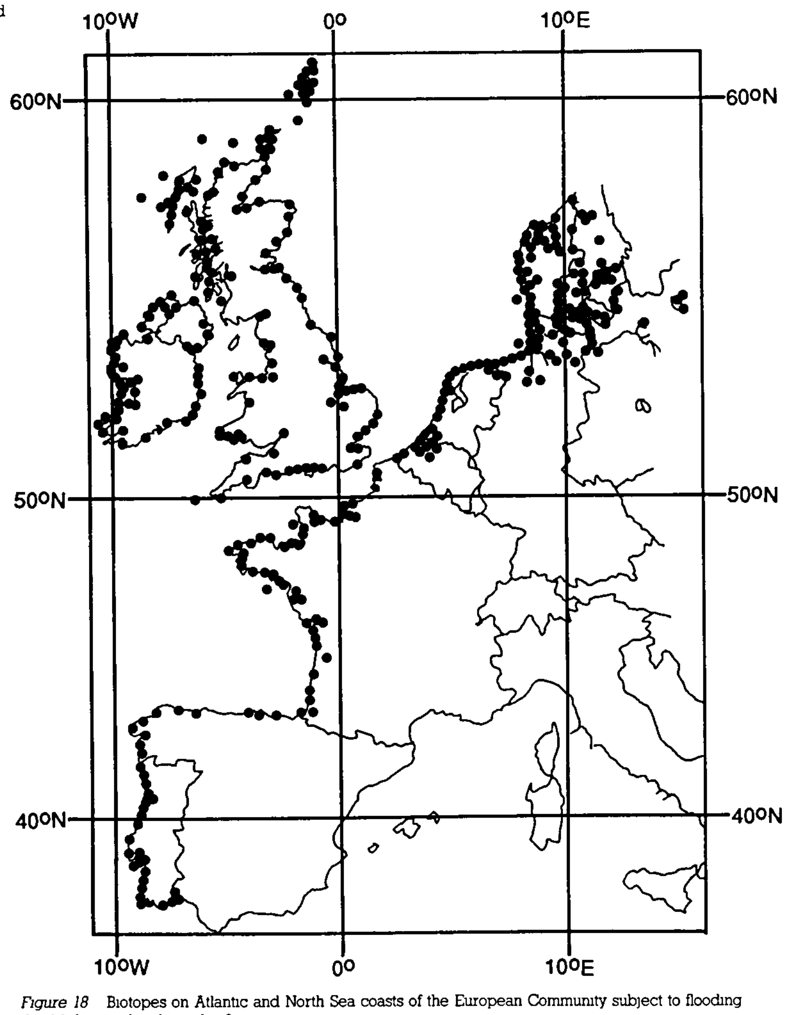

Figure 18 Biotopes on Atlantic and North Sea coasts of the European Community subject to flooding should the sea level rise by 3 m

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LANDSAT classification of Cambridgeshire

Mapping environmental patterns can provide the raw data to detect landscape changes for use in ecological monitoring and for resource assessment and management. It can provide data for modelling and prediction, processes which are of particular use in environmental impact assessments. Thus, there is a growing interest in the role that remote sensing might play in ecological research. The Environmental Information Centre, at ITE Monks Wood, is evaluating the use of various forms of remote sensing, developing and testing new methodologies where necessary. In addition, efforts are being concentrated on transfer of techniques to operational use in applied ecology.

LANDSAT earth observation data have been available since 1972, and are probably the best known and most widely used of the high-resolution data collected by satellites. Since 1984, the resolution has improved considerably, offering much greater potential for operational use in the UK.

The LANDSAT satellite completes global cover with a 16-day repeat cycle. If skies are clear, it collects ground cover information using the Multispectral Scanner (MSS) and, since 1984, the Thematic Mapper (TM) sensors. The sensors detect radiance, recorded in four wavebands of the spectrum in the case of MSS, or seven wavebands with TM. Radiance is recorded as digital numbers, from grid cells on the ground, each cell having a 'footprint' of 80 m x 80 m with MSS, or 30 m x 30 m with TM. The sensor is scanned across the flight path of the satellite to record a row of grid cells 185 km long; by the time this full scan is completed, the satellite has moved forward ready for the next scan. Thus, complete coverage is built up, as row upon row of grid cells. Finally, the data are transmitted to ground receiving stations, which prepare magnetic tapes of data for end-users.

By displaying the data using an image analysis system, pictures of the landscape are created (Plate 8). Such an image is made up of picture elements or pixels on a colour monitor, where each pixel is coloured according to the radiances recorded from the original ground cells; so the full image is constructed in much the same way as a conventional television picture. In addition, because the images are still held in digital form, they can also be enhanced, or the patterns can be analysed using computer-aided techniques.

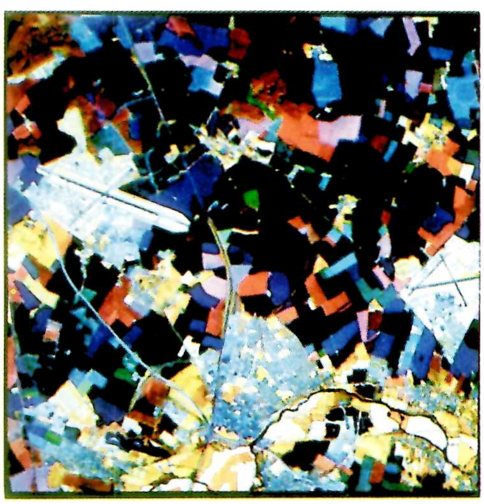

Plate 8. A LANDSAT Thematic Mapper multi-temporal image of a 10 km x 10 km part of Cambridgeshire. Infra-red bands 4 of October and 5 of July 1984 are displayed to the red and green channels of the display; the red band 3 of July 1984 uses the blue channel. The section shows Monks Wood (top left) with Huntingdon (bottom centre) and the floodplains of the River Great Ouse (bottom right)

LANDSAT TM images with 30 m pixels show patterns of the landscape, down to the scale of the individual field, at least in typical areas of lowland Britain. Various semi-natural habitats and other land uses may have unique spectral signatures which make them immediately identifiable. Where confusion remains, it may be possible to distinguish certain land classes using images made at different times of year.

For example, a July image of Cambridgeshire, made in 1984, showed detailed field patterns, with clear distinctions between a wide range of semi-natural habitats, agricultural and forestry uses, and developed land. However, there was still confusion between certain types of semi-natural vegetation and those arable crops which were still actively growing in July. An October image of 1984 distinguished these arable crops, which by then had been harvested. However, the autumn image no longer distinguished the range of semi-natural areas, and recorded arable and urban areas as having very similar spectral signatures. Clearly, in order to maximise the amount of information available on land cover in 1984, it was necessary to use data from each of these two seasons.

Satellite images suffer distortions caused, for example, by minor movements in satellite attitude, the earth's curvature and rotation, and the terrain relief. These distortions can be corrected, by resampling the grid of pixels to fit a standard base or map projection. Once this resampling is done, images and maps can be registered to each other, for use in combination. A twin-image or 'multi-temporal' composite was formed by registering the 1984 summer and autumn data to the British National Grid. In any display of the data, it was possible to select wavebands from each image, to create a composite image, with key characteristics of both data sets (Plate 8). Equally, it was feasible to analyse the patterns on the image, drawing on data from both dates. Thus, semi-natural vegetation could be distinguished from arable crops by virtue of its permanence, whilst arable crops, which cycle between vegetated and bare ground, could readily be separated from urban areas which are predominantly bare all year round.

It is possible to 'train' the image analysis computer to 'recognise' different features. Using a cursor on the display, the operator outlines sample areas of known land uses. The computer is then set to calculate key statistical characteristics for the training pixels in each class, for each waveband. Afterwards, the system is made to search the whole image systematically, deciding whether each pixel, in turn, shares the spectral characteristics of any of the training classes. In this way, a complete class map can quickly be built up, for a whole 185 km x 185 km scene if necessary, extrapolating from a limited input of training information. Such a classification has provided a 13-class map of Cambridgeshire (Fuller *et al.* 1989). The map comprises: water bodies; hay-cut, uncut, grazed and unmanaged grasslands; scrub, deciduous and coniferous woodlands; wheat, barley, oilseed rape and horticulture; urban and other bare ground (Plate 9). These classes cover 98% of the Cambridgeshire study area.

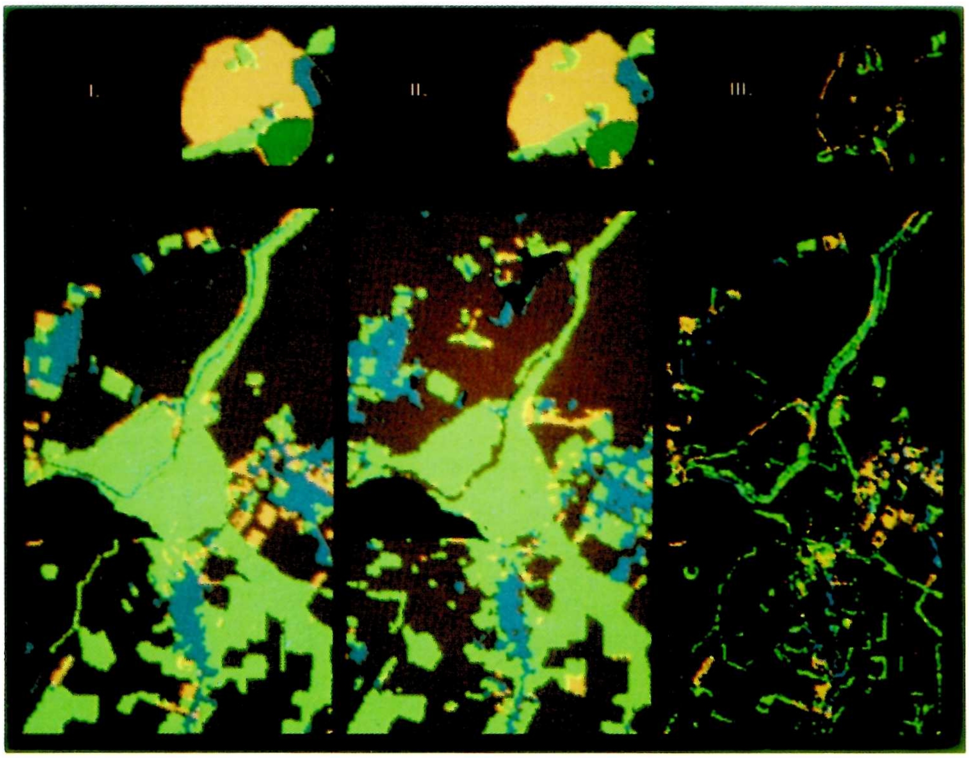

Plate 10. Check areas used in pixel-by-pixel tests of classification accuracies: (i) a digitised map produced by air photo-interpretation; (ii) the maximum likelihood classification of LANDSAT imagery; (iii) the differences between map and classification, coloured according to the 'true' class, ie that given on the map

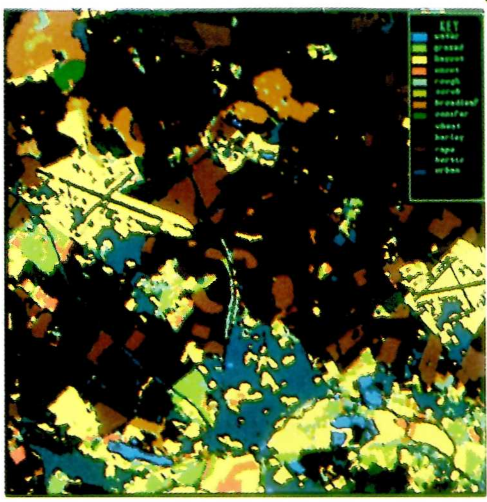

Plate 9. A 10 km x 10 km section of the Cambridgeshire 13-class map, produced by maximum likelihood classification of a summer/autumn multi-temporal composite of LANDSAT TM data. The section shows Monks Wood (top left), with Huntingdon (bottom centre) and the floodplains of the River Great Ouse (bottom right)

Checks against summary statistics from the Ministry of Agriculture, Fisheries and Foods show close correspondence in values for overall crop cover. Evaluation of the class map against a check sample of 500 land/water parcels showed semi-natural areas – the primary target of this exercise – to be classified with 84% overall success, according to the 'majority verdict' of all pixels in a land parcel. Excepting the fen areas, where fields are often too small to resolve using LANDSAT, the success rate in classifying individual land/water parcels reached 95%: these larger field patterns are more typical of arable farmland in lowland Britain. Sample check areas were mapped from air photographs and entered into the image analysis system using a video-camera input. Results of comparisons showed 82% correspondence between the check map and class map (Plate 10). Some of the difference was attributable to photo-interpretation error on the check map. Elsewhere, the errors represented problems along boundaries (Plate 10): sometimes they originated from slight misregistration between class map and check map. Other problems involved misclassification of edge pixels, with mixed contents where they straddled the boundaries of two dissimilar fields, and experiments are continuing to improve the classifications of these pixels. Overall, it is considered that the classification achieved 90% success rate, measured pixel by pixel (Fuller *et al.* 1989). However, further work will require the development of more sophisticated evaluation procedures.

In conclusion, it is now possible, using LANDSAT images, to provide accurate field-by-field classifications of lowland semi-natural habitats, arable crops, and other forms of land use, perhaps for a whole county, a region or even at the national scale. Until now, such classification has only been possible using highly labour-intensive survey techniques. Thus, remote sensing might be used to derive land use statistics, eg areas and crop yields, for studying the ecology of agricultural land. It is valuable for mapping patterns of semi-natural habitats in conjunction with ecological studies of population dynamics and dispersal. Monitoring landscape change is possible, such as natural succession in vegetation, or such land use changes as set-aside. Potential pollution effects can be assessed, perhaps the effects on water catchments of fertilisers used on arable crops. It is possible to map, and thereby plan, the best use of natural resources, eg mapping biomass patterns on grazing land in arid regions. The data might be useful for costing compensation payments of management schemes in conservation areas or in cost-benefit analysis, eg in evaluating land for a flood protection scheme. Environmental impact assessments are helped by remote sensing, not only through the ability to map and measure areas to be lost directly to developments, but also as the images provide information from the past for use in predicting the future. For example, the study of vegetation dynamics relative to natural hydrological cycles helps in assessing the impacts of drainage or water abstraction schemes.

R M Fuller

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Land use, reduction of heather, and natural tree regeneration on open upland

(This work was partly supported by funds from the Nature Conservancy Council)

There is now nationwide public concern about the fate of Britain's moorlands, largely because of continual losses to afforestation and agriculture. There is also much concern over the state of the remaining moorland. In many areas, increased browsing pressure by sheep and other animals is changing the vegetation and the other wildlife that depends upon it, while, in other areas, greatly reduced browsing now poses other changes, which could become more widespread if there were future reductions of sheep because of overproduction in the European Community countries. The problems associated with changing land uses and grazing pressures are illustrated below by two contrasting examples from north-east Scotland, one involving increased and the other reduced browsing.

Deer and heather

Most of the lower moorland areas in Britain and Ireland which are now largely covered by heather (*Calluna vulgaris*) were originally forest. These forests were cleared, mainly by man, centuries ago, and since then the ground cover has been kept open, partly by burning and partly by sheep, cattle and, in some areas, red deer (*Cervus elaphus*) eating the tree seedlings. It is well known that, when heather is heavily browsed by sheep and cattle, it can decline and be replaced by grasses. If burning and browsing of tree seedlings were to cease or become greatly reduced, the lower moorlands would be expected to revert towards forest, particularly near existing trees that can supply a source of seed.

Moorland is dominated by heather in many parts of Britain, and heather is particularly abundant in eastern parts, where precipitation is relatively low. Heather moorland forms a semi-natural environment providing habitats for vegetation and animals of conservation interest, and is of high value for amenity, recreation and scenery. Its main use is for the shooting of red grouse (*Lagopus lagopus scoticus*), along with sheep grazing, and large areas in the Scottish Highlands also support red deer.

Studies by ITE have shown that two of the main land use changes in Britain between 1978 and 1986 were losses of upland vegetation to forestry and to agricultural improvement. Since the 1940s, there have also been major losses of heather moorland in Britain as a result of higher sheep stocks (Sydes & Miller 1988). For example, sheep densities in the EC Less Favoured Areas in England and Wales rose from 2.9 ha^{-1} in 1951 to 6.0 ha^{-1} in 1981. Higher stocks of sheep, and locally of cattle, in much of upland Britain have led to a decline in the amount of heather and its replacement with grass. In turn, there has been a decline in the numbers of red grouse, whose main foodplant is heather, particularly where sheep densities have been very high, as in the southern uplands of Scotland, the Peak District and other parts of northern England. The resulting lower economic values from grouse shooting, an unsubsidised land use, have frequently led to a conversion to subsidised uses, particularly afforestation and, to a lesser extent, reseeded agricultural grassland and new arable fields. In addition, large areas which are still open moorland have less heather than previously, and this type of loss may be attributable to deer.

The main area of heather-dominated moorland in Britain is in north-east Scotland. Stocks of red deer on much of the open range are high, and have long prevented the natural regeneration of trees in unfenced woodland and on adjacent moorland. In 1987, the Red Deer Commission reported that deer numbers in some parts of the north-east Highlands had approximately doubled since the late 1960s, and, in their recent book entitled *Red deer in the Highlands*, Clutton-Brock and Albon suggest that fewer sheep and changes in weather may have contributed to the rise in deer density in the Highlands overall. However, the evidence adduced on sheep numbers in Scotland is uncertain, as sheep numbers on moorland were not separated from those on farm fields. Such an increase in deer numbers might be expected to result in high mortality in snowy winters, but so far this increase has not occurred in north-east Scotland. ITE studies have shown that natural mortality in the 1970s and 1980s was much lower in north-east Scotland than in the late 1940s and 1950s, when deer numbers were, in fact, smaller.

Plate 11. Change of heather-dominated to grass-dominated ground on the lower slopes of a moor in the Braemar area where numbers of red deer have greatly increased

Another hypothesis is suggested to explain the higher deer numbers, which does not exclude that proposed by Clutton-Brock and Albon – the deer have increased the carrying capacity of their habitat by their own heavy browsing, dunging and trampling. The amount of heather on the deer's main wintering

Table 6. The relative abundance of tree species regenerating on open upland in Deeside and Donside. Relative abundance is given as the number of one km grid squares containing regeneration of each species

Tree species	No. of km grid squares Deeside	Donside
Scots pine (*Pinus sylvestris*)	484	362
Birch (*Betula* spp.)	314	214
Rowan (*Sorbus aucuparia*)	228	189
Willow (*Salix* spp.)	149	84
Larch (*Larix decidua*)	137	229
Norway spruce (*Picea abies*)	41	76
Beech (*Fagus sylvatica*)	13	33
Holly (*Ilex aquifolium*)	16	0
Alder (*Alnus glutinosa*)	11	2
Oak (*Quercus* spp.)	6	6
Aspen (*Populus tremula*)	7	1
Rose (*Rosa* spp.)	5	0
Ash (*Fraxinus excelsior*)	1	3
Hawthorn (*Crataegus monogyna*)	2	0
Yew (*Taxus baccata*)	0	1
Total	584	440

grounds has declined, and palatable grasses have increased. These changes are most obvious on the glen bottoms and lower hill slopes, where the deer concentrate during snowy periods and in bad weather (Plate 11), and have not occurred appreciably on the higher slopes, where snow and exposure reduce deer usage. When heather is burned on these wintering grounds, the regenerating vegetation on the glen bottoms and lower slopes is mainly grass, whereas at higher altitudes it is heather. The height of the heather has also declined on the low ground. Such changes have led to fewer red grouse. Moreover, small patches of bare ground have appeared and soil erosion is beginning to increase. This evidence suggests that the increased numbers of deer are causing more long-term effects on the land.

Tree regeneration on grouse moors

Further east in north-east Scotland, on moorland where red deer are scarce or absent, a reduction in moor burning, combined with the running down or desertion of many hill farms, has led to large-scale colonisation of heather moorland by trees. A total survey of natural tree regeneration was carried out on open upland, mostly heather moorland, in the catchments of the Rivers Don and Dee in 1985 (Watson & Hinge 1989). Most of the regeneration involved a spread of young and, to a lesser extent, middle-aged trees over the last few decades on to ground which was known previously to have been treeless and which has not been planted. In Deeside, 584 one km grid squares on the Ordnance Survey map contained natural regeneration on open upland, and 440 in Donside (Table 6); the total Dee catchment area covers 2100 km^2, while the Don catchment is slightly smaller. Substantial areas in both catchments had regeneration with a single tree species, but mixtures of species, especially of Scots pine (*Pinus sylvestris*) with birch (*Betula* spp.), were common. The majority of the area with tree regeneration was on grouse moor, in both Deeside and Donside. Some small areas of regeneration were in places where heather moorland had been reclaimed into agricultural grassland, without destroying the middle-aged or old trees there before the reclamation; however, no young trees were present. Much natural tree regeneration had also occurred on lowland peat mosses. Deer 'forests' with high numbers of red deer (and generally few trees) showed no regeneration, neither did large areas of well-burned grouse moor nor smaller areas of heavily browsed moorland near farms with large stocks of sheep and cattle. On some estates, managers were reducing or removing the regeneration by burning and felling.

Plate 12 Disused grouse shooting butts on two areas that now lack red grouse

(a) on a Deeside area with rank heather overgrown by natural regeneration of Scots pine following reduced burning and browsing

(b) on a Donside moor where grass has replaced heather, in association with high densities of sheep

This natural transformation of land from open upland to boreal woodland has important implications for land use, nature conservation, wildlife, scenery, forestry policy, and water catchment. The transformation is well exemplified by the photograph of a grouse shooting butt now surrounded by trees, on an area where red grouse are no longer present (Plate 12). Plate 12 also shows grouse butts on a different area lacking in red grouse, where heather has virtually disappeared and been replaced by dense grass, in association with locally high densities of sheep.

The major changes described have been noted in exploratory observations and surveys, but justify more detailed research. The future of our uplands is closely linked to the solution of such problems. A better, impartial, understanding of the mechanisms behind these changes, and of the rates of change, is essential as a basis for rational decisions on land use and its social aspects.

A Watson

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Land use changes on the Lleyn Peninsula

(This work was partly supported by funds from the Nature Conservancy Council)

The intricate pattern of small fields, enclosed by hedges, banks and stone walls, together with open uplands and a fine coastline, gives the Lleyn Peninsula in north-west Wales a seemingly unchanging appearance (Plate 13).

In 1972, a study was undertaken to determine the nature conservation 'interest' of the whole of Lleyn, as opposed to protected sites such as Sites of Special Scientific Interest (SSSI), and to provide a baseline for future monitoring.

A commission from the Nature Conservancy Council in 1987, prior to the designation of Lleyn as an Environmentally Sensitive Area (ESA), provided a unique opportunity to examine the extent of environmental change over the previous 15 years. The survey method used (Buse 1974) was designed to examine detailed habitat changes in one geographical area, and thus differs, particularly in scale, from survey methods designed to detect regional differences at a national level (Bunce & Heal 1984; Barr 1989).

In the 1972 survey, habitats, such as bracken (*Pteridium aquilinum*), improved grassland, oak woodland (*Quercus* spp.), earth banks, etc, were used as the basic recording units. The habitats were surveyed in a randomly positioned 30 m radius sample, in each of the 410 one km squares of Lleyn. The same sites were resurveyed in 1987–88. Sixty-six habitat categories were used during the study, but are abbreviated to 18 in this report. For example, the edge habitat included hedges, banks with low vegetation, banks with hedges, and roadside verges. Similarly, scrub included gorse (*Ulex europaeus*) and bramble (*Rubus fruticosus*), and 'open' included cliffs, rocks and scree.

Changes in habitats

Table 7 and Figure 19 present a simplified picture, for 1972 and 1987, of the area of Lleyn (ie percentage of the total sampled area) covered by the agricultural, urban and semi-natural habitats.

Overall (using the data for the 66 habitats), there was an 8% change in the habitats of Lleyn. However, including losses and gains of particular habitats, 15% of the area had actually changed, and the change was widespread, occurring in 44% of the samples.

The increased area of improved grassland was particularly evident, and also of conifer plantations. These increases resulted in the loss of a wide range of other habitats. Amongst the agricultural habitats, the area of crops decreased, as did the area of 'reverting' improved grassland.

In 1972, the semi-natural areas (excluding conifer plantations) covered 32% of Lleyn. By 1987, this figure had decreased to 28% of Lleyn, a loss of 13% of its original area, or a total of 16 square

Plate 13 The Lleyn Peninsula

Table 7 Habitat change in Lleyn from 1972 to 1987

Habitats	Cover of habitats as % of Lleyn (sampled area) 1972	1987	Overall change
Agricultural			
Crops	3 75	1 51	−2 24
Improved grass	51 63	57 54	+5 91
Improved grass – reverting	6 89	5 75	−1 14
Semi-natural			
Sedge	6 63	6 41	−0 22
Scrub	1 83	1 62	−0 21
Bracken	3 87	3 17	−0 70
Acid grassland	2 62	2 57	−0 05
Dwarf shrub	2 06	1 97	−0 09
Open	2 09	1 78	−0 31
Marram	0 22	0 23	+0 01
Wetland			
Marsh	6 62	4 82	−1 80
Reed bed	0 22	0 29	+0 70
Water – still	0 22	0 19	−0 03
Water – flowing	1 32	1 36	+0 04
Woodland			
Conifer	3 04	4 00	+0 96
Deciduous	1 84	1 73	−0 11
Mixed	0 73	0 75	+0 02
Urban	4 34	4 28	−0 06

kilometres, equal to the area (4%) currently designated as an SSSI Such a loss is particularly significant, as most of the dispersed semi-natural habitats of Lleyn tend to be of equal nature conservation 'quality' to those chosen as being representative of Lleyn in more definable areas which have SSSI notification Although there was some loss from almost all the semi-natural habitats, such as scrub, bracken, acid grassland, dwarf shrub, and open habitats, the greatest change occurred in the marsh group, where 27% of this habitat disappeared

Changes in agriculture

Agricultural change was estimated by comparing the results of the agricultural censuses of the Welsh Office Agricultural Department for 1972 and 1985 for the 13 parishes of Lleyn The change in agricultural land use between these years is summarised in Figure 20, which shows the increase in grassland and the decrease in rough grazing and in crops

Some of the underlying reasons for the land use changes were apparent from the census data Owned, rather than rented, land had increased from 56% to 67% of Lleyn, and the number of holdings had decreased from 1118 to 912 There was, therefore, a general tendency towards increased farm size, although the number of very small farms had also increased Cattle numbers had slightly decreased (by 9%), but sheep numbers had increased by 65% Dairy farming had decreased, but mixed farming with cattle and sheep had increased

Changes in forestry

The area of forestry had increased by 45% (1% of the area of Lleyn) since 1972 More than one third of the increase was from marsh land, and about half was equally from improved grass, bracken and dwarf shrub Much of the planting was in the 'poorer' lowland areas The age of the trees showed that most of the forests were planted just prior and subsequent to the 1972 survey There was very little recent planting

Relationships between habitat change and land use change

The environmental change in Lleyn was mainly caused by agricultural change and improvement Much was due to the general increase in improved pasture in this predominanatly stock-rearing area Thus, some of the change was from crops and grassland reverting to improved grassland, while some was from an increase in the improved grassland area with farmers cultivating closer to field margins or to the edges of cliffs Other change was due to the improvement of wet areas by drainage to provide increased pasture

The additional forest area was equivalent to one sixth of the area accounted for by agricultural change The long-term nature of the tree crop, however, produces an abrupt and comparatively permanent change, compared with the more gradual changes attributable to agriculture

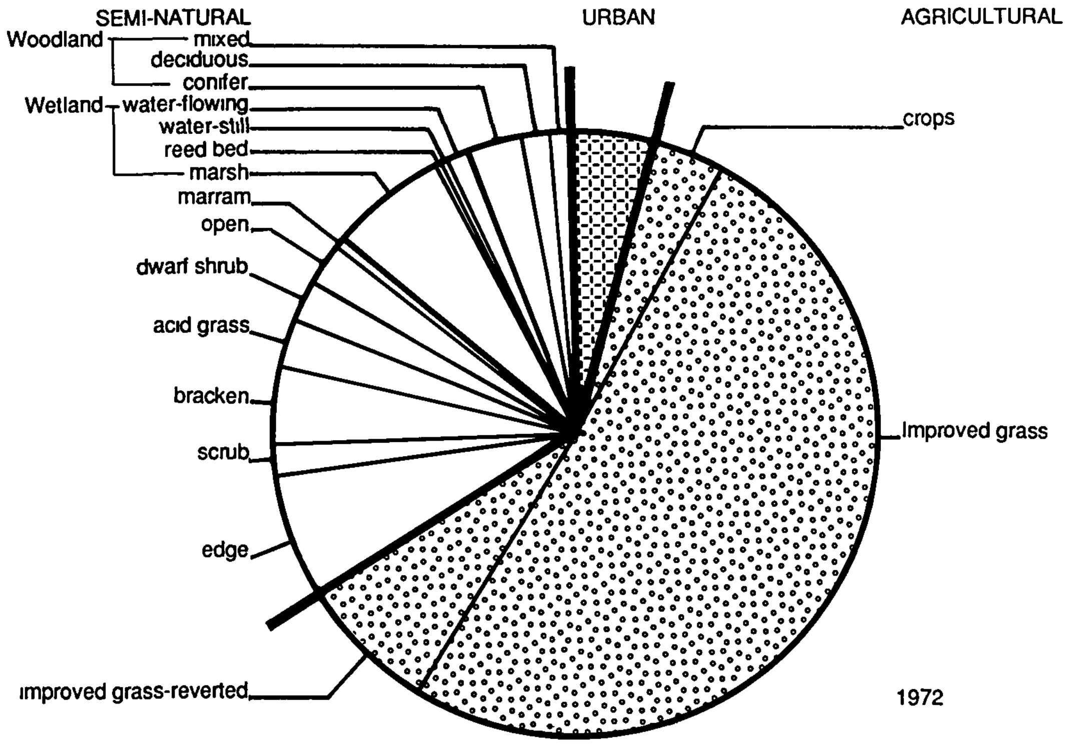
A number of physical factors were found to be related to the degree of change Thus, changes in habitat type were concentrated in the lowlands, and on less steep slopes, ie in those areas where agricultural improvement was economically feasible Similarly, change was greater on the gley soils than on the upland podzolised and rock-dominant soils

A comparison between parishes near the centre of population and other parishes showed that there was a significant difference in the proportion of changed to unchanged samples It was of interest that there was a greater increase in the proportion of very small farms in this area than elsewhere in Lleyn, and also in the proportion of part-time farmers

The relationships between the habitats, examined by ordination techniques, had changed between 1972 and 1987 In 1972, there were three main groupings of habitats one related to improved grassland, one to upland grassland, and one to marsh areas By 1987, the habitats were in two main groups one related to improved grassland, and the other to the foothills and uplands This difference suggests that Lleyn was becoming polarised into two groups of habitats the lowland, managed grassland areas, with managed 'edge' habitats of banks and hedges, and the semi-natural foothills and uplands, with marshes, woodlands, upland heath, and acid grassland habitats

The future

ESA designations are designed to maintain or enhance the landscape, wildlife and archaeological interest of selected areas Farmers voluntarily entering into an ESA agreement accept a



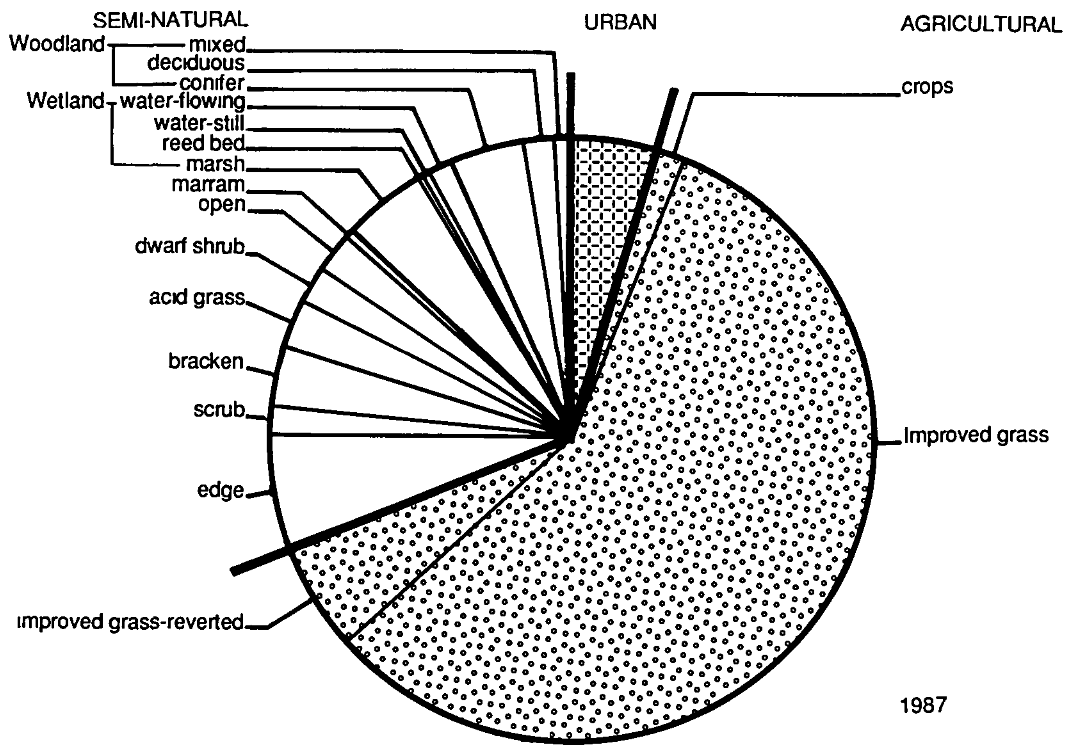
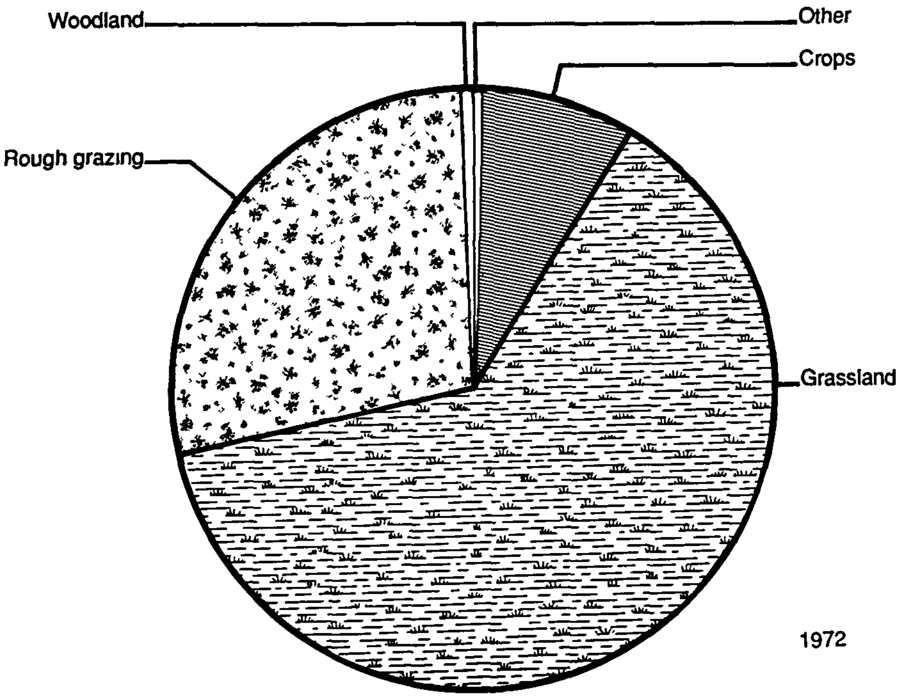


Figure 19 A comparison of the area of Lleyn covered by various habitats in 1972 and 1987



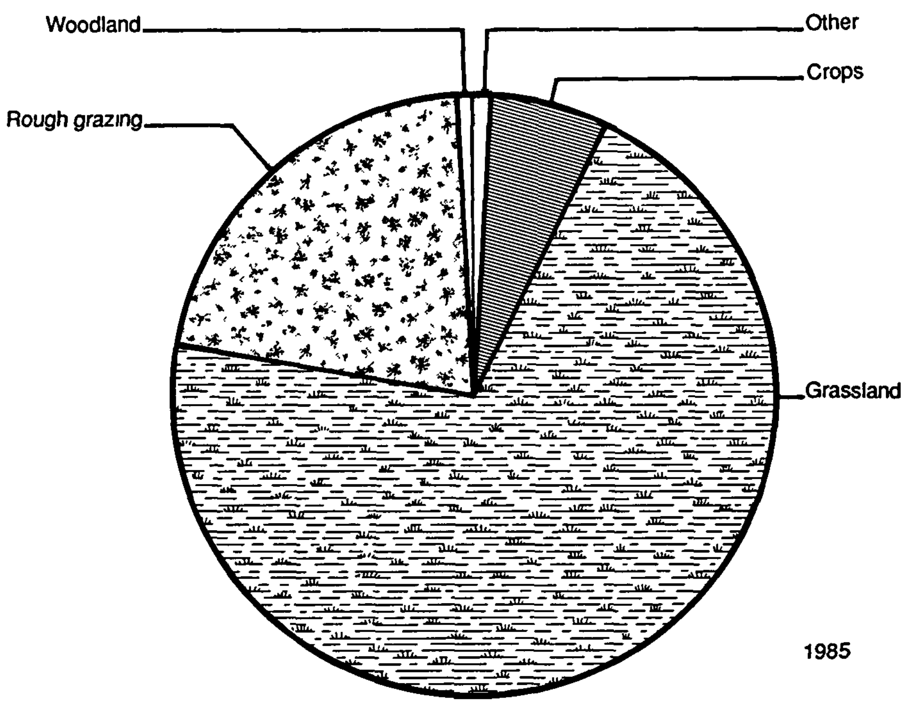


Figure 20 A comparison of the area of Lleyn covered by various agricultural land uses in 1972 and 1985

set of guidelines designed to achieve these objectives, and are compensated accordingly The Lleyn ESA differs from most designations in that it applies to the whole area, and not just to semi-natural habitats It should thus protect, even in the most productive areas, the intricate pattern of semi-natural areas so typical of Lleyn

What of the future? Prediction is difficult in a changing agricultural scene If future agriculture in such a stock-rearing area demands the improvement of more land, then the lower upland areas will become further exploited, increasing the polarisation of Lleyn However, the acceptance of the voluntary ESA agreements by farmers suggests that the rate of change will slow down In either case, data from the 1972 and 1987 surveys will provide a quantitative baseline

A Buse

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Distribution, longevity and survival of upland hawthorn scrub in north Wales

Scattered hawthorn (*Crataegus monogyna)* scrub is a feature of permanent pastures throughout much of the uplands of England and Wales Unlike the dense hawthorn scrub which invades fertile pastures in the lowlands, and can pose severe weed problems, it occurs as scattered bushes and small clumps which are not regarded by farmers as a nuisance – rather the reverse, as the hawthorns provide shelter from the elements for stock in winter

Upland scrub is also much favoured by conservationists, because it often provides the only woody vegetation over large areas of otherwise treeless terrain This enthusiasm is based on little scientific knowledge of the ecology of hawthorn and its associated species in the uplands, except in the case of birds It is known that hillsides with scattered hawthorn bushes provide ideal habitat for nesting species such as whinchat (*Saxicola rubetra*) and tree pipit (*Anthus trivialis*), and that winter visitors such as redwing (*Turdus iliacus)* and fieldfare (*T pilaris*) rely heavily on the fruit as a winter foodstore

The few references to the origins of upland hawthorn scrub in the literature suggest that, like its lowland counterpart, it originates by natural colonisation during periods of reduced grazing intensity Another possibility is that it is a remnant understorey from woodland which formerly occupied the sites, the trees having disappeared at some earlier stage Either way, it is possible that changes in upland farming practices, such as the reduction of inputs and sheep numbers, resulting from Government policies for extensification, might affect the population dynamics of upland hawthorn, and hence its conservation status and its importance as a weed Assessing the extent of such effects demands knowledge of the current status of hawthorn and its vulnerability to such change

A study was undertaken to survey the distribution of upland hawthorn in the Snowdonia National Park in north Wales, to investigate its origins and the factors limiting its occurrence, and to determine the age structure and conservation status of representative populations

Distribution of hawthorn scrub in north Snowdonia

Thirty-one widely dispersed sites were identified in the altitude range from 175 m to 750 m above Ordnance Datum (Figure 21), all of which occurred on steeply sloping valleysides among permanent grassland Three representative sites were chosen for special study (Table 8)

At most sites, some of the hawthorns occurred in clumps (Plate 14), while others were isolated (Plate 15) From field observation of morphological characteristics, it was suspected that some of the clumps consisted of clones derived from a single original bush by suckering Accordingly, the root systems of nine clumps of bushes, three from each site, were excavated Clear root connections occurred between at least

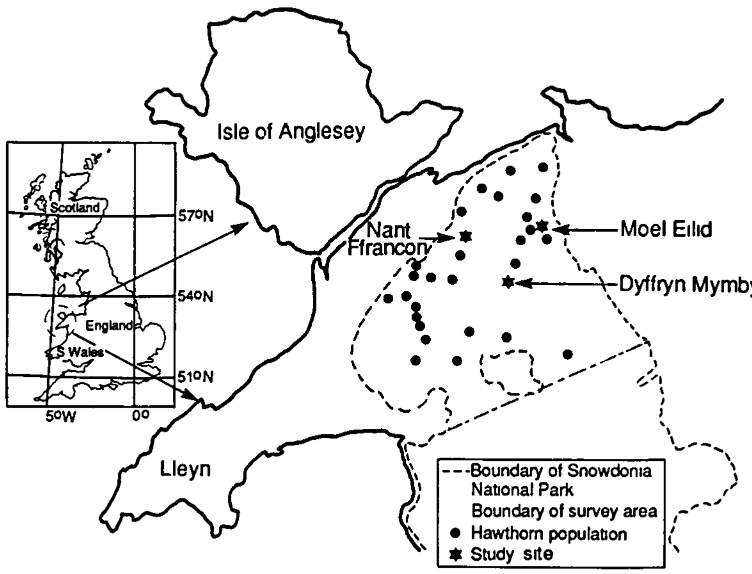

Figure 21 Map of north Wales showing the boundary of the survey area in the Snowdonia National Park and the distribution of hawthorn populations over one ha in extent

Table 8 Descriptions of the three upland hawthorn scrub sites chosen for special study

	Dyffryn Mymbyr	Nant Ffrancon	Moel Eilio
Area (ha)	26 6	12 0	3 6
No of hawthorns	1243	951	205
Hawthorns ha^{-1} (mean±SE)	47±6	79±12*	57±13
Altitude range (m)	200–350	250–500	375–425
Mean slope (°) (±SE)	20±5	30±4	23±3
Aspect	S	SE	SW
Other woody species	Hazel (*Coryllus avellana*) Crab apple (*Malus sylvestris*)	Blackthorn (*Prunus spinosa*)	Blackthorn (*Prunus spinosa*) Rowan (*Sorbus aucuparia*) Common sallow (*Salix cinerea*)

* The density of hawthorns at this site was significantly greater than at the other two sites (P<0 05)

Plate 14. A typical clump of hawthorns amid open space at the Dyffryn Mymbyr site. Note the absence of saplings

Plate 15. An isolated single-stemmed tree over 100 years old at the Dyffryn Mymbyr site

some of the bushes in all except one case. This suckering capability is of great significance, because it implies a potential for population to persist indefinitely.

Hawthorn distribution in relation to ground vegetation

The vegetation on sample plots located (i) beneath hawthorn bushes and (ii) in open grassland areas was surveyed, and 100 samples for all plots at the three sites combined were organised into three floristic groups, using a quantitative 'indicator species' analysis. The plant community data, together with information on the proportion of samples of each group associated with hawthorn bushes, and the soil types and pH ranges on which they occurred, are given in Table 9. This Table shows that hawthorn occurred only on freely draining brown earth or brown podzolic soils with pH >4.4, and was absent from less freely drained and more acid peaty soils. The relationship between the occurrence of hawthorn and the various components of the ground flora was calculated, and a significant negative correlation was found between the occurrence of hawthorn and purple moor-grass (*Molinia caerulea)*, as well as a significant positive correlation between the occurrence of hawthorn and rock or stone.

Age structure of hawthorn populations

The ages of the sampled hawthorns at each of the three study sites were determined by ring counts and are shown in Figure 22. The similarities between the three populations are apparent, particularly the wide age ranges of the bushes and the absence of saplings less than 20 years old. Almost 60% of bushes were between the ages of 40 and 70. The steady decrease in numbers of bushes over the age of 60 is consistent with a steady rate of recruitment prior to 1929, assuming that death is commoner after this age. Unfortunately, there were insufficient dead hawthorns with undecayed wood at the study sites to determine satisfactorily past mortality in relation to age.

It appears from Figure 22 that the maximum age attained by bushes at these sites was about 120 years. However, some trees at each site were clearly older. The largest trees were usually hollow or had badly decayed heartwood, which precluded ring counting.

Table 9 Indicator species and constancy tables (>40% frequency of occurrence) for the three groups determined by TWINSPAN analysis of the 100 combined vegetation samples from the three study areas, together with information on soil type and pH The proportions of samples in each group associated with hawthorns are recorded

	Group I	Group II	Group III
Indicator species	Bracken (*Pteridium aquilinum*) +	Heath bedstraw (*Galium saxatile*) +	Purple moor-grass (*Molinia caerulea*) +
	Tufted hair-grass (*Deschampsia cespitosa*) +	Brown bent-grass (*Agrostis canina*) +	Common bent-grass (*Agrostis capillaris*)
	Rough-stalked meadow-grass (*Poa trivialis*) +	Rock/stone +	Deer-grass (*Scirpus cespitosus*)
	Mat-grass (*Nardus stricta*) –		
Constancy tables (ranked by cover abundance)	Common bent-grass (*Agrostis capillaris*)	Sheep's fescue (*Festuca ovina*)	Purple moor-grass (*Molinia caerulea*)
	Sweet vernal-grass (*Anthoxanthum odoratum*)	Common bent-grass (*Agrostis capillaris*)	Sheep's fescue (*Festuca ovina*)
	Tufted hair-grass (*Deschampsia cespitosa*)	Sweet vernal-grass (*Anthoxanthum odoratum*)	*Sphagnum* spp
	Sheep's fescue (*Festuca ovina*)	Heath bedstraw (*Galium saxatile*)	Deer-grass (*Scirpus cespitosus*)
	Bracken (*Pteridium aquilinum*)	Bracken (*Pteridium aquilinum*)	Brown bent-grass (*Agrostis canina*)
	Rough-stalked meadow-grass (*Poa trivialis*)	Common tormentil (*Potentilla erecta*)	Mat-grass (*Nardus stricta*)
	Smooth-stalked meadow-grass (*Poa pratensis*)	Pill-headed sedge (*Carex pilulifera*)	Common tormentil (*Potentilla erecta*)
	Red fescue (*Festuca rubra*)	Field woodrush (*Luzula campestris*)	Common bent-grass (*Agrostis capillaris*)
	Yorkshire fog (*Holcus lanatus*)		Sweet vernal-grass (*Anthoxanthum odoratum*)
No of samples	32	55	13
Samples associated with hawthorn (%)	67	53	0
Soil types	Brown earth Brown podzolic	Brown podzolic Peaty gley	Deep peat Stagnopodzolic
pH range	4 40–5 90	4 53–4 75	3 80–4 75

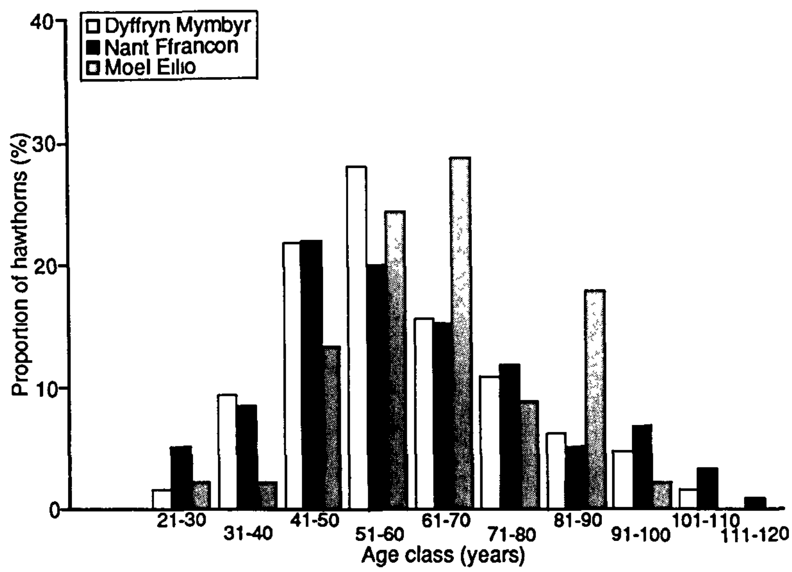

Figure 22 Age class distributions of sampled hawthorns at each of the three study sites in 1979

Careful search of five 5 m x 5 m quadrats at each site revealed no hawthorn seedlings at either Dyffryn Mymbyr or Moel Eilio, but occasional seedlings less than one year old were found at Nant Ffrancon Because seed production was heavy in most seasons at all sites, and germination tests revealed high seed viability,the absence of seedlings could not have been due to a scarcity of viable seeds Seed predation by small mammals was probably not of major importance, as their numbers are generally low in these tightly grazed swards

There were no saplings between the ages of one and 20 in any of the searched quadrats at the main study sites However, subsequently, a population of young saplings was discovered growing in grassland with patches of bilberry (*Vaccinium myrtillus*), in a field adjacent to the Nant Ffrancon main study area Significantly more of these saplings occurred in sample plots with more than 50% cover of bilberry than in those having a lower abundance of this species (Table 10), probably because it affords protection from sheep grazing all the seedlings were flat-topped at or slightly above the level of the bilberry canopy, and showed extensive evidence of repeated grazing

Table 10 Relationship between occurrence, number and density of hawthorn seedlings and cover abundance of bilberry

	Bilberry cover (%) 0-50	50
Number of sample plots	14	14
Number of plots with hawthorn seedlings	1*	7*
Number of seedlings	1*	23*
Mean seedling density (seedlings m^{-2} × 100)	0 2*	6 5*

The values marked * differ significantly from each other (Σ^2 =3 84, 1 df, P<0 05)

Hawthorn and sheep grazing pressure

The relationship between hawthorn recruitment (including seedlings and sucker shoots) in each ten-year period from 1880 to 1980, and mean numbers of sheep ha^{-1} averaged for the three parishes in which the study sites

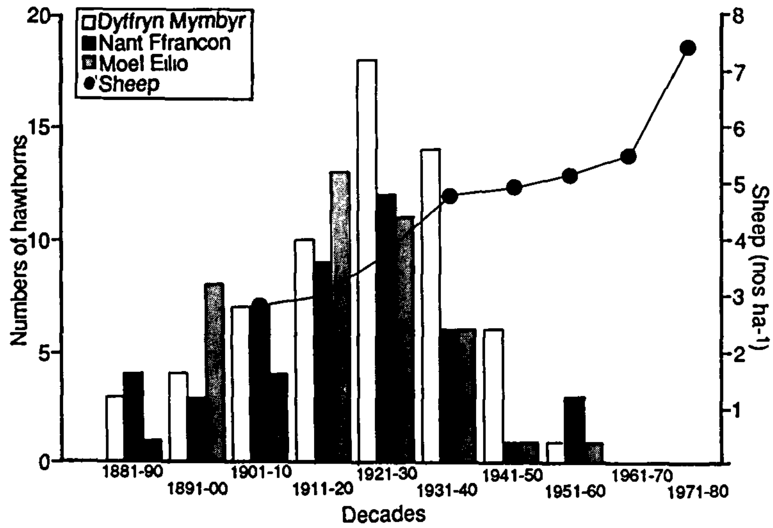

Figure 23. Relationship between recruitment of new hawthorns (seedlings plus root suckers) to the populations at each of the three sites and sheep density in June Sheep densities are averaged for the three parishes in which the study sites occur Note the sharp decline in new bushes from about the 1930s as sheep densities reached and exceeded 4 ha^{-1}

occurred over the period 1908–78, are shown in Figure 23 The relationship is inverse, with hawthorn recruitment declining as sheep numbers increased The increase in grazing pressure up to the 1930s appeared to have little effect on hawthorn regeneration, but the further increase thereafter was sufficient to reduce it, until, by the 1960s, no regeneration was possible – a situation which persists to this day These figures for mean parish sheep numbers, which can only give a guide to the numbers actually grazing the study areas, suggest that 3–3 5 sheep ha^{-1} may be the critical level, above which hawthorn regeneration is curtailed

Discussion

Upland hawthorn scrub has been shown to be widespread in Snowdonia Unlike in the lowlands, succession does not generally progress to woodland While lowland hawthorn scrub may develop quickly to form impenetrable stands, eg when grazing is reduced or ceases in the presence of an abundant, reliable seed source, the wide age class distribution of the bushes in the study areas suggests that upland scrub develops more slowly, as would be expected because seed sources are mostly few and far between Thus, upland hawthorn usually spreads gradually from a few bushes established from seeds brought in from a distance by birds However, suckering occurs commonly, and can lead to the formation of large clonal clumps, suggesting that populations may be very long-lived The possibility remains, therefore, that some populations may ultimately have been derived from hawthorns in the understorey of woodland which was cleared several centuries ago

The recent absence of regeneration is primarily due to the increased numbers of sheep Increased stocking has a particularly deleterious effect on hawthorn, which grows only on the better-drained land with mesotrophic bent-grass/fescue (*Agrostis/Festuca*) grassland (Table 9), which, in turn, is particularly attractive to sheep Unless sheep grazing pressure is reduced substantially in the areas where hawthorn bushes grow, and for periods long enough to allow the bushes derived from seed or suckers to reach a size where they are immune to grazing (probably a minimum of 15 years), there will be no further recruitment in most populations This conclusion raises the question of whether the reductions in sheep numbers which might occur as a result of implementing farm extensification policies could lead to such a situation, and whether expansion of hawthorn invasion might pose a weed problem in these circumstances It seems unlikely that this situation will arise, as summer stocking rates would have to fall from the present 7 5 sheep ha^{-1} to pre-war levels of less than 4 sheep ha^{-1} before substantial regeneration would occur Assuming that stocking levels remain well above this level, there will be no immediate conservation problem because most populations contain many middle-aged trees However, because there has been no appreciable recruitment in the last 40 years, and mortality appears to increase substantially over the age of 80, there is likely to be a very marked decline in populations from the 2020s onwards

Root suckering, which appears to be possible from the roots of even very old bushes, probably offers the best chance for long-term survival Suckers are more likely than seedlings to develop into substantial plants during brief periods of reduced stocking density, because of access to the food resources of the parent plant, and the avoidance of hazards associated with seed germination and establishment Perhaps the prevalence of root suckering in upland hawthorn is the result of selection for this character over the centuries in populations exposed more or less continuously to severe grazing pressure

J E G Good

Environmental pollution

The programme of research on environmental pollution aims to understand and quantify (i) the input of pollutants to terrestrial ecosystems, (ii) their transfer through ecosystems and foodchains, (iii) the impact of the pollutants on plants and animals, and (iv) methods of ameliorating these impacts.

The following articles illustrate these various threads in current ITE research. Thus, the report on radionuclides focuses on their transfer through upland ecosystems and on research to determine how long the radiocaesium from the Chernobyl fallout will remain available to plant uptake, and possible transfer to grazing animals. The reports on acid mists and pesticides are mainly concerned with the impact of pollutants and with the mechanisms by which the trees, or birds, are affected. The tree work has shown the potential importance of acid mists in forest dieback, while the research on pesticides demonstrates how different pesticides can interact to affect partridges.

ITE research on climatic change and soil protection concerns both causes and impacts. The work on climatic change is planned to expand considerably over the coming years, and will involve both experimental studies and computer modelling. Soil protection concerns the development of guidelines and legislation to reduce the detrimental impacts of man's activities on soils, essential in a crowded island. ITE's involvement in the *Phragmites* work covers the ecology and establishment of the reed beds which provide an ecological method of pollution control.

Acid mist, frost hardiness and the decline of red spruce in the Appalachians

(This work was supported by funds from the United States Department of Agriculture/United States Forest Service)

During the last decade, a decline in the health of fir (*Abies* spp.), spruce (*Picea* spp.), and beech (*Betula* spp.) has been observed in parts of Europe, particularly in West Germany, and in North America. Many hypotheses have been proposed linking these forest problems with air pollution, but no single hypothesis has successfuly withstood experimental tests.

As 'forest decline' is used to describe a range of forest problems with different species and in different countries, it seems unlikely that the same agent and mechanism are responsible for all the observed problems.

One species which has shown a marked decline in its native habitat in the last few years is red spruce (*Picea rubens*), in the Appalachians of eastern North America. This species occupies a restricted altitude range (700–1000 m), but is commonly exposed to low cloud at many sites. As a result of the long-range transport of sulphur and nitrogen oxides, the cloudwater contains high sulphate and nitrate concentrations, and has a pH in the range 2.5–4.0.

Staff at ITE Edinburgh have worked in collaboration with the Universities of Nottingham and Lancaster to test the hypothesis that the interception of polluted cloudwater reduces the winter hardiness of red spruce.

Red spruce seedlings grown in clean air were placed in open-top chambers (Plate 16), and were subjected to six acid mist treatments in the pH range 2.5–5.0. This wide range of concentrations for the treatments spans the extreme events observed in the field, but in its mid-range has two treatments (at pH 3.0 and pH 3.5) which approximate the 'average' cloudwater deposited on red spruce in the Appalachians. The acid mist was applied twice each week throughout the summer, and in the frost hardening period (May–December). At intervals during the autumn, shoots were detached from the seedlings in the different treatments and subjected to a simulated night air frost in a programmable freezing cabinet. At each harvest date, a range of freezing temperatures were simulated for different shoots. In this way, the lethal temperature for 50% of the shoots (LT_{50}) was estimated. The techniques used to determine the shoot damage and LT_{50} were based on electrolyte leakage.

Damage estimates using electrolyte leakage

Following freezing, the middle section of shoot was placed in a 20 ml vial with an aliquot of deionised water, and solution conductivities were measured during the following seven days to follow the change in electrolyte concentration. After 14 days, the shoots were scored for visible damage, on a scale 0 = no needles damaged, 1 = <50% needles damaged, 2 = >50% needles damaged, and 3 = shoot brown, assumed dead. Conductivity values were used to derive a normalised leakage rate (k), by fitting the conductivities (c) to the equation:

$$c(t) = c\,(\text{auto}) \times (1 - e^{-kt})$$

where c(auto) was the conductivity of the autoclaved solutions. The comparison of k values with visible damage showed that

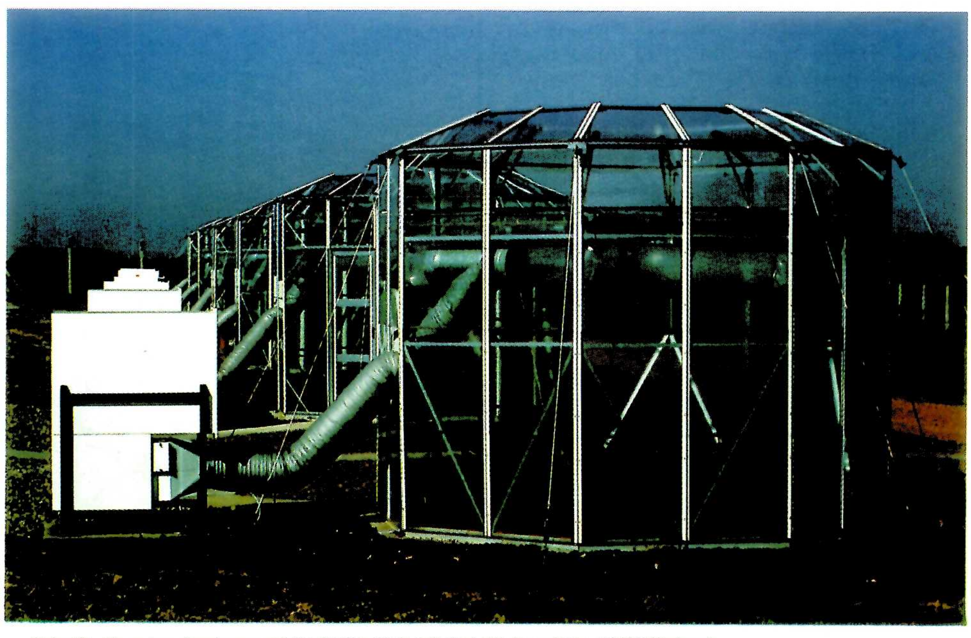

Plate 16 Open-top chambers used for studies of air pollutant effects on trees at ITE Edinburgh

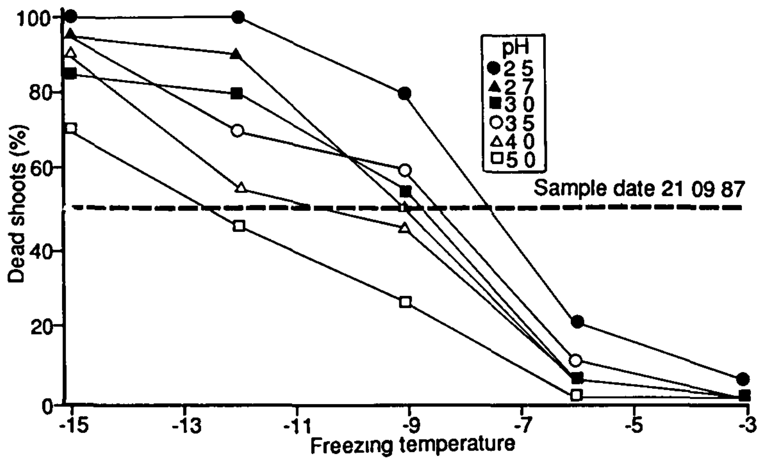

Figure 24 Proportion of red spruce shoots killed in the frost hardiness assessments following exposure to six different acid mist treatments

shoots with values <0 4% h^{-1} would die, while shoots with values >0 4% h^{-1} would have little or no damage to their needles These critical values were used to assess shoots as 'dead' or 'alive' The percentages of dead shoots for each acid mist treatment were then fitted as a function of temperature, using a probit function to derive an LT_{50} value for each acid treatment, ie the freezing temperature at which half the shoots in the sample population were killed

The measurements of lower lethal temperatures for the needles allowed the progress of frost hardiness of the seedlings to be followed throughout the autumn

On 21 September, when the majority of trees had set bud, the lethal temperature for the death of 50% of needles (LT_{50}) was highest (-8°C) in the pH 2 5 treatment and lowest (-13°C) at pH 4 0 (Figure 24), although the only significant difference (P>0 05) was between pH 2 5 and the other treatments By the time of the next assessment, many of the laterals used in the freezing tests from the pH 2 5 and 2 7 treatments bore visibly damaged needles These needles were not removed on this occasion prior to the measurement of conductivity, and it is likely that their significantly higher leakage rate accounted for the apparent dehardening seen on the 5 October (Figure 25) Between 21 September and 5 October, when night screen temperatures fell below 5°C for the first time and to 2°C or below on two occasions, the shoots from the pH 3 0–5 0 treatments acquired about 5°C more hardiness, but maintained the initial treatment differences By the third sampling date (19 October), differences in the LT_{50} were quite marked, with shoots from the pH 2 5 treatments having an LT_{50} of −16°C, compared with that of nearly −30°C for the pH 5 0 treatment

In later tests in November, it became increasingly difficult to estimate the LT_{50} accurately for pH treatments 3 5–5 0 The reason is apparent in Figure 24, which shows the percentage of shoots killed in relation to freezing temperatures for the shoots sampled on 30 November The freezing cabinet has a capacity to cool down to −39°C and, by the end of November, very few shoots were being irreversibly damaged at −36°C, >30% from the pH 3 0–5 0 treatments

The results from the frost hardiness testing may be summarised as follows

1 Frost hardiness increased in all shoots from mid-September, at a rate of about 0 5°C per day, although there was a delay in hardiness in those shoots exposed to the most acid treatments

2 At any sampling date, the shoots receiving the greatest concentrations of acidity, nitrogen and sulphate were most susceptible to frost injury, with LT_{50} values up to 15°C warmer than for those shoots receiving the smallest concentrations

3 Although there was not always a significant difference in LT_{50} values between successive levels of acidity, the ranking of the six levels of treatment was reflected in the ranking of the response

Plants from all treatments were scored for visible injury throughout the experiment, and the results from these measurements are shown in Figure 26

A clear effect of the acid mist treatment was observed with the LT_{50} between the control and most acidic treatment, differing by as much as 15°C during October Such differences in field conditions would predispose trees receiving large impacts of polluted cloudwater to autumn frost injury Although there are difficulties in extrapolating to mature trees in the field,

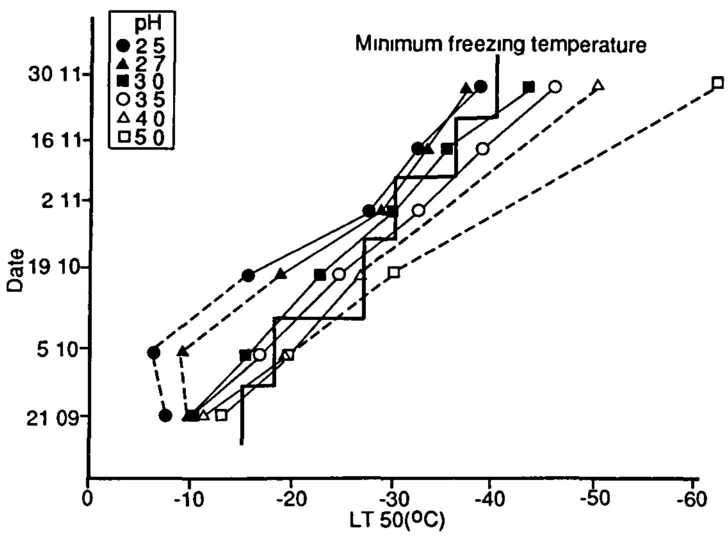

Figure 25 Development of frost hardiness in red spruce exposed to six different acid mist treatments expressed as LT50 for shoot death

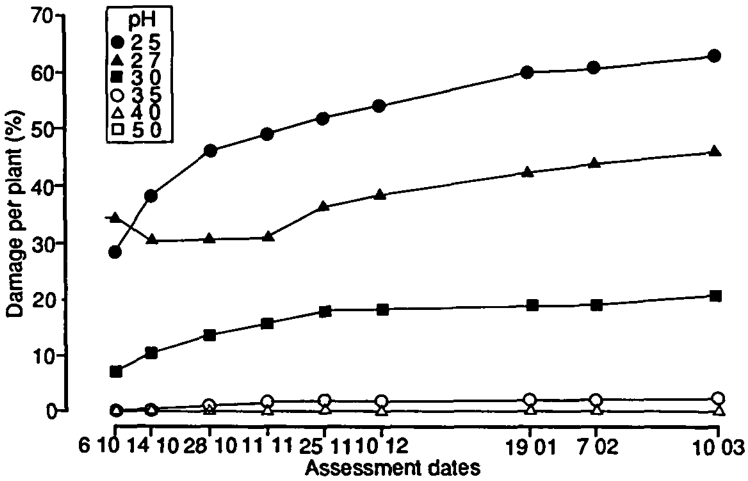

Figure 26 The development of visible injury on acid mist treated red spruce seedlings with time following the first signs of injury on 4 October By 4 October the seedlings had received twice weekly applications of acid mist for 16 weeks

two related studies make such extrapolation simpler In the first study, red spruce shoots were taken from mature trees at two high-elevation sites in the Appalachians and shipped by air to the ITE laboratory for frost hardiness tests These samples showed a pattern of frost hardening and absolute levels of hardiness similar to young plants from the open-top chamber experiments The second study of the meteorology and air chemistry of high-elevation 'red spruce' sites by the University of Nottingham formed part of the ITE collaborative project Rates of deposition of the major ions were established at mountain sites, and were shown to be within the range of the pH 3 0 and 3 5 treatments in the open-top chamber study It seems plausible, therefore, that the pollutants captured in cloud droplets by the red spruce are a predisposing factor in the observed decline The visible injury observed on foliage from the different treatments was linearly related to the concentration of applied mist (Figure 27) The straight line response was an unexpected feature of the results, and one that had not been noted by earlier studies at ITE

In addition to the frost hardiness and visible injury work, a range of plant physiological measurements were made to establish likely damage mechanisms

Water relations

Measurements taken in October/ November 1987 showed that acidic mists decreased the relative water content associated with zero turgor and increased the cell wall elasticity In consequence, the treated seedlings suffered *mild* water stress, evidenced by a reduction in shoot water potential Acidic treatments also affected the stomatal response to CO_2, such that the normal stomatal closure in response to CO_2 was absent This result may have important implications for mechanistic studies, and is to be investigated further during 1989

Photosynthesis and stomatal conductance

Gas exchange was measured in March 1988 on seedlings treated in 1987 Acidic mist (pH 2 5) increased the chlorophyll content of the remaining needles over

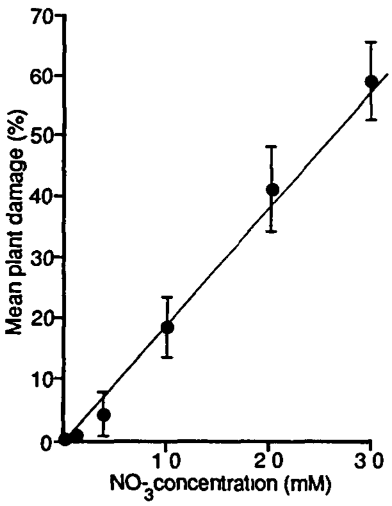

Figure 27 The relationship between visible injury on red spruce seedlings following six months of treatments with concentrations of the major ions in the

two-fold, and the rate of photosynthesis per unit area by about 70% (at light or CO_2 saturation) However, the rate of photosynthesis per unit chlorophyll was reduced

Acidic mist made the stomata more sensitive to low light levels and insensitive to CO_2 concentrations

These measurements show a range of treatment responses by physiological processes, and have identified, in particular, the changes in cell wall properties and normal stomatal function They represent an important step in locating physiological damage mechanisms, and will form the basis of further study

D Fowler

Pollution control by *Phragmites*

(This work was supported by funds from the Water Research Centre)

Recent advances in the use of the common reed *(Phragmites australis)* for wastewater treatment could soon give a new meaning to the term 'sewage treatment plant' The reeds are grown in specially constructed beds through which wastewater is passed Compared to conventional methods of sewage treatment, these reed bed treatment systems (RBTS) are just as effective, cheaper to construct and maintain, and more in keeping with the natural environment (Brix & Schierup 1989) They are particularly appropriate for small, rural communities, where a bed of 600 m^2 could treat the sewage from a population of up to 200 people Over the past four years, reed bed treatment systems have been constructed at 27 sites in the UK, mainly by Water Authorities (Plate 17) The wastewater is usually from domestic sewage, but the system also has considerable potential as a means of cleaning up farm effluents and some industrial discharges

The theory behind RBTS is neat and simple (Figure 28) The extensive root and rhizome system of the reeds provides a hydraulic pathway along which wastewater flows Atmospheric oxygen (5–50 g O_2 m^2 day^{-1}) passes down the hollow stems and rhizomes, and diffuses

Plate 17 New technology sewage treatment? A reed bed treatment system at Kingstone and Madley (Welsh Water Authority)

into the rhizosphere and soil around the roots. In this aerobic zone, the wastewater is treated by microbial action and ammonium is oxidised to nitrate (nitrification). Anaerobic treatment of the wastewater and the reduction of nitrates to nitrogen (denitrification) occur in the anaerobic areas in the surrounding soil. In addition, phosphates are adsorbed by the soils, and some additional aerobic composting of sludges occurs on the ground surface. The net result of these processes is, in theory, an effluent of consistent quality, with reported decreases of up to 95% in biological oxygen demand, 94% in phosphorus and 88% in nitrogen (Brix 1987).

However, this 'back to nature' method has not been without its problems or its critics. In practice, the performance of RBTS in the UK and on the continent has rarely lived up to the expectations of theory. The problems have included: failure of the reeds to grow, wastewater flowing over the surface of the bed rather than through it, no nitrification suggesting little oxygen transfer into the system, and generally lower standards of performance than were initially anticipated. To help overcome these problems, the Water Research Centre has been co-ordinating research and development in the UK. The eventual aim is to produce management guidelines for reed bed treatment systems in the UK, based on practical experience being gained by the Water Authorities at existing RBTS sites, and on programmes of research in three main areas:

1. studies on the decomposition processes in RBTS beds, including work on the cycling of nitrogen (University of Bath, Portsmouth Polytechnic);

2. studies on the mechanisms and rates of oxygen transfer into the rhizosphere (University of Hull);

3. studies on the ecology, establishment and management of reeds (ITE).

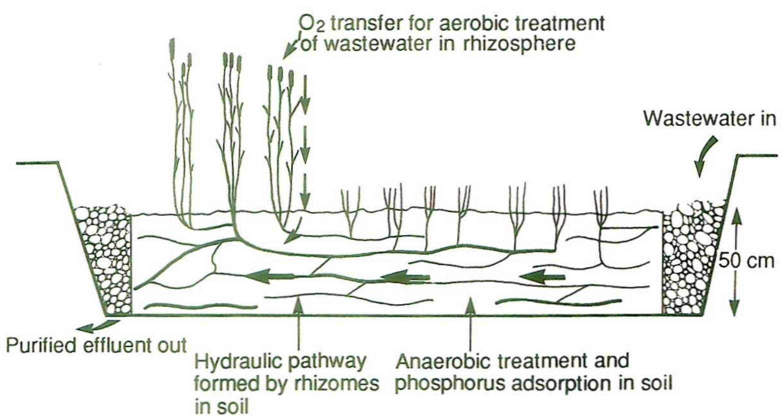

Figure 28 Key features of a typical reed bed treatment system

Staff at ITE Monks Wood have mainly been involved in the work on reed establishment and management (Parr 1987). A good growth of reeds, particularly below ground, is an essential prerequisite of RBTS, but, in practice, there have been frequent failures of reed establishment. In a survey of reed growth in UK beds, growth was found to be unsatisfactory in 73% of cases (Parr 1989a). Research on the germination ecology of the reed and into the effects of water levels on the growth and establishment of reeds has already helped avoid further failures, and some of the previous recommendations on reed bed establishment have been substantially revised. In the past, the recommended method was to use reed rhizomes transplanted in the autumn. However, the work has shown that planting in spring or early summer is preferable to autumn, and that reed seedlings should be used in preference to rhizomes.

Reed seedlings are rarely observed in natural reed beds in the UK, a fact which has given rise to a common misconception that reed stands in the UK cannot regenerate from seed. However, ITE research has confirmed that, in many reed stands, seed production is plentiful, the seed is viable, and seedling growth in a moist and weed-free environment is vigorous. A survey of 32 UK reed beds showed that, although there was considerable variation in seed production, seed was produced at 23 of the sites, with eight sites producing over 200 seeds per flower head. Maximum germination was attained at a fluctuating day/night temperature regime of 30°C/ 20°C, with germination rates ranging from 37% to 100% (mean = 81%). Most seed germinated within seven days.

Seedlings grown from seed germinated outside, on moist soil, in mid-May had produced an average of 10.9 g (±0.8 g) of shoots and 140 cm (±8 cm of rhizome by the autumn. However, small seedlings are susceptible to competition from other species and to fluctuations in water level, causing high mortality. To overcome this problem, seedlings were cultivated in glasshouses and planted out in mid-May, by which time the plants had already begun to produce rhizomes. By mid-September, these plants had produced an average of 38 g of shoots and 440 cm of rhizomes. Their rate of growth exceeded that achieved by transplanted

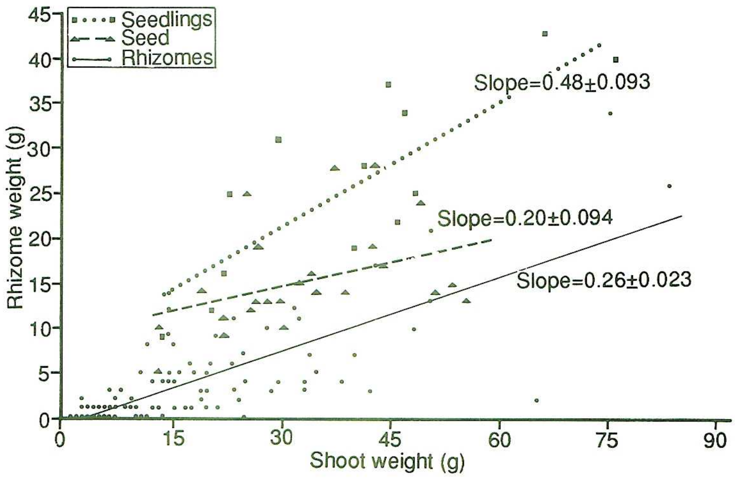

Figure 29. Reed seedlings provide the most effective means of establishing beds for reed bed treatment systems. After one growing season, seedlings produced consistently more rhizomes and had higher rhizome/shoot ratios than plants cultivated from seed or transplanted rhizomes

rhizomes grown under the most favourable conditions (Figure 29).

Reed seedlings have now been used to establish new reed beds successfully in RBTS beds at Little Stretton (Severn Trent Water Authority) and Freethorpe (Anglian Water Authority) (Plate 18). On the basis of these trials and from the results of the ITE research, the use of reed seedlings is now considered to be the quickest and most reliable method of establishing a new reed bed.

One of the main factors associated with poor reed growth in RBTS systems is the growth of weed species, especially sorrell (*Rumex* spp.), stinging nettle (*Urtica dioica*), great hairy willow-herb (*Epilobium hirsutum*), and grasses (*Poa* spp. and *Agrostis stolonifera*). Some experiments have been started to evaluate the long-term effects of weed populations on reed growth (Parr 1989b). The objectives are to quantify the effects of some major weed species on the growth and establishment of reeds, and to assess the benefit of control measures, including, flooding, chemical control and cutting. The effect of varying water levels on rhizome growth is also being investigated. At present, although a good cover of reed shoots can be achieved within two or three years, it may take twice that time for the root and rhizome system to mature. Work at ITE Furzebrook on genotypic variation in reeds is looking for varieties which are best adapted to the RBTS environment. Use of such varieties should further improve the rate of reed establishment and reed performance as sewage treatment plants.

Despite the problems of RBTS, and it is probably too soon to make a reliable judgement about the performance of existing beds in the UK, early results have been sufficiently encouraging to justify continued research and development. Furthermore, interest in using natural communities of plants to purify wastewaters should not be confined to these artificially constructed systems. It is important to understand and appreciate fully the role of naturally occurring wetland communities in keeping waters clean. There may be much to gain from allowing reeds and other wetland plants to thrive in drainage ditches, streams and rivers.

Plate 18. A farm sewer dyke used to clean wastewater before it is discharged into a local stream. The dyke is shown eight weeks after planting with reed seedlings (Severn Trent Water Authority)

T W Parr

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Radionuclide transfer in terrestrial ecosystems

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Merlewood Radioecology Group

The Radioecology Group at ITE's Merlewood Research Station was formed as a result of the publication in 1978 of the report of *The Windscale Enquiry* The aims of the Group are to study the factors and mechanisms which control the movement and deposition of radionuclides in the terrestrial environment

Initially, work was concentrated on the Sellafield area of Cumbria and on radionuclides released to the environment by the reprocessing plant Involvement with the Chernobyl accident began in April 1986, when gamma-emitting fission products were deposited over large areas of the uplands in western Britain Whilst those radionuclides with short half-lives decayed rapidly, the caesium isotopes with their longer half-lives (Cs-137 half-life c30 years, Cs-134 half-life c2 years) have remained actively recycling in the upland environment

Work within the Group now covers a range of radionuclides emitting alpha (plutonium, americium) and gamma (Cs-134, Cs-137 and silver-110 m) radiation Research on radionuclides emitting beta radiation will become important in the future as changes in fuel reprocessing take place at Sellafield, and studies have been initiated through a CASE studentship with the University of Lancaster, awarded under the NERC Special Topic programme

Fallout from the Chernobyl accident

The first stage of all the investigations carried out by the Radioecology Group has involved a detailed field survey to establish the spatial distribution of the radionuclides and the degree of variability found in the ecosystems studied The initial phase of the work on the Chernobyl deposit produced a map for the UK of the activities of grassy vegetation and the underlying soils, this map showed the highest activities to be where heavy rainfall coincided with the passage of the Chernobyl cloud These areas were concentrated in the north and west of Britain The initial survey provided an incomplete cover of the country, and it has been followed by more detailed surveys, to increase the resolution, in selected areas A recent survey in Scotland has identified an area of heavy contamination at the eastern end of Glean Spean, which was not located by the coarser original survey Many of the results from the surveys relevant to the Chernobyl deposit were used to define areas where restrictions on the movement and slaughter of sheep were required

Radioecology of Chernobyl fallout

Current research on the Chernobyl deposit is concentrating on the mechanisms involved in and the factors controlling radiocaesium transfers in upland ecosystems Much more of the radiocaesium has remained available for plant uptake in the organic soils of the uplands, compared to lowland regions where mineral soils predominate In Scotland, plant uptake from organic soils was, on average, ten times that from mineral soils The clays and micas of mineral soils bind radiocaesium very strongly, making it largely unavailable to plants The organic soils of the upland regions, however, which received high levels of Chernobyl fallout, contain little clay and are acidic in nature, as a consequence, they do not immobilise radiocaesium in the same way as mineral soils Radiocaesium can, therefore, be recycled in the upland systems, from soils to vegetation, and then back to the soil via plant litter It is this cycling which is maintaining high levels of radiocaesium in vegetation and concentrations in tissue of domestic stock (sheep) and wild animals (red deer (*Cervus elaphus*), grouse (*Lagopus lagopus scoticus*) and hares (*Lepus timidus*)) above the 1000 Bq kg^{-1} fresh weight (fw) declared for sheep Recent laboratory studies conducted with soil scientists at ITE Merlewood have shown that over 80% of the radiocaesium in bent-grass (*Agrostis* spp) litter is available for recycling, whilst field studies have indicated that the radiocaesium litter accounts for more than 10% of the total radiocaesium in heather (*Calluna vulgaris*) ecosystems

The concentrations of radiocaesium found in wild plants growing on the acidic upland soils vary considerably, as Table 11 shows for a selection of species from Corney Fell, Cumbria Plants in the Ericaceae family (the heaths) are reported as containing the highest concentrations At Corney, both heather and bilberry (*Vaccinium myrtillus*) contain over 5000 Bq kg^{-1} dry weight (dw) of radiocaesium Uptake of radiocaesium varies, therefore, with soil type and between plant species on a given soil type The potassium status of a soil also influences radiocaesuum uptake, because the two elements are chemically similar and behave in a similar manner in biological systems As a result, high levels of available potassium in a soil reduce the plant uptake of radiocaesium in effect by diluting its concentration in the soil Significantly, levels of potassium in organic upland soils are often low Bryophytes (mosses) obtain the bulk of their water by capillary action, so their

Table 11 The activity concentrations of radiocaesium in vegetation on Corney Fell, Cumbria, in July 1987, showing the marked variation in uptake between plant species

	Cs-137 (Bq kg^{-1} dw)	Cs-134
Higher plants		
Heather (*Calluna vulgaris*)	6590	2075
Bilberry (*Vaccinium myrtillus*)	3964	1194
Brown bent-grass (*Agrostis canina*)	1247	379
Heath rush (*Juncus squarrosus*)	1132	303
Soft rush (*Juncus effusus*)	936	295
Common cotton-grass (*Eriophorum angustifolium*)	595	121
Mat-grass (*Nardus stricta*)	514	153
Bryophytes		
Sphagnum spp	7472	2813
Polytrichum commune	4026	1445
Polytrichum alpestre	3543	1187

mechanisms for concentrating radionuclides are different to the higher plants which depend on the absorption of soil water

The levels of radiocaesium in grazing animals reflect those in the vegetation being eaten Therefore, the varying concentrations of radiocaesium in different plant species must be considered in relation to the grazing preferences of the different animals For instance, in some areas sheep and red deer may graze heather more heavily during the winter months, whereas heather is the main item of diet throughout the year for grouse Radiocaesium levels in animals also vary as they move between different grazing areas and with the seasonal patterns of vegetation growth These patterns of variation have been studied on an upland sheep farm within the restricted area of Cumbria

The radiocaesium activity of ewes at the farm declined when they were brought on to the farm's enclosed pastures, and rose when they were returned to the open fell (Figure 30) where the radiocaesium content of vegetation remained higher than on the pastures

Despite the reduction in radiocaesium activity of the mixed grassland vegetation grazed by sheep over the study period

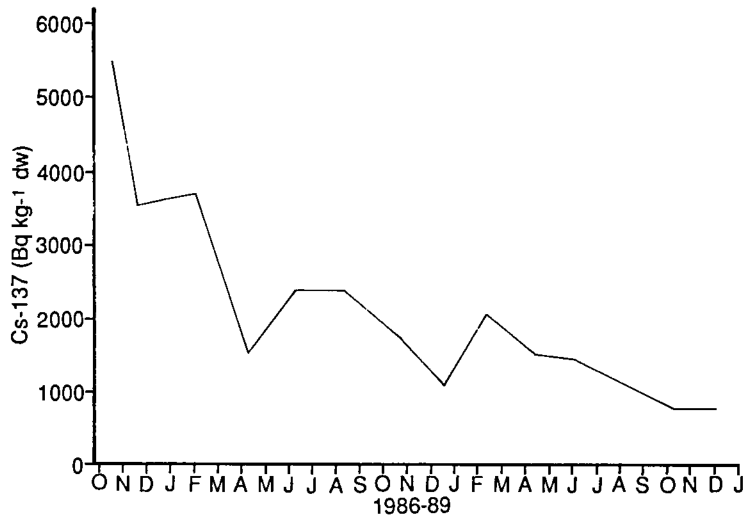

Figure 31 The Cs 137 activity concentration of vegetation samples taken from unimproved grazing land showing an overall decrease in the level of contamination

(Figure 31), the radiocaesium activity of the ewes grazing on the fell was higher in the summer and autumn of 1987 and 1988 than in the autumn of 1986 This rise appears to be due to the radiocaesium originating from the Chernobyl fallout becoming more readily available as it has been incorporated into plant material, by the cycling processes mentioned above, rather than when it was present as a direct deposit on the surface of the vegetation, as would have been the case in 1986

A rise in activity does not always follow the transfer of the sheep on to the fell During the winters of 1987–88 and 1988–89 when the ewes returned to the fell after mating on the enclosed pastures, their radiocaesium activity did not rise as at other times when they were moved from the pastures to the fell The digestibility of herbage is reduced during the winter, and this factor may cause a reduction in radiocaesium transfer Also, the intake of similar vegetation to that in the study area is known to be considerably higher in the summer than at other times of the year, so that radiocaesium intake would increase during the summer The measurements from the first winter (1986–87) after deposition of fallout from the Chernobyl accident are obviously different from the successive years, as the radiocaesium activity of the ewes rose when they were returned to the fell At present, the reasons are unclear, although the rise may have been associated with the presence of residual direct deposit on the vegetation surface

The addition to the sheep feed of radiocaesium binders, such as the clay mineral bentonite, zeolites and iron-hexacyanoferrates, to reduce radiocaesium uptake by housed animals is well documented The use of counter-measures to reduce levels in free-ranging animals, however, is not so simple In co-operation with the Macaulay Land Use Research Institute (MLURI), pastures at the study farm were treated with powdered bentonite Results

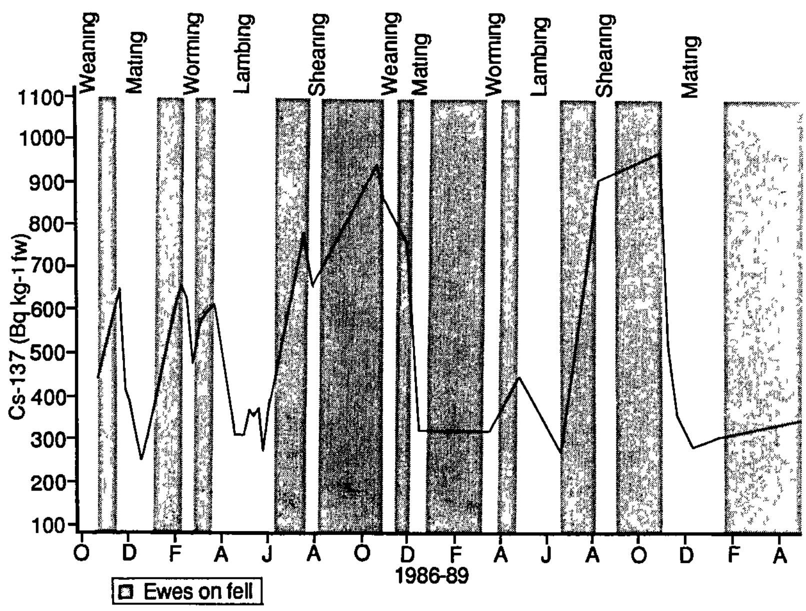

Figure 30 Changes in the Cs-137 activity concentration in the muscle of ewes grazing at the study farm in west Cumbria The effect on their radiocaesium burden as they moved from enclosed pasture to open fell is clearly shown

looked promising, with a 40% reduction in the radiocaesium activity of ewes grazing the treated pastures after four weeks However, the ewes' herbage intake and body weight were considerably reduced, and this option does not appear realistic The Norwegian School of Agriculture has successfully reduced radiocaesium levels in free-ranging sheep and reindeer using saltlicks and slow-release rumen boli impregnated with ammonium iron-hexacyanoferrate complex (ACFC) In a joint study with Norwegian scientists, the effectiveness of these counter-measures will be assessed under the agricultural regimes of upland Britain

An alternative method of reducing radiocaesium levels is to remove the animals from the contaminated areas With the help of the National Radiological Protection Board and the Ministry of Agriculture, Fisheries and Food, ITE has established that, once removed from upland farms to uncontaminated lowland pastures, lambs lose their radiocaesium body burden with a biological half-life of approximately ten days Such a move is part of the normal management practice because, with the relatively severe climate of the regions which received the heavy deposition of Chernobyl fallout, very few sheep are sold ready for slaughter Instead, they are sold to lowland farmers for fattening This movement of sheep has led to concern that radiocaesium in excreta deposited by lambs when they arrived at the lowland farms would significantly increase the radiocaesium activity of vegetation at these farms In a lysimeter study, the uptake from urine and faeces by vegetation growing on both mineral and organic soils has been assessed On both soil types, less than 1% of the radiocaesium in faeces and less than 0 3% in urine were recycled to vegetation over a twelve-month period

Freshwater radioecology

Prediction of the likely duration of the cycling of the radiocaesium requires information on the temporal changes in its availability within soils This aspect is being investigated as part of the ITE programme of work on the geochemistry of radionuclides in soils, which is concentrating on the higher organic upland soils in Cumbria, typical of those found in the high-deposition areas of north Wales, north-west England and Scotland (ie rankers, podzols, peats and peaty gleys)

The Cs-134/Cs-137 ratio in these soils reflects the ratio present in each contributory source (weapons fallout, industrial discharges and accidental release), the magnitude at each source, and the time since deposition It is fair to say that the pre-Chernobyl Cs-134 activity was negligible in all these soils, and it is thus possible to distinguish between Chernobyl-derived and 'non-Chernobyl' components Chernobyl-derived radiocaesium comprises from 30% to 50% of the total at these sites However, early measurement of the isotope ratio in the 'exchangeable' fraction of the radiocaesium has shown that this fraction consisted almost entirely of Chernobyl-derived radiocaesium, in other words, the Chernobyl-derived radiocaesium was, initially, less firmly bound in these soils than the older radiocaesium Over time, however, the composition of the exchangeable fraction has changed, and the Cs-134/Cs-137 ratio has fallen to the same value as it is in the whole soil This result suggests that the Chernobyl-derived radiocaesium has been redistributed within the soil into the same 'pools' in which the older caesium is held This hypothesis is presently being tested by isolating various soil fractions (clay minerals, humic/fulvic acids, cellulose residues) from samples collected in both October 1986 and March 1989, in an attempt to define the changes over time

Long-term availability of radiocaesium in upland ecosystems

The Chernobyl fallout is also being used as a marker for freshwater cycling processes in a joint study with the Institute of Freshwater Ecology (Ferry House) and the University of Lancaster Studies in two contrasting lakes, Windermere and Esthwaite, have determined the magnitude of both direct deposition to the lake surface and indirect input from the catchment Measurements of dissolved and particulate radiocaesium concentrations over time and throughout the water column, together with an analysis of a time series of sediment cores, have been integrated into a numerical model describing radiocaesium dynamics in the lakes The main findings are that sedimentation in association with algae is a dominant pathway for radiocaesium transport in the lakes, and that the majority of the radiocaesium deposited on to the catchments has been retained in the soils

Current studies on the behaviour of radionuclides released by the Sellafield reprocessing plant

Although the Chernobyl accident resulted in a change in emphasis in the work of the Group, research is continuing on the fate of past and current releases from the Sellafield reprocessing plant This research is concentrated on the long-lived actinide elements which present a potential risk to man, and one study is investigating the uptake of plutonium by plants In order to simulate soil pore water, a hydroponic system has been constructed Water is pumped through silt obtained from the Ravenglass estuary, and a continuous low concentration of 3–18 mBq l^{-1} has been measured After filtration to remove suspended particulates, this water is circulated with nutrients through a series of growth troughs containing plants After a growth period of one month, measurable concentrations of both plutonium and americium have been found in the upper plant tissues of 0 2–0 5 Bq kg^{-1} This work initially used rye-grass (*Lolium perenne)* and is continuing to investigate the mechanisms of uptake using clover (*Trifolium* spp) and barley, in collaboration with the University of Newcastle

Research into the physicochemical associations of the actinide elements in soil is also continuing to identify mechanisms of immobilisation Plutonium and americium are associated with humic and fulvic acid fractions, and the majority of the actinide activity in a humic fraction of a gley soil has been found to be high in molecular weight material, together with iron and manganese Both this fraction and the lower molecular weight material have been separated by gel permentation chromatography and isolated, and it appears that the high molecular weight, actinide-rich fraction consists of colloidal clay/humic acid aggregates The effects of humate and fulvate complexing on the availability of the actinide elements to the plants will be tested

Direction of future research

Data from earlier studies are now being

collated, and mechanistic and predictive models are being developed In collaboration with Sutton Bonington School of Agriculture (University of Nottingham), data from both field and laboratory sheep studies are being used to develop a 'sheep ecosystem model' Further data are being obtained in joint experiments with MLURI on the behaviour in sheep of other nuclides likely to be released from nuclear installations (H-3, C-14, ruthenium, Ce-139, S-35, Ag-110, Zn-65 and Co-60) Together with the Soil Survey and Land Research Centre, the potential recycling of radiocaesium has been assessed from the different soils found in Cumbria It is hoped that this area of research will be expanded jointly with the Land Use Study Team at ITE Merlewood Data obtained from Cumbria before the deposition of Chernobyl fallout have been modelled with the University of Lancaster to show the distribution of radionuclides released from the Sellafield plant throughout the country

Studies of the behaviour of radiocaesium in different 'natural' or 'semi-natural' ecosystems affected by the Chernobyl accident have just begun Field studies will be conducted in Scotland (with the help of ITE Banchory), Norway (with the Norwegian School of Agriculture) and northern Italy (with the Italian Research Institute ENEA) The transfer of radiocaesium through the different ecosystems to a variety of grazing animals will be compared

The ITE studies, and those of others, have shown that a number of factors may affect the transfer of radionuclides to grazing animals However, most of these factors have not been fully investigated Staff at ITE Merlewood have prepared a joint proposal to the Commission of the European Communities, involving Belgian, Italian, Irish, Greek, Norwegian and other UK laboratories, to study the effect of such factors as plant species, animal age, animal breed, physiological condition, and the soil contamination of vegetation on the transfer of radionuclides to grazing animals

As mentioned, the importance of work into beta-emitting radioisotopes will become increasingly important when new reprocessing equipment at the Sellafield site comes into operation In order to investigate the behaviour of these isotopes in the environment, it is hoped to expand ITE's analytical facilities to include the capability for low-level beta counting

A D Horrill, F R Livens and N A Beresford

Scientific principles of soil protection in the UK

(A joint study with the Soil Survey and Land Research Centre, funded by the Department of the Environment)

Many countries have long had policies, and associated legislation, designed to maintain the productive potential of the soil resource Much of the legislation refers to 'soil conservation', but actually focuses almost entirely on the prevention or limitation of soil erosion In fact, the term 'soil conservation' has become virtually synonymous with the control of soil erosion

In the past, there has been little explicit legislation to protect soils in north-west Europe However, in recent years, there have been increasing pressures for measures to protect and conserve soil resources for use by present and future generations These pressures have arisen from a realisation that there are increasing threats to the ability of soils, and not only agricultural soils, to fulfil the functions on which man's use of soils depends The main concerns are the sterilisation of soils by urbanisation, physical depletion (erosion), chemical depletion (leaching), acidification, contamination (by chemical and toxic wastes), and the effects on the soil fauna and microflora of the overuse of pesticides and herbicides Some countries are also concerned about the problems of compaction, drainage, and salinisation

Some of the concerns relate to problems of water pollution, because soils have become increasingly important for their ability to act as filters to remove solid matter from percolating water, to act as buffers to absorb rainwater and control its transport to the groundwater table or streams, rivers, and lakes, and to protect groundwater and food chains against pollution by physicochemical and chemical processes Hence, problems of water pollution by nitrate, phosphate, heavy metals, herbicides and pesticides are considered amenable to control by measures which protect soils

Any soil protection policy would need to recognise the types of soil occurring in the UK and their differences from those in other countries, such as those in southern Europe Thus, soils in the UK are young and still evolving, many have impeded drainage in a cool, wet climate, and most have been influenced by man for many hundreds of years

Soil protection *versus* soil conservation

The use of the term 'soil protection', as distinct from 'soil conservation', is relatively recent, and seems to have originated in Europe, and particularly within the European Community 'Soil protection' is generally used to indicate a broader approach to the maintenance of the soil resource which considers all possible threats, including erosion There would appear to be further differences the existing soil conservation policies throughout the world are aimed primarily at maintaining agricultural or forest productivity However, current ideas about soil protection are not linked to any particular use of soils, but are incorporated in the view of soil as a complex system which carries out various functions

Soil protection in the European Community

In Europe, the first moves towards the development of a soil protection policy were made by the Federal Republic of Germany and the Netherlands In 1985, the Federal Republic of Germany published its *Bodenschutzkonzeption*, essentially a set of principles that the Federal Government would like to see adopted into the legislation of the Lander In 1987, the Dutch Soil Protection Act became operative, and was the first explicit soil protection legislation in north-west Europe

At present, the UK has no such soil protection legislation, although a number of laws and regulations provide implicit protection However, the UK recognises the need to establish the basic principles of soil protection, with a view to optimising the management of its soil resource This recognition implies the consideration of issues other than those covered by the traditional ones of agriculture and forestry There is a need for (i) sound advice on the basic principles of soil protection which might be appropriate to the UK, and (ii) recommendations on what may be the best use of soil in terms of minimal risk and its location in relation to designated areas where there may be restrictions

The importance of the definition of 'soil'

A soil protection policy would protect anything defined as 'soil' However, 'soil' may be defined in a number of ways for different purposes The definition used in a soil protection policy will have a major influence on the structure and implementation of that policy Protection policies being developed in mainland Europe use a broad definition, stressing that soils are complex, dynamic systems In these cases, soil protection aims to protect the soil as a functional system

Aims of a soil protection policy

Soil protection policies do not aim to prevent natural changes or the natural evolution of soils, but, rather, aim to protect soils against adverse changes resulting from man's activities In this context, 'adverse changes' are those which impair a soil's ability to carry out its normal range of functions The central aim of the Dutch soil protection policy is the maintenance of 'good soil quality' The prevention of adverse changes can be seen as the mirror image of that

However, a policy based solely on the prevention of adverse changes in soils would be too restrictive, as areas of soils exist which have already suffered adverse changes and can expect more in the future A soil protection policy should also be concerned with the restoration of damaged soils It should be realised that such a policy could not realistically aim to protect soils against all man-induced changes

The prevention of adverse changes and the restoration of damaged soils could form the basis of a UK soil protection policy However, problems could arise if a soil protection policy was based on the prevention of 'soil degradation', because that term has come to be linked with the maintenance of the productive potential of soils for agriculture and forestry, and a soil protection policy should have broader aims Furthermore, current concerns about the leaching of nitrate, organic pollutants, and phosphate from soils to groundwaters are not considered in discussions on degradation

The concepts 'soil quality' and 'adverse changes' require definition in the context of a soil protection policy In the Netherlands, it has been suggested that reference values for 'good soil quality' should be such that the soil poses no harm to any use by human beings or animals, can function in natural cycles without restriction, and does not contaminate other parts of the environment Problems arise in attempting a quantitative definition of 'soil quality' because of the natural complexity of soils and their heterogeneity at a range of scales from millimetres, through metres, to kilometres There is no single parameter which can be used to define 'soil quality' or 'adverse changes' A series of reference parameters are required, but, even given such a series, there is no single set of reference values for those parameters which might define 'quality' because of the natural variability between and within soils and the variation in impact of given stresses on soil processes and functions Reference values could really only be set with respect to a given end use, eg growing winter wheat, to the ability of a soil to perform certain functions, eg to supply plant nutrients, or to the operation of certain soil processes Any quantitative definition of soil quality which is relevant to several functions or uses will only be possible for a few parameters, eg heavy metals

Similar problems arise with the quantitative definition of 'adverse changes' However, in this context, an alternative approach would be to aim to prevent changes in soils which cannot be reversed naturally or by ecological

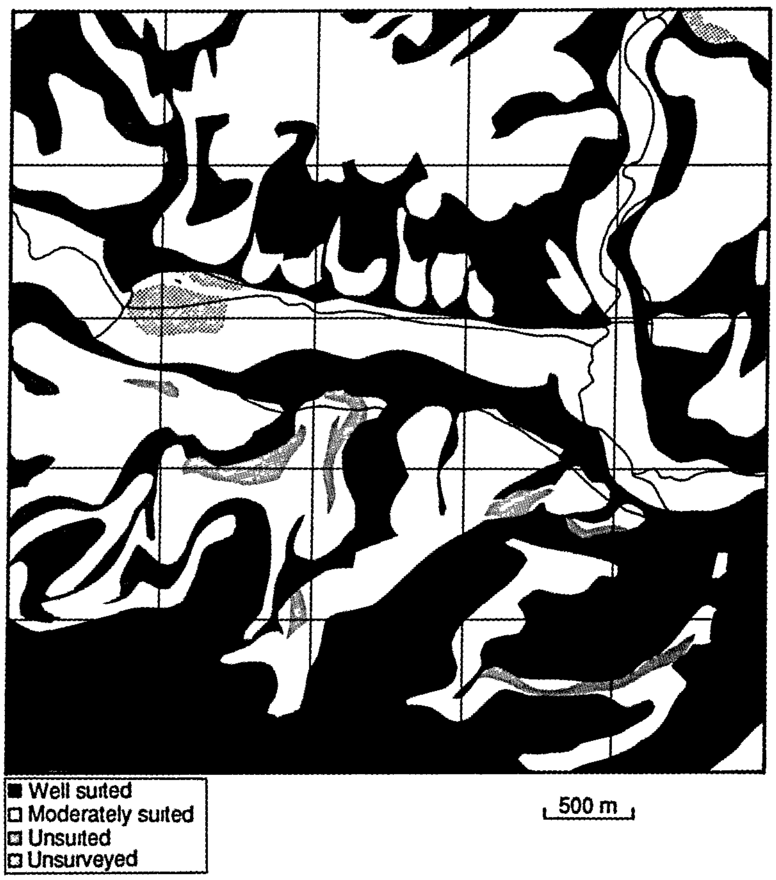

Figure 32 The suitability of land around Wilton Wiltshire for the growth of winter wheat (reproduced by kind permission of the Soil Survey and Land Research Centre)

management, or to prevent changes in soils greater than those which occur as a result of natural variations in other environmental factors, such as climate Currently, it is not possible to define the limits of change of most reference parameters which are naturally reversible or are within the range resulting from environmental variation However, in some cases, it is possible to identify, qualitatively, changes which are not reversible naturally

Susceptibility and sensitivity of soils to stress

Although quantitative definitions of 'soil quality' or of rates of 'adverse' or 'undesirable' changes may not be possible at present, soils can be ranked in terms of their susceptibility and sensitivity to given stresses In this context, soil sensitivity can be seen as the magnitude of the response of a soil to a given stress, or the rate of that response The susceptibility of a soil system to stress may be defined as the likelihood of a given form of degradation occurring as the result of that stress The ranking of sensitivity requires a conceptual model incorporating those factors which control the response of a soil For example, a soil may be susceptible to erosion, and erosion results from a soil's sensitivity to rainfall That sensitivity is determined largely by soil texture, slope, and surface cover

A soil which is well suited to a particular use will have low susceptibility and sensitivity to stresses imposed by that use Changes induced in such a soil will not be greater than those which are easily reversible Hence, one aim of a soil protection policy should be to use land for the purpose for which it is best suited For example, although soil may be suitable for growing winter wheat (Figure 32), a high susceptibility of the soil to nitrate leaching (Figure 33) would make that use unsuitable in the context of a broadly based soil protection policy A similar approach can be applied to dispersed, as opposed to localised, stresses Thus, soils can be ranked in terms of their sensitivity to acidic deposition, in this case, the controlling factors would be cation exchange capacity, base saturation, and texture

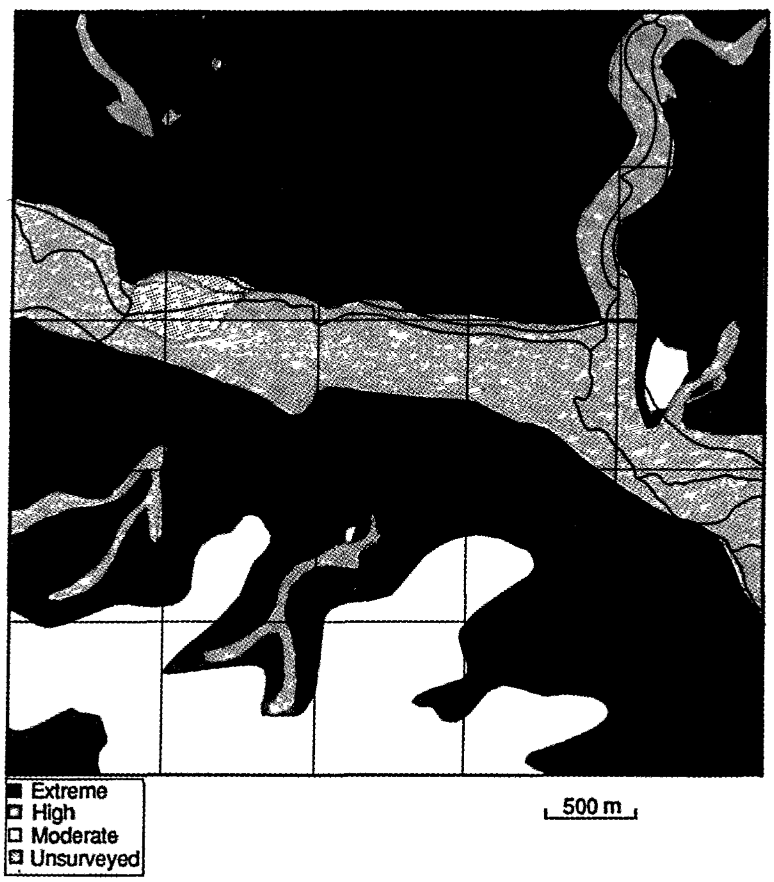

Figure 33 The potential nitrate leaching risk of soils around Wilton Wiltshire (reproduced by kind permission of the Soil Survey and Land Research Centre)

Soil buffering capacity, resilience, and the reversibility of changes

The concepts of buffering capacity, resilience, and reversibility are related to sensitivity, and may also be useful in formulating soil protection policies The buffering capacity of a soil is its ability to absorb or neutralise the impact of a given threat or stress, and hence to delay the effect Resilience is a measure of the ability of a soil system to recover naturally once a threat or stress is removed or the loading of the given stress or threat is reduced The effect produced by a stress is reversible if the property or properties which have changed can be returned to their original values Soils and ecosystems are generally resilient within certain limits, but, if the property of interest moves outside those limits, the soil will not recover naturally The effect may still, however, be reversed by management measures Some effects are irreversible – the accumulation of heavy metals in soils is generally irreversible

The implementation of a UK soil protection policy

The implementation of a soil protection policy for the UK would require

1 characterisation of the soils in the UK and their current properties, followed by an assessment of their degree of degradation,
2 monitoring of changes in soils over time,
3 assessment of the impact of man's activities on soils, particularly the impact of changes in land use and management on their characteristics and functioning,
4 definition of acceptable loads of man-induced stresses and means of controlling those stresses,
5 development of alternative management methods and techniques to reduce the impact of man's activities on soils,
6 definition of target values of soil parameters for the rehabilitation of damaged soils

The data bases held by the Soil Survey and Land Research Centre and the Macaulay Land Use Research Institute clearly form the basis of the required information on the soils of the UK However, the resolution of those data bases, and the information they contain, may necessitate further input Considerable soil information for semi-natural sites is held by organisations such as the Nature Conservancy Council The national, or regional, assessment of such change would require a network of long-term monitoring sites, such as those which are being established in other European countries The value of these long-term monitoring sites has been demonstrated by the classical plots at Rothamsted Experimental Station

The impact of man's activity on soils could be included in the Environmental Assessment Regulations, which implement the EC Directive no 85/337 While it might not be possible, at present, to produce quantitative assessments of impacts, soils could be ranked in terms of their sensitivity, as a first stage Critical, or acceptable, loads provide a means of linking a soil protection policy with legislation for the control of activities which may have adverse effects on soils The development of less-damaging land management strategies has been referred to as 'optimisation' in the Netherlands, where great efforts have been made to develop models for matching nitrate fertiliser inputs to plant demand Parallel work is in progress in the UK Another aspect of less-damaging land management would be the introduction of new technology, eg wider tractor wheels to reduce the loading on the soil The evaluation of the success of any restoration measures should include reference parameters which cover biological, chemical, and physical aspects of soils and their functioning Wherever possible, reference or target values should be assigned to each parameter

The key question is 'how could a soil protection policy be implemented in the UK?' An important requirement of the Town and Country Planning Act is that, in deciding whether or not to give planning permission, the planning authority 'shall have regard to the development plan for the area and to any other material considerations' The value of the soil for any purpose, or its susceptibility to damage by the proposed development, in any location may be regarded by the planning authority as a 'material consideration', if the value, quality, or susceptibility of that soil could be demonstrated Maps providing such information would be of value to planning authorities if the required data were accessible In the UK, various legal instruments are available for protecting the environment However, they are not linked or co-ordinated under a broad policy, and responsibilities are spread between departments Furthermore, three-quarters of the UK, or at least of England and Wales, is excluded from planning control by virtue of its use for agriculture or forestry Any soil protection policy would require links with general environmental policies and legislation, such as those concerning controls on emissions, pollution of waters, and planning legislation, and with agriculture and forestry policies and legislation

P J A Howard

Interactive effects of pesticides in partridges

Most studies to assess the potential hazards of pesticides to birds and other animals are restricted to the effects of a single chemical in isolation This is the only legal requirement However, in the field, birds may be exposed to a number of different pesticides, because more than one pesticide has been used at the same time in a 'cocktail', because several chemicals have been used sequentially, or because the bird has moved from an area where one pesticide has been used to an area where another has been applied Studies on possible interactions between combinations of pesticides have received scant attention, particularly in birds (Ludke 1977) The paucity of such information was the reason for this study, which was done at the School of Animal and Microbial Sciences, University of Reading, by G Johnston and Dr C Walker, in collaboration with ITE Monks Wood, as part of the NERC Special Topic on Animal Ecotoxicology The red-legged partridge *(Alectoris rufa)* was chosen for the study because it occurs widely on agricultural land and is, therefore, likely to be exposed to a range of pesticides, and also because it is easily kept in captivity and is available commercially

In view of the large number of possible combinations of pesticides to which birds may be exposed, it is obviously desirable in such a study to select combinations which may be expected to interact in some way, particularly those which may result in increased toxicity There are two main mechanisms by which the toxicity of one pesticide may be increased by another by the induction of an enzyme which activates one of the pesticides, or by the inhibition of an enzyme which detoxifies it The study has so far been mainly concerned with the former mechanism

Enzyme induction

The aims of the first part of this study were two-fold First, to examine the effectiveness of the environmentally persistent organochlorine DDE, the major metabolite of DDT, and the fungicide prochloraz, to act as inducing agents (ie their ability to promote the production of various enzymes, some of which are involved with destroying these 'foreign' compounds) (Riviere 1983), second, to

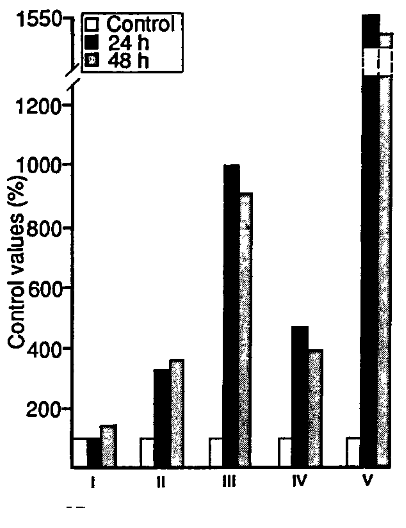

Figure 34 The effects of prochloraz on various liver parameters in partridges. Birds were given an oral dose of corn-oil alone (controls) or 180 mg kg^{-1} body weight prochloraz in corn-oil and killed 24 h or 48 h later The Figure shows (i) liver weight (g) (ii) microsomal protein (mg g^{-1}) (iii) the amount of the enzyme cytochrome P-450 (nmol kg^{-1} body weight) and the activities of two other enzymes; (iv) aldrin epoxidase (nmol kg^{-1} body weight min^{-1}) and (v) EROD (nmol kg^{-1} body weight min^{-1})

All values are expressed as means of values in control birds 24 h and 48 h after dosing Treatment with prochloraz markedly increased all of these parameters determine the effects of prochloraz pretreatment on the subsequent toxicity of the organophosphorus insecticide, malathion, once induction has occurred. Prochloraz on its own is not particularly toxic to vertebrates.

DDE was found not to be an effective inducer in the partridge, whereas prochloraz was found to be a potent inducer of mono-oxygenase enzymes in the liver. There was an increase in liver weight and nearly a four-fold increase in liver microsomal protein content. The activities of several enzymes in the liver, including cytochrome P-450, were increased several-fold above those of the controls, when expressed in terms of body weight (Figure 34).

Pretreatment with prochloraz in corn-oil caused a dramatic increase in the toxicity of malathion to partridges; three out of four pretreated birds died within ten minutes of receiving low intraperitoneal doses of malathion. The activities of the enzyme cholinesterase in both serum and brain were depressed by 100% in two of these birds, whilst the third showed depressions of 100% and 82%, respectively. Significant increases in liver weight, liver microsomal protein and cytochrome P-450 content confirmed that these birds were in the induced state at the time of malathion administration. In

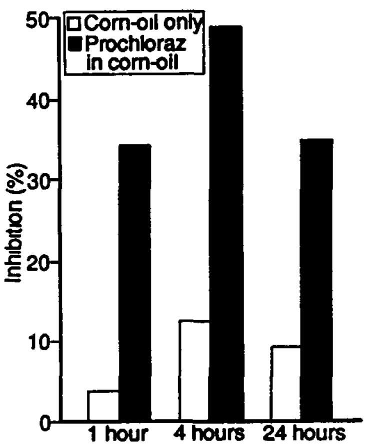

Figure 35. The effect of pretreatment with prochloraz on malathion induced inhibition of the activity of the enzyme serum cholinesterase. Partridges were treated orally with corn-oil alone or 180 mg kg^{-1} body weight prochloraz in corn-oil. After 24 h, all birds were given 11 mg kg^{-1} body weight malathion orally. Blood samples were taken before dosing with malathion and 1 h, 4 h and 24 h later. The Figure shows % inhibition of cholinesterase activity compared to activity before dosing with malathion. In birds pretreated with prochloraz malathion caused a much greater inhibition of cholinesterase activity.

contrast, birds treated with corn-oil alone and given the same doses of malathion displayed a slight elevation of serum cholinesterase after one hour, and only a 25% inhibition after four hours. Prochloraz pretreatment also resulted in a significant increase in susceptibility to low oral doses of malathion (Figure 35).

Malathion itself is inactive within the animal's body, but it is activated by the mono-oxygenase enzymes to produce malaoxon, which is very toxic because it inhibits the activity of the cholinesterase enzymes. In mammals and birds, but not insects, most malathion is rapidly detoxified by another enzyme to produce malathion monoacid and diacid, so preventing the accumulation of the toxic malaoxon. Thus, malathion is much more toxic to insects than to birds and mammals.

To determine why prochloraz increased the toxicity of malathion to birds, the metabolism of malathion was compared *in vitro* by microsomes from the livers of two groups of birds. One group had previously been dosed with prochloraz in corn-oil, while the other group was given corn-oil alone. Microsomes from both groups were incubated with C^{14}-labelled malathion, and the resulting metabolites were separated by thin-layer chromatography before using a linear analyser to locate the radioactive areas. Microsomes from the control birds yielded only one major metabolite, identified as malathion monoacid (Figure 36). In contrast, microsomes from the prochloraz-treated group yielded three distinct metabolites, the most prominent of which was malaoxon. The others were malathion monoacid and diacid. Thus, in control microsomes, malathion is rapidly detoxified to the malathion monoacid, whereas in induced microsomes metabolism is predominantly to the toxic malaoxon, brought about by one or more forms of cytochrome P-450 induced by prochloraz. So, although both prochloraz and malathion alone are fairly safe for birds, the combination of the two becomes lethal.

The toxicity of other organophosphorus compounds following pretreatment with prochloraz is currently being assessed. Dimethoate and chlorpyriphos have been selected because they require metabolic activation for toxicity. Preliminary results suggest that there is also a potentiation of toxicity of these compounds in

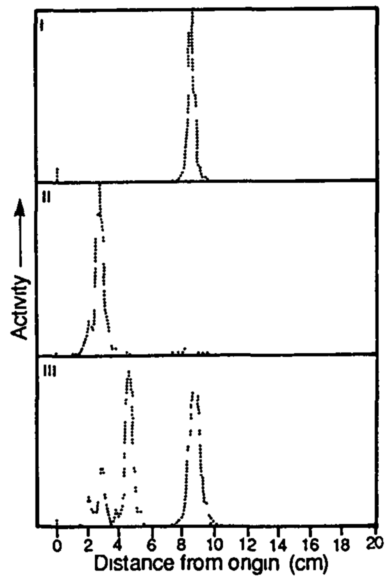

Figure 36. Traces from a linear analyser. Microsomes were prepared from the livers of partridges which had been treated with corn-oil alone or with prochloraz in corn-oil 24 h earlier. Microsomes were incubated *in vitro* with C^{14}-labelled malathion. The resulting metabolites were separated by thin-layer chromatography and run on a linear analyser to locate the radioactive areas. The Figure shows (i) the trace from C^{14}-labelled malathion standard, (ii) the trace from control microsomes showing only one major metabolite malathion monoacid, (iii) the trace from microsomes from prochloraz-pretreated birds showing three metabolites of which the most prominent is the toxic malaoxon.

prochloraz-treated birds. Several other fungicides, such as myclobutanil, propiconazole and penconazole, are being investigated in combination with malathion, and results suggest that all of these compounds are capable of causing an increased susceptibility to malathion toxicity in the partridge.

Enzyme inhibition

The results described so far have dealt with the increased toxicity of insecticides brought about by pretreatment with a fungicide which increased the activity of the enzymes needed to activate the insecticide. A further study is concerned with increased toxicity caused by an inhibition of the enzymes involved with detoxifying a pesticide, and, in particular the effects of partial inhibition of blood esterase enzymes on the toxicity of the carbamate insecticide, carbaryl. Carbaryl was given orally at a dose corresponding to either 20% or 10% of the lethal dose to control birds, and to birds which had previously received low doses of malathion. Although there were no significant differences between malathion-pretreated and control birds in either the concentration of carbaryl detected in the blood or in the degree of inhibition of cholinesterase enzymes, three of four malathion-pretreated birds showed symptoms of poisoning, and one of these birds died As no signs of toxicity were observed in four control birds, it appeared that an interactive effect had occurred which was not apparent from blood analysis Further work aims to confirm this observation and to establish the mechanism

Effects on reproduction

A collaborative study with the Karolinska Institute, Stockholm, showed that treatment with prochloraz induced several forms of cytochrome P-450 enzymes in the livers of partridges Because gonadal steroid hormones, essential in reproduction, are metabolised by cytochrome P-450 enzymes, it is possible that prochloraz could affect the normal reproductive function This possibility was investigated Birds were treated with repeated oral administration of prochloraz and malathion, alone or in combination, throughout the breeding season and data were obtained at successive stages on induction and reproductive status in males and females Results showed that all birds which received repeated prochloraz treatment were maintained in an induced state for the three months of the experiment There were no significant differences between any of the experimental groups and controls in terms of testis, ovary or oviduct weights, or plasma concentrations of luteinising hormone or testosterone However, it must be pointed out that, in retrospect, the birds used in this study were too young Many of the control birds did not become fully sexually mature, and there was a great deal of variation between individuals The negative result is, therefore, not conclusive Further work will investigate whether prochloraz-stimulated induction does alter the metabolism of gonadal steroid hormones

Little attention has been paid to the possible interactive effects of pesticides Results show that such effects can be important, and this conclusion gives some cause for concern It is unclear if such interactions have ever been a major cause of mortality Because the levels of each pesticide involved in such synergisms may be well below their individual lethal levels, and because these pesticides are often rapidly metabolised in any case, post-mortem analysis of tissue residues would not have pinpointed this factor as the cause of death

A S Dawson

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Ecological impacts of climatic change

(This work was partly supported by funds from the Department of the Environment)

Several recent observations have revived concern that emissions of 'greenhouse' gases could change the world's climate dramatically in the coming 50–100 years These observations are that (i) concentrations of radiatively active gases (RAGS) other than CO_2 are increasing rapidly, especially methane, nitrogen oxide, tropospheric ozone and chlorofluorocarbons, (ii) historic temperature data have now been critically analysed, and there is agreement that the world has warmed by about 0 5°C in the past 100 years, with five of the ten warmest years in the last 100 having been in the 1980s, and (iii) all five major General Circulation Models of the atmosphere predict a global warming of 2–5°C resulting from effective CO_2 doubling

The scenario

'Effective CO_2 doubling' means that the combined effect of all the greenhouse gases in trapping infra-red radiation (heat) on the earth is equal to the effect of doubling the CO_2 concentration Such a doubling is likely to occur by the year 2050 AD CO_2 concentrations themselves are likely to double towards the end of the next century The predicted warming of 2–5°C by 2050 AD is the warming to which the earth will be committed over the long term, once the oceans have warmed The actual global warming by 2050 AD is likely to be 1 0–2 5°C, and high latitudes will warm more than tropical latitudes The global increase in mean sea level is likely to be about 35± 20 cm by 2050 AD (less than previously predicted) There are no reliable predictions for particular regions of the world, but it is assumed that the UK will follow the global trend Rainfall may increase, but evapotranspiration could increase faster There is no evidence that the UK will suffer more extreme weather

Over the past year, ITE staff have undertaken desk studies and planning exercises, and begun new projects on (i) land/atmosphere exchange of RAGS, especially methane and the nitrogen oxides, and (ii) the impact of increased CO_2 levels and temperature rise on terrestrial ecosystems

Desk studies for the Department of the Environment

In 1988, the Department of the Environment and NERC commissioned six desk studies of the impact of increases by 2050 AD of CO_2 to 540 ppmv (parts per million by volume), mean temperatures of 3°±1 5°C, rainfall ±20%, and a sea level rise of 80 cm (all somewhat larger values than in current scenarios)

The subjects and main conclusions were as follows

1 *Direct effects of CO_2 increases on trees and forests* (ITE and the University of Edinburgh)

   In general, increased CO_2 levels will promote photosynthesis and decrease the loss of water through stomatal pores in leaves However, over several years, plants may adapt to high CO_2 levels and then respond less than in short-term experiments Seedlings and young trees grow 20–120% faster at doubled CO_2 concentrations, but no experiments have been done on mature trees or on trees without nutrient or other limitations No information is available on stand responses, which can only be assessed using mathematical models

2 *Effects of climatic change on trees and forests* (ITE and University of Edinburgh)

   Trees are vulnerable to climatic

changes which occur within their lifespan, and are especially vulnerable to winds, fires and pest outbreaks In the absence of water stress, spruce at 400 m altitude could grow up to 40% faster, following a 1°C rise in temperature, and tree rings show increased pine growth at 1–2°C warmer temperatures However, with increased water stress, conifers would be adversely affected, and more broadleaved tree species could be grown Also, peaty upland soils will improve in the long term

3 *Effects of CO_2 and climatic change on agriculture* (University of Nottingham)

Doubled CO_2 levels might increase crop yield by an average of 30%, and reduce water loss per unit of yield Increased temperatures (3–4°C) would accelerate the development of crops such as wheat, leading to lower yields, but would increase the yields of crops which grow into the autumn, like sugar beet and potato, by 50–70% The geographical distributions of crops would change, and large, but uncertain, changes could occur in pest and disease incidence

4 *Effects of climatic change on species, ecosystems and processes of conservation and amenity interest* (ITE and Unit of Comparative Plant Ecology, University of Sheffield)

The relative abundance of plant species will change, especially in southern Britain, with grasses and early-flowering bulbous plants (like bluebells *(Hyacinthoides non-scripta)*) becoming less common except in dry places Many species will expand northwards, on to north-facing slopes, and to higher altitudes These changes will occur in spurts, in particular years, and could be altered by land use practices The most threatened plant species will be those currently growing in wetlands and on mountains and heathlands

5 *Impacts of climatic change on freshwater ecosystems* (Institute of Freshwater Ecology)

Most UK lakes will not be seriously affected, but many nutrient-rich lakes may produce more algal blooms Many fish will be adversely affected, especially the northern cold-water species like Arctic charr *(Salvelinus alpinus)* and whitefish *(Coregonus* spp), but also trout *(Trutta* spp) in southern streams

6 *Effects of sea level rise on coastal ecosystems of conservation and amenity value* (ITE)

A sea level rise of 20–165 cm by 2050 AD would cost about £5–8 billion in sea defences Sea walls would not be protected by salt marshes on the seaward side All invertebrate and bird species that depend on marshes and mudflats would suffer

Highlights of the ITE research programme

1 *Radiatively active gases*

There are great uncertainties about the sources of methane, including releases from the boreal wetlands Two methods will be employed to measure the methane given off by wetlands The first is to place boxes (cuvettes) upside down over the ground and to measure the rate at which methane accumulates inside them The second is to measure the increase in concentration of methane in the air from high up towards the ground (the gradient), and the micrometeorological processes that make it possible to calculate the rate at which methane is released to produce the measured gradient (the flux gradient) In addition, experiments will be done in open-top chambers (small glasshouses with no roof) to determine the effect of temperature on methane emissions from wet organic soils A second subject of concern is the build-up of ozone in tropical regions this is the ozone near the ground (not stratospheric ozone), and is produced by the action of light on nitrogen oxide gases that are emitted from agricultural soils, as well as from cars and power stations

2 *Impacts on forests*

Impacts of climatic change on forest growth and water use will be assessed by a combination of experimental studies (in open-top chambers), the use and development of mathematical models of tree and forest growth, and the use of historic and spatial information on changes or differences in tree growth (using tree ring records and site differences)

3 *Impacts on natural vegetation*

Changes in natural vegetation will be determined by using historic records, by monitoring change (especially in montane communities), by screening species for responses to temperatures, and by developing models of the population dynamics of plants having different life forms (including Arctic plants)

4 *Impacts on soils*

Increases in temperature will change the rate of decomposition of organic matter and alter the rate of release of nutrients Many of the changes in natural vegetation may result indirectly from changes in soil properties Information will be obtained by measuring the decomposition of standard litters in different climates, by using heating cables to warm soils in the field, and by experiments in laboratory microcosm units In addition, work will be done to determine the impact of elevated CO_2 levels on nutrient release from soils

5 *Impact on invertebrates*

Invertebrates are very responsive to small changes in weather patterns The ITE data bases will be used to relate past changes in species distribution to climate, and existing and new models are being developed for key species to show how climatic change alters insect fecundity/mortality, insect/plant and insect/natural enemy relationships

6 *Impacts on coastal ecosystems*

In order to predict the impact of sea level rise on coastal ecosystems, more needs to be known about salt marsh physical processes across the zones from mudflats to marshland, the dynamics of salt marsh vegetation, the methods of stabilising coastal structures with vegetation, and the patterns of sediment erosion and accretion on soft coasts A review is planned of the wildlife dependent on low-lying areas, and the impact on conservation of different strategies for coastal defence

M G R Cannell

Population ecology

Work in this programme area is concerned with understanding what determines the distribution and abundance of plants and animals. A knowledge of the factors that influence population levels is necessary for the successful management of plants and animals, whether for conservation reasons, for human use, or for pest control. Such knowledge is also helpful in understanding and predicting the effects of environmental change on populations.

The projects described below fall within the general theme of population ecology, and illustrate part of the current range of work within this programme.

Population dynamics of radio-tagged goshawks

(This work was partly supported by the Swedish Sportsman's Association, Conseil International de la Chasse, and a Swedish charitable trust)

The northern goshawk (*Accipiter gentilis*) is a subject of controversy in many countries. As a result of predation on game and poultry, it is frequently killed by hunters and farmers. On the other hand, because goshawks are shy and elusive by nature, bird-watchers tend to underestimate their abundance and object to any exploitation by man. Despite a European population of at least 40 000, European Commission legislation for the Convention on International Trade in Endangered Species (CITES) now effectively treats the goshawk as an endangered species. If it had been enacted before 1970, this legislation would have prevented the imports for falconry which re-established a small British goshawk population (Marquiss & Newton 1982).

Population models can help to reconcile divergent views on problem species, by predicting the impacts of human exploitation and thus enabling effective management. Previous attempts to model goshawk populations were based on ring recoveries, which suggested a first-year mortality of 60–70%, and indicated slow population growth, even if all birds bred from their second year onwards (Mueller, Berger & Allez 1977). However, a high proportion of ringing recoveries came from hawks killed by man: this fact can seriously overestimate first-year mortality if dispersing juveniles are prone to encounter humans, whereas adults tend to die in the forest. At pheasant farms in Sweden 70–80% of killed hawks were juveniles (Marcström & Kenward 1981a).

Plate 19 Juvenile goshawks trapped near the nest for radio-tagging. A male (left) is 65% the weight of a female (right)

In 1980, a collaborative project was set up between ITE and Uppsala University to build a population model by radio-tagging goshawks on Gotland, a 3100 km^2 Baltic island about 100 km from mainland Sweden. Gotland was chosen because it was large enough for up to 200 active goshawk nests, but small enough to search for radio-tags in two days by road or three to four hours by air, and isolated enough for ringing to suggest that only 2–4% of hawks immigrated or emigrated to the mainland.

In each of six years, up to 35 juvenile hawks were caught near nests after their feathers were full grown (Plate 19), and equipped with 14 g tail-mounted radios. These radios lasted 8–12 months, and contained mercury switches which altered the rate of their signal pulses to help indicate whether a bird was perched in a tree, feeding, flying, or lying dead on the ground. The tags, which were ultimately shed by moulting, were 1–2% of each bird's weight (typically 700–1000 g for males, 1000–1600 g for females), and did not influence weights or dispersal tendency (Kenward 1978). Including older hawks, a total of 352 goshawks were radio-tagged to measure survival and breeding performance at different ages, and causes of death.

Plate 20. Goshawks were radio-tracked using a minibus with a direction-finding antenna

The location of each tagged hawk was usually checked at least once a week, using a minibus equipped with a mast-mounted directional antenna and repeater compass (Plate 20). Checks were made at night, because at that time live hawks were in trees, giving a slow signal pulse with a good detection range. During the day, hawks were sometimes feeding on the ground in hollows, in which case they were hard to detect. The whole island could be covered in two nights. If a hawk was missing, its previous range was checked more thoroughly for the weak, fast signals typical of a dead hawk. The whole island was covered by air up to twice a year for birds whose signals had been lost.

Survival estimates were complicated, because hawks could leave the tagged population through tag failure as well as death. Survival over a long period was, therefore, estimated as the product of survival in many consecutive short periods, 'censoring' tags whose signals were lost from all subsequent periods. However, this procedure overestimates survival if tag failure was sometimes associated with death, eg if tags were chewed by a scavenger. A correction could be applied by dividing censored tags into those moulted or known to fail without death of the bird, and those with unexplained signal loss. The proportion of hawks that were later recaught was very similar in both categories: 17 of 70 birds whose tags were moulted or otherwise known to fail, compared with 16 of 68 birds whose signals were lost inexplicably. This showed that there was little tendency for hawks to die at the time that their signals were lost. An independent checking technique supported this conclusion, so the recorded survival was not an overestimate.

On this basis, 51% of male hawks died in their first year, compared with only 36% of females (Figure 37). There was a similar sex-linked difference in mortality in the second year of life, but from then on mortality was estimated at 21% for both sexes.

Of 67 dead hawks, 36% were killed by man (which was legitimate for birds attacking poultry), and 13% were killed by other hawks or impacts. Fifteen per cent had starved to death, another 9% were starved with evidence of disease, and only 3% had definitely succumbed to disease. The other 24% died of starvation or disease, but were not recovered fresh enough for autopsy.

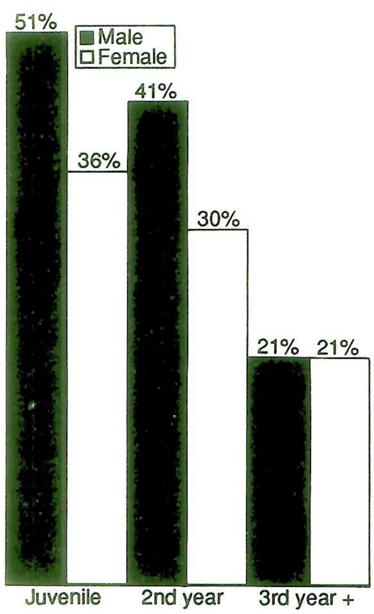

Figure 37. The annual mortality of goshawks on Gotland was higher for males than for females in both their first and second year of life, but was similar for both sexes in adults

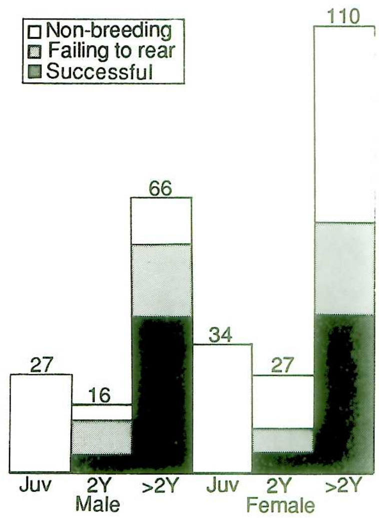

Figure 38. Because fewer males than females survived for two years, the adult goshawk population on Gotland contained a large excess of females, with many more non-breeders. Although many males nested in their second year, most failed to rear young. A higher proportion of older hawks was successful in both sexes

On Gotland, no birds attempted to breed in their first year, although Ziesemer (1983) estimated that 21% of juveniles did so in Schleswig-Holstein. Even in their second year, only 25% of females laid eggs, and 53% each year thereafter, largely because the females outnumbered males by 1.56:1 as a result of the differences in prebreeding mortality (Figure 38). A similar excess of adult female sparrowhawks (*Accipiter nisus*) has been estimated from ringing data by Newton (1986), and may in part result from female hawks being larger than males, and therefore having more reserves for surviving periods of food shortage. Moreover, only female goshawks can take adult hares (*Lepus timidus*), and a higher proportion of females than males killed rabbits (*Oryctolagus cuniculus*) on Gotland.

Using uncorrected estimates of survival and breeding success for each sex, the goshawk population model predicted a 17% per annum decline in numbers on Gotland, but was stable if adult survival was increased by 4% and the proportion of adult females breeding by 6%. These were reasonable corrections, as trapping of adults in winter selects poorer individuals (Marcstrom & Kenward 1981b), whereas the whole brood was marked at nests The model showed that the high first-year survival, compared with previous estimates, was balanced by a relatively high proportion of unbreeding adults, especially females If the data on juvenile breeding from Ziesemer (1983) were included in the model, the population would have increased by 27% per annum, despite 36% being removed by man It seems that goshawk populations can tolerate quite a high level of mortality caused by humans

This work provided much new information on goshawk predation, post-fledging behaviour and dispersal mechanisms Similar work is needed for other large raptors which are thought to suffer high prebreeding mortality, and are therefore managed conservatively, despite protests about predation on game and livestock Uncompromising protection can result in illegal, unselective forms of management, such as poisoning, which may well be more detrimental to raptor populations than the legal killing of some goshawks in Sweden

R E Kenward

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Changes in numbers and breeding performance of seabirds: evidence for changing conditions in the northern North Sea

(This work was partly supported by funds from the Nature Conservancy Council)

Many seabirds feed in the upper trophic levels of marine food webs, and are both numerous and conspicuous In comparison to other top marine predators such as whales, seals and fish, they are relatively easy to study and thus can be used as indicators of the health of the marine environment Seabirds have been used widely to monitor the incidence of pollutants, eg organochlorines, heavy metals, oil and plastics, throughout the oceans and, to a somewhat lesser extent, as indicators of large-scale changes in fish stocks

Sandeels (*Ammodytes* spp), particularly *Ammodytes marinus*, are a key component of the North Sea ecosystem, and form a large part of the diet of many commercially important fish, such as cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), seabirds and seals, and are also the target of a substantial industrial fishery The potential for competition between seabirds, marine mammals, fish and the fishery has been recognised since the 1970s

Many of the North Sea's seabirds breed in colonies on mainland cliffs or on offshore islands along the coast of eastern Britain During the last 20 years, considerable effort has been directed at monitoring changes in the numbers of many species, but much less attention has been paid to determining the biological processes involved or the causal factors Parameters such as adult survival, breeding success, chick growth rate, and time spent by adults at the colony are all likely to be related to food availability, and are, therefore, potential indicators of trends in prey populations Over the past three years, work has been in progress to develop low-input techniques for the routine monitoring of some of these parameters in a range of seabird species over a wide geographical area

Changes in breeding success

In a recent survey by ITE and the Nature Conservancy Council (NCC), data on breeding success from 23 kittiwake (*Rissa tridactyla*) colonies bordering the North

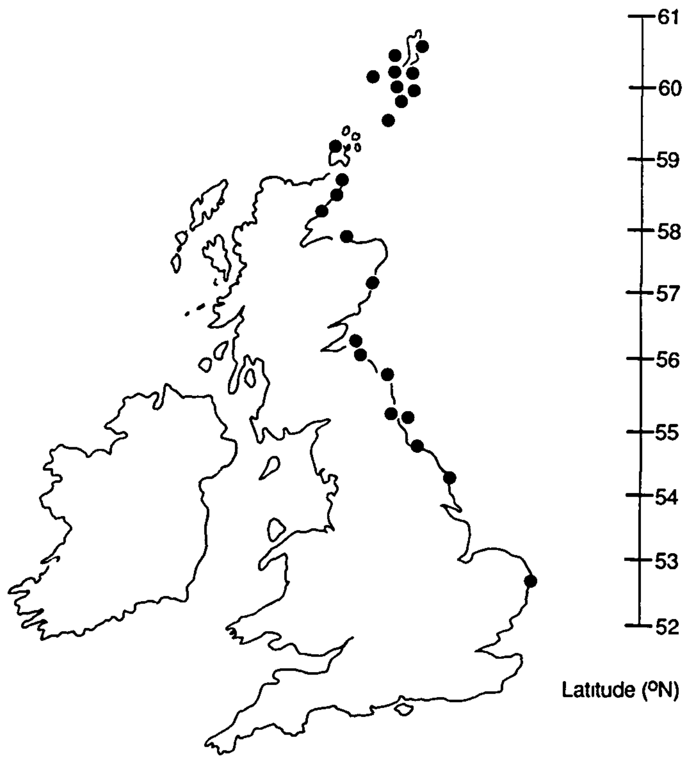

Figure 39 Locations of kittiwake colonies in east Britain where breeding success was recorded in 1986–88

Plate 21. Kittiwake on nest

Sea were collected between 1986 and 1988 (Figure 39). This small gull, which feeds at, or just under, the surface of the sea, is particularly suitable as a monitoring species because (i) it is common and widespread, (ii) it breeds on cliffs where its nests and young can easily be counted without causing disturbance to the birds or danger to the observer, (iii) it has a clutch of one to three eggs so that there is potential for variation in breeding success, (iv) it feeds its young mainly on sandeels, (v) a 'short-cut' method had already been developed (by ITE) to measure its breeding output, and (vi) much is already known about its population trends and biology from research by J Clarkson and colleagues at the University of Durham.

The results indicated considerable spatial and temporal variation in kittiwake reproductive success in north and east Britain. In 1986 and 1987, breeding success was generally high, with about one young fledged per breeding pair, but colonies in Shetland produced few young. In contrast, breeding success in 1988 was also lower in colonies well south in the North Sea, and the situation in Shetland had deteriorated to such an extent that all (or nearly all) of the chicks died (Figure 40) at eight colonies monitored by M Heubeck (Shetland Oil Terminal Environmental Advisory Group). Overall, there was a significant north/south trend in breeding success over the whole range, with success declining by 0.18 chicks fledged per completed nest for every 1° shift north.

The reduction in breeding success in 1988 was due mainly to chicks dying, although, in the northernmost colonies, some pairs deserted their eggs. Changes in the extent and severity of the breeding failures were matched by changes in the

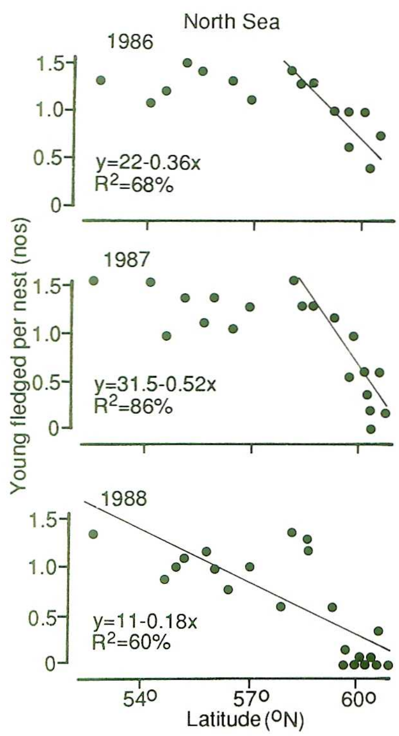

Figure 40. Breeding success of kittiwakes at the colonies plotted in Figure 39, showing a latitudinal decline within Shetland, Orkney and Caithness in 1986 and 1987 and throughout the western North Sea in 1988. The lines indicate significant linear relationships between young fledged per completed nest and latitude over the latitudinal ranges shown

timing of the main period of loss. Thus, in Shetland, losses occurred earlier in 1988, when there was almost complete breeding failure, than in 1986 or 1987 when some chicks fledged, although relatively few by British standards. Similarly, in 1988, losses occurred earlier and were more severe in the most northerly colonies, whilst further south failures occurred later and were less extreme.

Sandeel shortage

Sandeels were by far the most important item in the chicks' diet, but, in several colonies where food samples were collected, the proportion of sandeels present was markedly lower in 1988 than had been recorded previously. Also, there were fewer 0 group fish (ie fish hatched in the current year). Thus, there was a suggestion of a link between the availability of 0 group sandeels and kittiwake breeding success.

The evidence that food shortage was responsible for the low breeding success was mostly circumstantial, but, taken as a whole, compelling. First, the reduction in reproductive output coincided with a marked increase in the frequency with which young, including small, chicks were left unattended. Normally, small nestlings always have one or other of the adults with them, although larger chicks are occasionally left alone. There was no evidence that adult kittiwakes were just sitting on ledges away from their nests or occupying loafing areas, and the inference was that they were at sea trying to find food. Second, several other seabird species, which also depend on sandeels to feed their young, reared few or no chicks in Shetland in 1988. The species most severely affected were small-sized, inshore, surface or near-surface feeders, such as Arctic tern (*Sterna paradisaea*) and puffin (*Fratercula arctica*), or those which klepto-parasitise these species, ie the Arctic skua (*Stercorarius parasiticus*) and great skua (*Catharacta skua*). In contrast, deep-diving species, such as the guillemot (*Uria aalge*) and shag (*Phalacrocorax aristotelis*) were largely unaffected.

The stocks of sandeels around Shetland have declined in recent years, and this decline has been attributed to overfishing by a local fishery, which started in 1974 and reached a peak in 1982, and/or to natural factors. The available data from fishery research tend to support the latter cause for, although sandeel numbers have certainly declined, the spawning stock in 1986 was reported by P A Kunzlik (Department of Agriculture and Fisheries for Scotland) to be still more than 60% of the maximum recorded in 1984. A series of years when relatively few young sandeels recruited into the population appears to have resulted in a decrease in smaller-sized sandeels, on which many of the seabird species depend for food for their young It is possible that adverse environmental factors could be influencing the survival of larval sandeels and/or the transport of larvae into and out of the Shetland area However, the results of the survey of kittiwake breeding success suggest that the situation in Shetland, although more severe, is part of a more widespread change which extends well south into the North Sea

Additional evidence for a north/south gradient in conditions in the North Sea is provided by a series of counts of 18 guillemot colonies made over the past 15–20 years by the organisations listed in the acknowledgements These counts show that numbers increased at all the colonies during the 1960s and 1970s but the most northerly colonies started to decline about 1980, and, by 1988, numbers at all but the two most southern colonies counted, those at St Abb's Head and the Farne Islands, were decreasing

Poor recruitment

Long-term, detailed studies by ITE on the Isle of May, Firth of Forth, have revealed changes in the demography of the guillemot and puffin populations there, which occurred in the early 1980s and coincided with the levelling off in numbers after two decades of continuous steady increase In the guillemot the number of immatures recruiting into the population fell, although adult survival remained high, whilst in the puffin survival of both adults and immatures was reduced. However, in contrast to the kittiwake, neither species has, as yet, shown a reduction in breeding success, although adult guillemots in 1988 spent as little time as possible with their young One adult must remain with the chick to protect it from predators but, whereas in 1983 the pair spent an average of 60 minutes together while changing over, in 1988 the period was only seven minutes These observations indicate that the duration of a feeding trip had increased, and birds were having to travel further to feed and/or taking longer to catch prey in the feeding area

The future

There is, therefore, growing evidence of widespread changes in the population processes of a variety of seabirds breeding in colonies bordering the North Sea, and there is strong circumstantial evidence that these changes are associated, at least in part, with a reduction in food availability during the breeding season While it is as yet impossible to confirm a link with any specific environmental change, and indeed it is likely that the causal factors involved will be complex, long-term studies of the demography, feeding ecology and behaviour of seabirds and sandeels will provide essential information for the development of a realistic multi-species model of the North Sea ecosystem

Acknowledgements

ITE is grateful to the many observers who undertook much of the fieldwork, and to their parent organisations, principally the Royal Society for the Protection of Birds, the Shetland Oil Terminal Environmental Advisory Group, Britoil plc, the Universities of Aberdeen and Glasgow, and the Nature Conservancy Council, for fruitful collaboration

M P Harris and S Wanless

Declining fritillaries: the next challenge in the conservation of Britain's butterflies

(This work was partly supported by funds from the Nature Conservancy Council)

British butterflies have experienced enormous declines over the past 40 years Many sites have been destroyed, but, for conservationists, the most worrying feature has been the fact that many rarer species have also disappeared from Nature Reserves and land where foodplants remained abundant Indeed, it looked as if the British populations were following the pattern of those in the Netherlands, where more then 20% of all resident species have recently become extinct

Experience has shown that most attempts to conserve scarce butterflies fail, unless they are based on a detailed knowledge of each species' ecological requirements (Thomas 1984a) Considerable progress has been made with a few rarities (Thomas 1983, 1984b, 1989, Thomas *et al* 1986, Warren 1987), but there remain many declining species that cannot be conserved because they have not been studied at all The most urgent recent case involved certain butterflies that breed in woodland, notably five species of fritillary whose larvae feed on violets (*Viola* spp) The high brown fritillary *(Argynnis adippe)* is the most acutely threatened Colonies once bred in most large southern woods, but are now restricted to a handful of western sites even the recent map (Figure 40), based on data from ITE's Biological Records Centre and local surveys, greatly overemphasises the current status, for most of the remaining colonies in central England disappeared during the 1980s (Thomas & Webb 1984) The pearl-bordered fritillary *(Boloria euphrosyne)* has declined almost as rapidly, but from a higher baseline, whilst the small pearl-bordered *(B selene)* (Plate 22), dark green *(A. aglaja)* and silver-washed *(A paphia)* fritillaries have fared only slightly better

It has long been recognised that these declines were associated with the

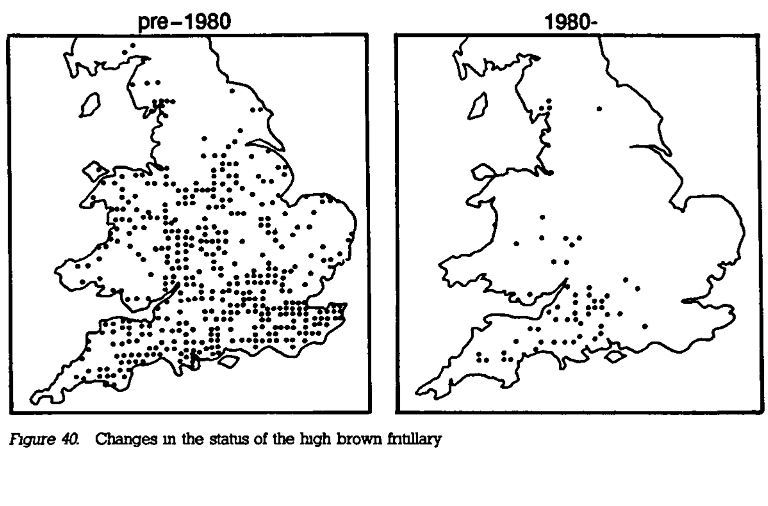

Figure 40. Changes in the status of the high brown fritillary

Plate 22. Small pearl-bordered fritillary

replacement of coppicing in British woods by modern forms of silviculture, which result in shadier conditions and fewer violets on the forest floor. However, most fritillary colonies have disappeared from woods that still contain a great abundance of violets, and losses have been particularly severe in broadleaved woods, including Nature Reserves. Most remaining populations are confined to young conifer plantations, but are likely to become extinct as the trees mature.

Research into the requirements of the violet-feeding fritillaries started in 1984 in an attempt to define the exact conditions needed by each species. This research has involved making intensive studies of the behaviour and habitat preference of each butterfly within two heterogeneous sites, coupled with more superficial analyses of a range of woods that held various-sized (or no) populations of the different species. Adult fritillaries were individually marked, released and recaught in order to assess their ability to disperse and colonise new habitats, and measurements were made of the features of each site that were used by every stage of each life cycle. Particular attention was paid to an analysis of the precise places chosen for egg-laying: the species, density and growth form of violets were recorded where eggs were laid, together with measurements of the incidence of direct and indirect light, the integrated temperatures at ground level, and the stage of each microhabitat within the woodland succession.

As with earlier studies of butterflies, the needs of each fritillary's young stages proved to be much more specific than had previously been thought. Although a variety of violet species can be eaten, all fritillaries usually eat the same violet on a particular site. However, there is little overlap between the plants that are chosen. The pearl-bordered fritillary uses young violets that have recently sprung up in bare ground, or which are growing in a warm, sheltered microclimate. The small pearl-bordered fritillary lays on the same violets a year or two later, when the plants are larger and surrounded by lusher growth, whilst the dark green fritillary – which is more characteristic of open grassland – uses large-leaved clumps that are partly choked by grass and yet not shaded by trees. The silver-washed fritillary breeds within the body of a wood on clumps of violets growing in sunny patches beneath a thin cover of trees, but even this species requires direct sunlight to reach at least 25% of the woodland floor. More research is needed on the high brown fritillary, but it appears to need large clumps of established violets growing in bare, open ground by the edge of shrub.

The five fritillaries, therefore, use violets at different stages quite early in the woodland succession. Suitable conditions can be short-lived for any particular species, especially on soils where there is a vigorous regrowth after a clearing. A complicating factor is that these butterflies also have limited powers of dispersal (Figures 41 & 42): marking experiments have shown that the silver-washed fritillary flies freely throughout a wood, but appears reluctant to cross farmland to reach neighbouring sites. The small pearl-bordered fritillary is considerably more sedentary; recent clearings that contain ideal breeding conditions are not necessarily colonised, if there is a barrier of a few hundred metres of shady woodland to cross.

The implications of this research are that woods need more frequent small-scale clearings than they currently receive, if they are to contain continuity of the breeding habitats of every violet-feeding fritillary; a break of perhaps three to five years between clearings can be fatal for the pearl-bordered fritillary, and, once lost, there is little chance that a site will be recolonised when suitable conditions

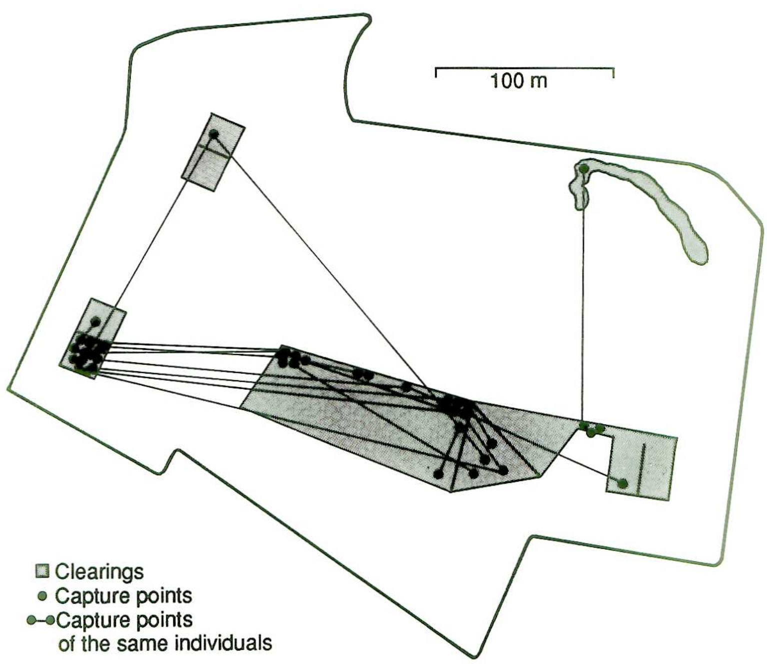

Figure 41. Movements of the silver-washed fritillary between clearings in an isolated wood. (o—o) represent captures of the same individual over a period of two weeks; the butterflies are moving freely through the wood.

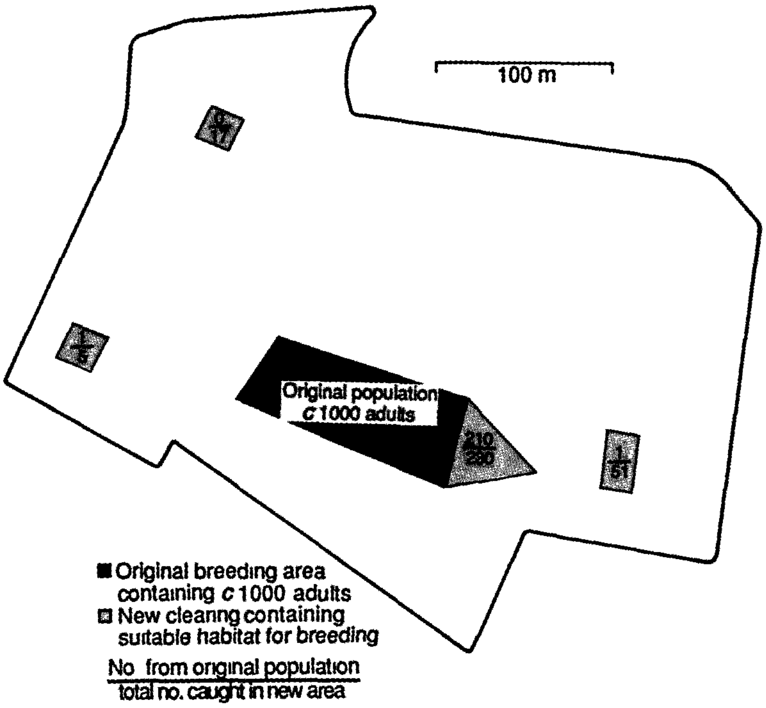

Figure 42 Movements of the small pearl-bordered fritillary between its breeding areas within the isolated wood shown in Figure 41 The original population was confined to a large clearing shown in black. Four new clearings were made, all of which contained abundant violets suitable for egg-laying during the experiment Twenty marked adults were introduced to each new clearing the figures represent the number of captures made in each clearing in the following two weeks and the proportion of these that were immigrants from the original population Only two immigrants were caught in the three clearings that were 100–150 m from the old population whereas 210 captures of immigrants were made in the clearing that adjoined the old area

recur, unless another colony exists nearby This possibility is becoming remote as the remaining populations become more isolated

Although most modern woods are too shady to support any species of fritillary, it seems likely that it will be possible to conserve populations on Nature Reserves and in commercial woodland, if small areas of land are suitably managed Encouragement can be taken from the case of another fritillary, the heath *(Mellicta athalia)*, which also breeds on early successional plants in fresh clearings Ten years ago, this rarity was reduced to about eight British sites and had disappeared from both the Nature Reserves that had been established to save it Research at ITE Furzebrook (Warren 1987) showed that this species had similar requirements to the pearl-bordered fritillary, and that all known remaining colonies were doomed to extinction in the near future if management plans were not changed An emergency programme was introduced, and within five years each of its two Reserves were again supporting colonies of several thousand adults Other Reserves were also established and have responded similarly to science-based management, whereas the few sites that were left to normal forestry practices have already lost their heath fritillary populations

J A Thomas and R G Snazell

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Population dynamics of estuarine mussels

Estuaries are important breeding areas for fish, they support shell fisheries, and they are important winter feeding areas for migratory wading birds and wildfowl They are also prime targets for land claim, various forms of development, and waste disposal Ecologists are often asked to comment or advise on the likely outcome of such schemes While it may be possible to answer in general terms, it is difficult to make predictions because the mathematical relationships describing the interactions within and between the various biological components are lacking or incomplete The factors which determine the density of one of the most important species (in terms of biomass), the mussel (*Mytilus edulis*), have been studied in the River Exe estuary in Devon These factors have been incorporated into a mathematical model which can be used as a predictive tool There is also a parallel study of the main winter predator of adult mussels on the Exe, the oystercatcher (*Haematopus ostralegus*), and the two studies will be combined to model the predator/prey system

The entire intertidal mussel population was studied because mussels are known to move voluntarily when young, and storm-driven immigration or emigration can cause errors in studies restricted to one location The population was sampled in March and September over a seven-year period from September 1976 to 1983 Each survey consisted of 600 samples (each 0 04 m^2), distributed over

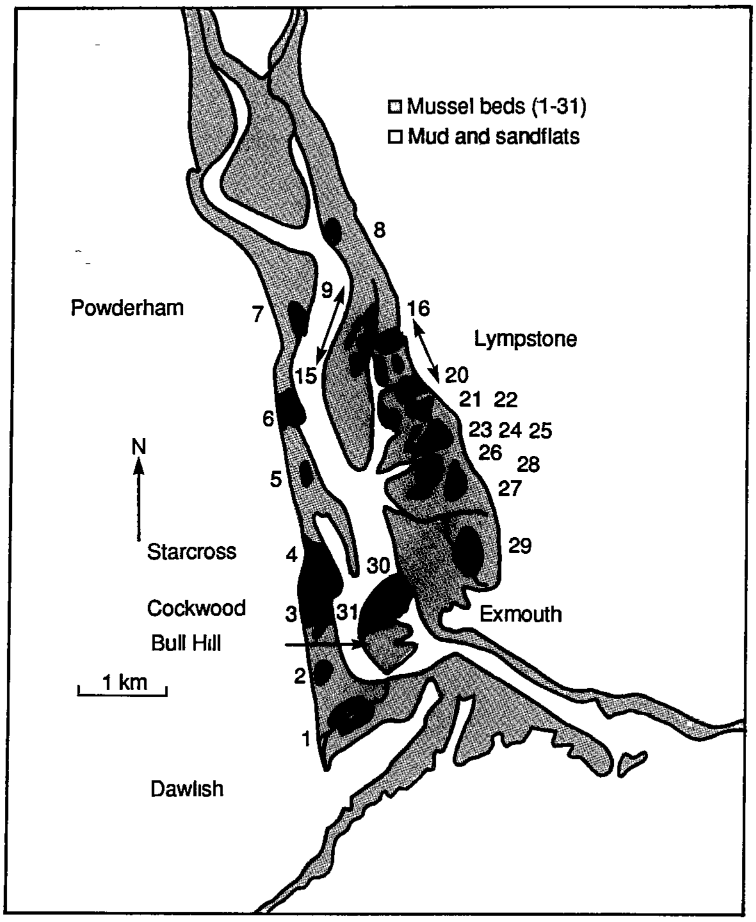

Figure 43 Map of the River Exe estuary, showing the location of the mussel beds (numbered 1–31) in September 1976 Not all of the beds are shown as separate areas Some areas of mussels were divided into two beds along natural boundaries, such as freshwater streams (beds 3 & 4) or deep channels (beds 30 & 31) Only twelve beds remained at the end of the study

the mussel beds according to a stratified random sampling scheme The number of samples allocated to each bed was in proportion to its area, weighted by the standard deviation of the density estimates of the most abundant age classes of mussels present The mussels were counted and measured, and their age distribution was determined from a subsample (40%), for which the winter spawning rings on the shells were identified and counted The areas of the mussel beds were determined by walking 9–20 lines at right angles to a fixed baseline, measuring distances with a one m pacing stick and noting when boundaries were crossed This method was preferred to more conventional mapping techniques because the surface topography of some beds was uneven

Of the 31 mussel beds sampled in September 1976 (Figure 43), 12 contained 82% of the mussels, the remainder were either very small or contained only a low density of widely scattered mussel clumps By March 1980, only the 12 major beds remained, the others having been destroyed by storms However, the decline in mussel bed area (24%) was countered by an equivalent increase

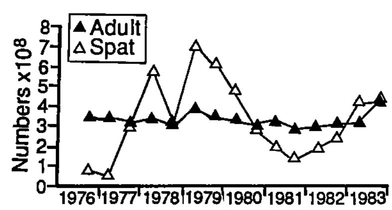

Figure 44 The numbers of (i) adult mussels 1–9+ years old, and (ii) mussel spat, 0 year in the estuary between 1976 and 1983 The numbers of adults varied little and showed no significant trend whereas the numbers of spat mussels varied widely within and between years, suggesting that a strong regulatory factor acted upon the mussels in their first year on the beds in the estuary

(36%) in mussel density in the remaining beds, so that the numbers of adult mussels showed no significant trend (Figure 44i) It seems, therefore, that most of the mussels from the smaller beds were incorporated into the larger beds

In contrast to the stability of the adult density, which only varied between years by a factor of 1 5, spat mussel (0 year) density varied widely (17-fold) throughout the study (Figure 44ii) This variation indicates that a strong damping process was acting in the first year

Density-dependent mortality in the first year and the period when it occurred were investigated by key factor analysis This analysis divided the lifespan into a number of stages (egg, larva 1, , adult), and determined (i) the stage at which mortalities were density-dependent, and (ii) the greatest influence on changes in the total generation mortality (called the key factor) These mortalities need not be the same, and rarely are

It was possible to measure five stage mortalities within the first (0) year k_1 and k_2 were losses of potential eggs due to the failure of the adult females to grow to the maximum possible size at each age, on the different beds and in different years, respectively k_3 was the losses in the plankton and primary settlement stages, or the failure of plantigrade larvae to settle on the adult mussel beds k_4 was the losses in the first summer, and k_5 the losses in the first winter, on the mussel beds

In their second summer, mussels develop a gonad and are regarded as adults The lifespan of mussels in the Exe is about ten years, but the study lasted only seven years, so the key factor analysis could not be applied beyond the first year

The analysis showed that only losses during the first winter on the mussel beds (k_5) were density-dependent (Figure 45), and operated in a strongly regulatory manner Above the critical density of 57 m^{-2}, few extra mussels survived as density increased, resulting in the damping seen in Figure 44 The mortality agent was probably predation by juvenile shore crabs (*Carcinus maenas*)

Losses in the plankton and primary settlement stages (k_3) were identified as the key factor in the first year, having the greatest influence on changes in the total

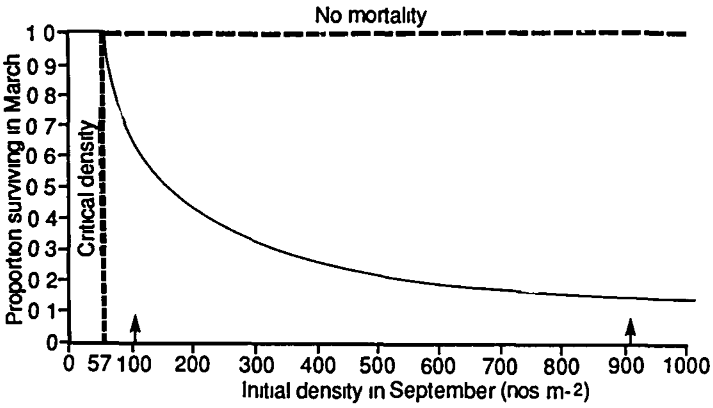

Figure 45 The effect of the first-winter density-dependent mortality k_5, on the proportion surviving in March, as the initial density in September (N_5) increased. The curve was calculated using the equation, $k_5=0\ 685 \log N_5-1\ 204$ The arrows indicate the range of densities recorded. As the initial density increased, few extra individuals survived, and the numbers entering the adult population were regulated within narrow limits

mortality (K) between years These losses were also by far the largest, and had, therefore, the greatest influence on the level of K

k_3 was inversely density-dependent in six out of seven years The 1977 cohort suffered twice the normal winter and spring rainfall, and the spring spat fall failed, despite the potential egg production in September 1976 being the largest recorded This failure was probably due to both lowered salinities in the estuary and the large amounts of liquid mud deposited on the mussel beds by the flooded River Exe

The other losses in the first year, k_1, k_2 and k_4, were independent of density It was possible, therefore, to develop a predictive model, incorporating the density-dependent relationship for k_5, the inverse density-dependent relationship for k_3, and mean values for the density-independent mortalities, k_1, k_2 and k_4, which explained *c*90% of the variability in the total losses in year 0

The total density of adults was remarkably stable (Figure 44), but did vary a little, for example, density increased in spring 1979 following the large spat fall in 1978, but then declined through 1980, despite an even larger spat fall in 1979 This evidence suggested the possibility of density regulation within the adult population

The pattern of mortality varied with season (summer or winter) and with increasing age Following the large loss during the first winter (mean 68%), there were only small gains in the summer and losses in the winter for the next four years Only the summer immigration of three-year-old animals (mean +10%) was statistically significant From their sixth year onward, there were increasingly large losses each year in summer after spawning (mean 39%) and in winter, as a result of predation by oystercatchers (24%)

However, density-dependent mortality was detected only in the second winter and tenth summer, ie in the youngest and the oldest adults The mathematical relationship describing the tenth-summer mortality indicated an almost perfect density dependence, but this could not be an important population regulatory mechanism, as few animals reached this age The second-winter mortality had the potential to operate in a strongly regulatory manner, but there were significant losses of second-winter mussels in only three of the seven years studied

The second-winter mortality was also related to the total density of 'all' (1–9+ year) adults (r^2=72%) and, more specifically, to the density of 'young' (1–4 year) adults (r^2=75%), perhaps indicating competition among adults for food or space Mortalities during the fourth, fifth and sixth summers were also related to the total densities of young or all mussels The equations describing these relationships indicated that these were overcompensating mortalities, which means that, above the critical densities at which these relationships operated, two or more mussels died for every one recruited to the adult population Potentially, this behaviour could have caused violent fluctuations in density, but, in reality, did not do so because the total density of adults did not greatly exceed the critical densities (mean values +7% to +30%) and soon fell below them These relationships could, therefore, do no more than act as a 'fine-tuning' mechanism, retaining adult densities within narrow limits

The study has shown that the greatest mortality of mussels occurs in the plankton/settlement stages However, the population was regulated by the mortality of spat mussels in their first winter on the mussel beds, not by oystercatchers eating adult mussels So, what part do oystercatchers play in the population dynamics of the mussels? On average, they ate 24% of the adult mussels each winter, but, because their preferred size range included the most fecund mussels, egg production was reduced in spring by 37% However, more importantly, mussel spat in the Exe only settled within the byssus threads of adults By removing adult mussels, oystercatchers could reduce the amount of space for spat to settle On the other hand, 'thinning out' the adults could reduce competition for food for those spat which do settle, and could enhance their chances of survival These subtle effects require an experimental approach to unravel, and will be the subject of further studies

S McGrorty

The Arctic: a stressed environment for plant growth and reproduction

Global warming and climate change are probably the greatest environmental problems currently facing mankind Predictions from the various General Circulation Models (GCM) generally agree that the greatest changes will occur at the highest latitudes Temperatures between latitudes 60° and 90° could increase by aboout 3°C and 4°C in winter, and by about 0 5° and 0 9° in summer by the year 2040 The impacts of global warming on vegetation are, therefore, likely to be recognised at high latitudes sooner than elsewhere

While the predictions of climate change are uncertain, it is clear that we are in a poor position to predict the extent, nature, mechanisms and speed of the impacts on plant populations and communities ITE is collaborating with scientists at Abisko in Swedish Lapland and on Svalbard, in an attempt to understand and model the relationships between the population dynamics and environment of species near their distributional limits By considering the responses of a plant to its environment at all stages of its life cycle, it should be possible to relate climatic change impacts to the populations and abundance of a species, and to identify sensitive stages and processes

Arctic environments

Arctic environments have long, dark winters and short growing seasons with continuous, but low intensity, daylight Growing seasons are short because of low air and soil temperatures in exposed habitats, and the long duration of the snow cover in sheltered habitats Plants usually have developmental processes extended over more than one season, and perennials with pre-formed flowers and evergreen leaves are common

Decomposition rates are slow, and freeze/thaw cycles in moist soils with permafrost create disturbance through the repeated frost-heave of soils The associated meso- and microtopographical features lead to a pronounced microclimatic and edaphic patchiness both in space and time, and plants compensate for this patchiness and generally low soil fertility in many ways, such as conserving, storing and recycling nutrients As temperatures in the Arctic increase, much of the permafrost will thaw and the patchiness will decrease, thus enabling the development of a more uniform vegetation core

The vegetation of the Arctic varies from aggregations of few species into islands surrounded by bare ground in the high Arctic to continuous two-storied canopies in the forest tundra of the sub-Arctic In the most extreme and exposed habitats with open vegetation, non-clonal cushion plants which propagate either by seeds or viviparous propagules are the dominant life form among vascular plants. In less extreme habitats with closed vegetation, however, clonal plants which maintain their populations by vegetative spread rather than seed recruitment are common.

Case studies

Cassiope tetragona

On high Arctic Svalbard, studies of a slow-growing ericaceous dwarf shrub have revealed an historical record of leaf production, leaf extension growth and flowering over a 20-year period

Cassiope tetragona is evergreen. Its leaves photosynthesise for up to five years but remain attached to stems for 15 or more years, and two patterns of leaf length are evident Short leaves alternate with longer leaves on a regular and annual basis, and there is an overall trend of increasing leaf length as the shoot develops (Figure 46) By removing this developmental trend, it is possible to correlate the number of leaves produced each year and leaf length with climate These correlations show that leaves are formed one year before they open, and that temperature and precipitation in the spring of the current and preceding years correlate significantly with leaf production (Figure 46) Thus, poor leaf length in 1981 and 1982 was associated with cold summers, whereas an increased number of large leaves was associated with higher summer temperatures and precipitation between 1978 and 1980

Such studies establish baselines of plant responses to climate in recent times in those areas where dendrochronology is often impractical Future changes in leaf production and development can then be interpreted as either a new response to a changing climate, or transient variation similar to that in the past The data are also being used to investigate fluctuations in reindeer (*Rangifer tarandus*) populations on Svalbard related to the amount of plant food available, and to identify years in which flowering occurred

Lycopodium annotinum and *Carex bigelowii*

In the closed vegetation of the Arctic, recruitment to populations from sexual reproduction often occurs only after disturbance, eg fire, frost-heave or overgrazing, and then clones may maintain themselves indefinitely, and certainly for hundreds of years

The production of annual segments of growth in the creeping *L annotinum* enables clones to be treated as populations of parts, each with probabilities of survival and fecundity related to age Population growth models developed during collaborative studies with the Universities of Lund and Lancaster show that the growth of clones was most sensitive to changes in survival probabilities, particularly in the youngest age classes

In the locations where the clonal sedge *C bigelowii* has been studied, no

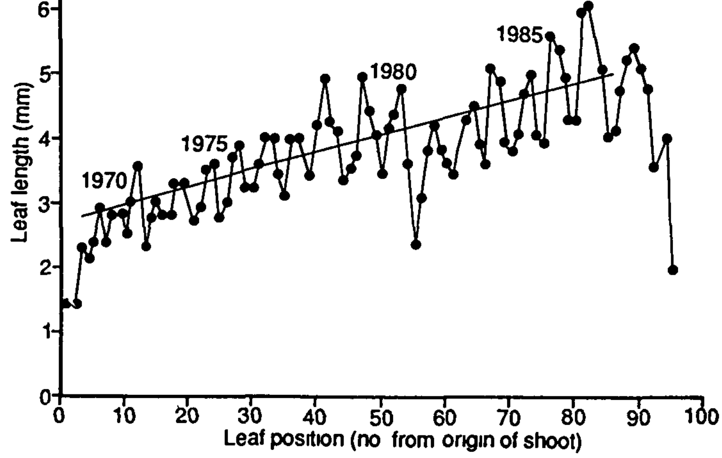

Figure 46. Example of variations in leaf lengths related to their position on shoots of *Cassiope tetragona* The thick line represents the general developmental trend, and each peak represents one growing season's production of leaves. Thus, in 1979 six large leaves were produced in a warm summer whereas in the cooler summer of 1982 only four small leaves were produced

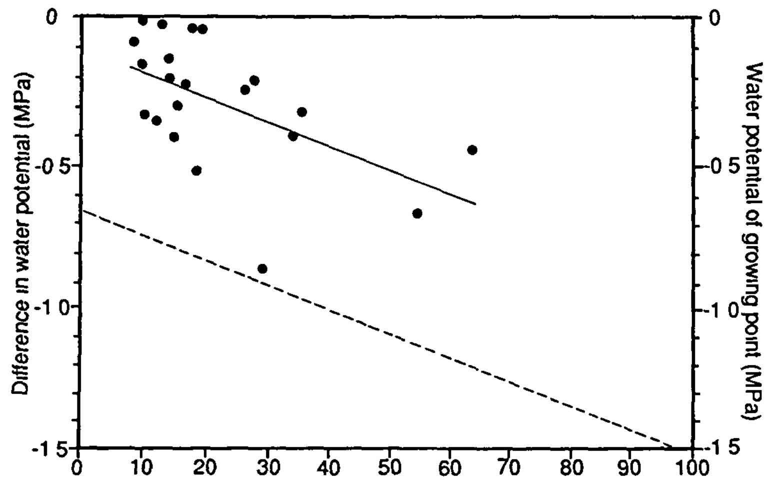

Figure 47 The water potential of the growing point of *Lycopodium annotinum* related to the distance between it and the nearest root The negative values indicate that the growing point has a lower water potential than the root and that water will flow from the root to the growing point The broken line represents distances predicted by assuming a mean root water potential of –0 62 MPa and shows the predicted maximum distance (97 cm) when the growing point dies at ~ 1 4 MPa. As temperatures increase with climate change this distance will decrease

seedlings have been found However, the populations of tillers are still controlled by flowering Flowering occurs in older tillers, which then die, and varies in frequency from year to year After a peak in flowering frequency, the population of tillers crashes due to the death of flowering tillers, but then increases as buds break dormancy This pattern appears to create cycles in tiller densities which must be understood if the climatic effects are to be interpreted, particularly the relationship between flowering and climate

Within *L annotinum*, the growing points of the horizontally creeping branches, or stolons, are the priority sinks for water, nitrogen, phosphorus and potassium There is a gradient of decreasing water potentials from old to young tissues, which ensures a flow of water and nutrients to the growing point

This subsidisation of the growing points allows the horizontal branches to cross unfavourable microsites where roots cannot develop However, as the distance between the growing point and nearest root increases, the water potential of the growing point decreases (Figure 47) Eventually, the water deficit of the growing point becomes too great, and it dies It is, therefore, possible to calculate the maximum patch size (97 cm) in which *L annotinum* can survive (Figure 47) If temperature increases as the climate changes, however, the growing points will experience water stress sooner, the patch size which *L annotinum* can tolerate will decrease, and its distribution will become limited

While the growing points are important sinks for water and some nutrients, they are also important sources of hormones, which control the number of side branches and their rates of development This control is sensitive to nitrogen supply As the climate changes and decomposition rates increase, the control system will break down and parts of the same plant will begin to compete with each other for resources, thereby damaging their chances of survival As there is no bank of dormant buds in *L annotinum*, it is sensitive to such damage

The persistence of connections between old and young branches enables the efficient recyling of scarce nutrients to priority sinks Approximately 63%, 64% and 90% of nitrogen, phosphorus and potassium respectively are recycled, and the plant can survive with only 5% of its total dry weight invested in roots However, if nutrients become more available as decomposition rates increase with increasing temperatures, the small roots will be unable to compete with the larger roots of other species, and *L annotinum* will be displaced

C bigelowii forms extensive tiller systems, and there is a division of labour between tiller generations Young tillers possess leaves and export energy-containing compounds to older leafless generations at least eleven years older (Figure 48i), while these old leafless generations retain active roots, and take up and translocate nitrogen to the young photosynthesising tissues (Figure 48ii)

The young tillers of *C bigelowii* suppress the growth of many buds on the older attached tillers, but, when connections between the young and old tillers are broken, old dormant buds begin to develop *C bigelowii* is tolerant of grazing and disturbance when a tiller is defoliated, there is increased translocation of photoassimilates from neighbouring tillers, but this translocation decreases if damage continues These two mechanisms ensure that *C bigelowii* will be able to buffer changes in climate or disturbance to some degree, but not indefinitely

A deterministic, or unvarying, growth model of the architecture of *L annotinum*, based on population dynamics data, showed that the observed mean angle of branching and the presence of apical dominance decreased the risk of overlap between branches within the clone In the field, however, each plant has a different form (Figure 49i,ii) For example, the direction of growth can soon be diverted from the initial direction by microtopography The apparent chaos of the architecture found in the field can be simulated by introducing random elements into the architectural model (Figure 49iii,iv)

This model includes the possibilities for growing points to survive and die at different ages, for branching to occur and direction of growth to change, for roots to be produced, and for clones to fractionate into separate plants The model has identified features and age classes sensitive to change, and has provided long-term predictions of how clones develop However, the random variations are unintelligent, and a process-related model is being developed in which the death of growing points, root production, direction of growth, etc, are related to the environment For example, *L annotinum* seems unable to respond to nutrient-rich pockets, and its clonal architecture seems to be suited to continuous mobility This characteristic may serve to reduce competitive encounters, which will increase as more opportunistic species respond rapidly to climate change

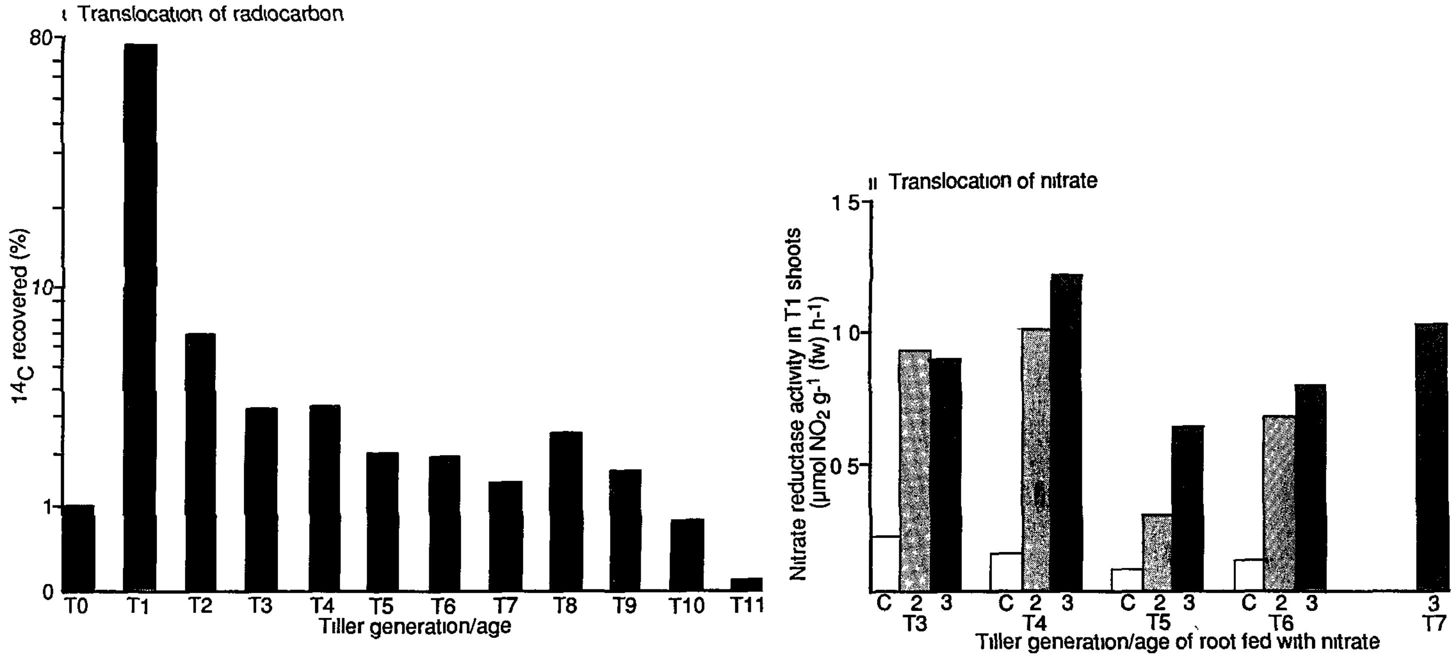

Figure 48 The different functions of different tiller generations in *Carex bigelowii* illustrated by translocation between them This is one of the processes which will help *C bigelowii* initially to accommodate the impact of climate change NB (i) shows ^{14}C in each tiller generation, whereas (ii) shows nitrate only in the T1 generation

i Translocation of radiocarbon from a young photosynthesising tiller (T1) labelled with $^{14}CO_2$ to older leafless generations

ii Translocation of nitrate, determined by assaying the activity of the inducible enzyme nitrate reductase to the young T1 tiller from older tillers whose roots were incubated in nitrate

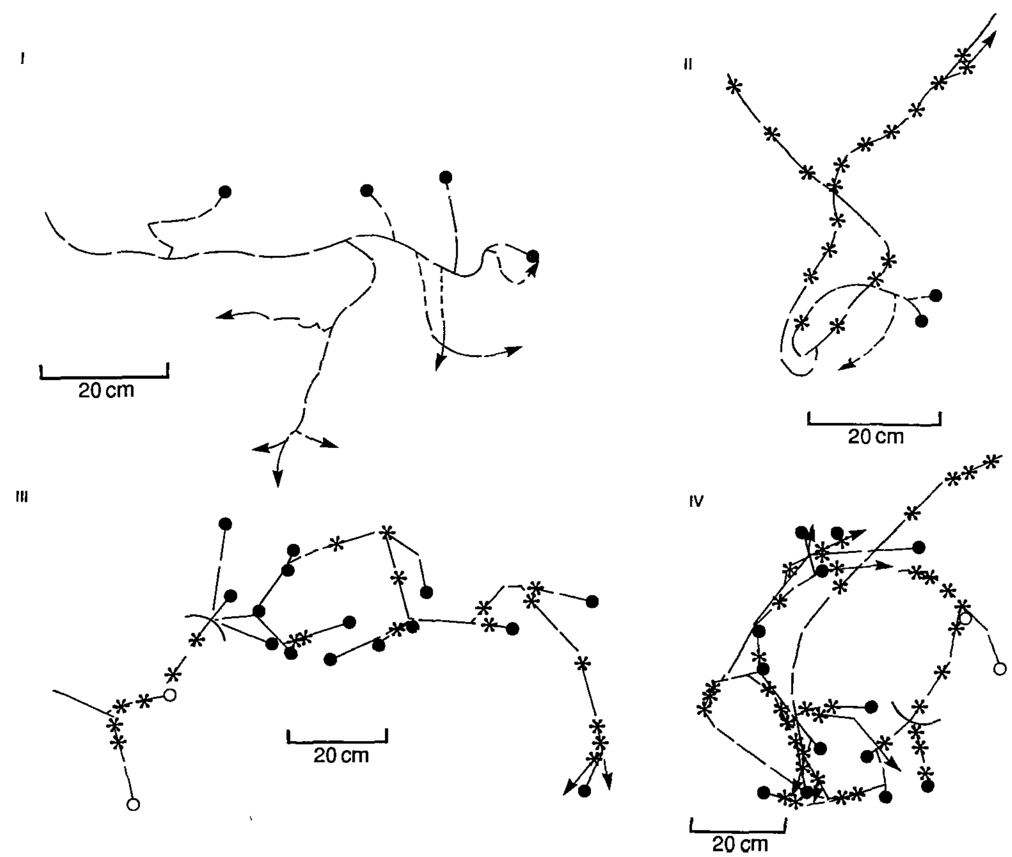

Figure 49 Maps of the horizontal branch systems of *Lycopodium annotinum*

i-ii Examples of plants mapped in the field

iii-iv Examples of plants simulated by the random architectural model for 25 years After 25 years, (iii) had two living growing points 19 dead and 17 roots shared between four plants, three of which died. (iv) shows the ability of the plant to turn through 360° (see also (ii)) It has six living growing points 22 dead and 34 roots shared between two plants, one of which survived.

Gaps delimit annual segments
Circles = dead growing points
Arrows = living growing points
Stars = roots
Thin lines bounded by arcs = senescent parts of the clones
Large arrows = start and initial direction of clone

Such models of clonal growth will enable us to predict some responses to climate change

In contrast to *L annotinum*, *C bigelowii* responds to patchy soil fertility and light penetration Two types of tiller are produced, one with long and one with short rhizomes When growing in nutrient-rich pockets, more short-rhizome tillers are produced, thus maximising the exploitation of the resource This opportunistic response is accompanied by aggressive competitiveness, and dense swards may be produced Thus, as nutrient availability and temperatures increase due to the change in climate, *C bigelowii* will be able to take advantage of the improved conditions

Conclusions

In the high Arctic where climate change will be greatest, the prevalence of slow growth and reproduction by seed and bulbils will lead to early impacts on plants such as *Cassiope tetragona*. Such species should be targeted for monitoring

At lower latitudes in the Arctic, clonal integration may provide a buffer against the patchiness of the habitat, and against such impacts as grazing and climate change Clones may respond slowly at first to climate change, and then the impacts may be sudden Monitoring the impacts on clonal plants may, therefore, be inappropriate, and predictive models are required

The two totally unrelated species, *Lycopodium annotinum* and *Carex bigelowii*, share many attributes of clonality which are successful in Arctic environments However, the opportunistic responses of *C bigelowii* and its ability to tolerate disturbance may favour its initial ability to withstand climate change, in contrast to the relatively inflexible *L annotinum*

The stress-tolerant strategies of Arctic plants are mirrored by species from alpine and montane areas further south Similar responses to climate change could, therefore, be expected However, in the alpine and montane areas of temperate regions, the degree of change will not be as great as that in the Arctic and will be slower Thus, an early understanding of plant responses in the Arctic should enable the prediction of the type of change which will occur in related environments further south

T V Callaghan

The understanding of successions is fundamental to community ecology, and the following three articles illustrate different aspects of ITE work.

The report on phosphorus and successional changes in lowland heaths uses the PCAL model to investigate not only the relationship between nutrient status and successions, but also the perturbations caused by different management regimes, notably grazing. The analysis is used for determining suitable methods for heathland conservation. The second report also uses an ITE-developed computer program (TABLEFIT), to provide an objective numerical method for classifying vegetation types even with incomplete data sets. The automated identification of types provides the ability to specify likely trends in succession, soil and other factors, that can then be used for site evaluation and management.

The third report considers the possible effects of climate change on populations and the more subtle changes within communities. It emphasises the problems in separating directional change from background fluctuations, and illustrates how long-term data sets can be invaluable for separating cause and effect (especially through simulation modelling), whilst recognising the need for controlled experiments of comparative ecophysiology.

Plate 23. Great Ovens Hill, Dorset, where open heathland has survived in the absence of grazing, but with some invasion by Scots pine (*Pinus sylvestris*) from an adjacent plantation

Phosphorus and successional change in heathland vegetation

Heathland undergoes continual change, and management decisions must consider both structural and functional relationships. Common heather *(Calluna vulgaris)* dominates the vegetation when there are low levels of plant nutrients in soil with a pH between 3.5 and 6.7, the climate is oceanic, and there is protection from low temperatures by snow cover during the winter. Factors such as grazing and burning must also be sufficient to arrest natural succession to scrub and woodland. Most heathlands were once subject to 'rights of common', where grazing in combination with heather burning maintained a low nutrient status in the soil and prevented the establishment of trees and scrub. Unfortunately, grazing by stock has now ceased in many areas, and the loss of rabbits (*Oryctolagus cuniculus)* by myxomatosis has reduced grazing pressure, with the result that many heathland areas have now become birch (*Betula* spp.) woodland.

Studies of production and nutrient budgets (Gimingham, Chapman & Webb, 1979) have tended to consider *Calluna* heathlands as a single entity. However, lowland heathlands in southern England are characterised by higher temperatures, lower rainfall, and lower soil nutrients, whilst upland heaths are characterised by lower temperatures, higher rainfall and generally higher nutrient levels in the soil (Chapman & Clarke 1980). Lowland heathlands in Britain occur on a variety of soils, and show a range of vegetation from open *Calluna* to woodland containing only relict areas of heathland. Many such sites have been open heathland in living memory. Sites can be placed within three broad vegetation categories:

1. *Calluna* heathland with little or no invasion by scrub or trees;
2. sites which are still *Calluna* heathland, but with invasion by gorse (*Ulex europaeus*);
3. sites where there has been extensive invasion by birch, and where *Calluna* now only survives in small patches.

A model (PCAL), developed by Chapman, Rose and Clarke (1989) and based upon data from dry heathland in Dorset, has been used to examine the long-term consequences of management techniques and the importance of specific factors in the phosphorus economy of *Calluna* heathlands. This model is controlled by the growth of the vegetation described by the Gompertz function, but is limited by the availability of inorganic phosphorus in the soil. Root production has been assumed to be directly proportional to above-ground

Plate 24. Bramshot Heath, Hampshire – an area subject to colonisation by birch and gorse, and open heathland now restricted to small areas

production Inputs to the system are in the form of carbon by photosynthesis, and phosphorus from atmospheric deposition and mineral sources

Available inorganic phosphorus is assumed to be present in the soil either as adsorbed phosphorus or within the soil solution The equilibrium between these two forms is described by the Langmuir equation

$$y = a\ s\ x/(1+ax)$$

where y = adsorbed phosphorus ($\mu g\ P\ g^{-1}$),
x = soluble phosphorus ($\mu g\ P\ ml^{-1}$ soil solution,
s = adsorption maximum in $\mu g\ P\ g^{-1}$ soil, and
a = constant defining the rate of equilibrium

The concentration of phosphorus in the soil solution predicted by this equation, the volume of water draining from the root zone, and the soil moisture equivalent are used to calculate drainage losses of inorganic phosphorus from the system

The losses of phosphorus predicted by the model depend upon the constants in the Langmuir equation Soils from a range of heathlands in southern England have been examined in relation to their phosphorus adsorption characteristics, and placed in one of the three vegetation categories described above (Chapman, Rose & Bassanta 1989)

The soils examined showed a range of adsorption curves At one extreme were soils derived from Tertiary sands, with adsorption maxima of less than 100 μl P g^{-1} soil, while at the other extreme were soils from Dartmoor with adsorption maxima in the order of 4000 $\mu g\ P\ g^{-1}$ soil Soils from other heathlands in lowland Britain produced values between these two extremes

When the phosphorus adsorption maxima for each site were plotted against levels of isotopically exchangeable phosphorus, there was a clear relationship with vegetation type In the absence of grazing, or alternative management, open *Calluna*-dominated heathland can persist where the phosphorus adsorption of the soil is less than about 70 $\mu g\ P\ g^{-1}$ soil However, in the absence of grazing, invasion by gorse is likely where the

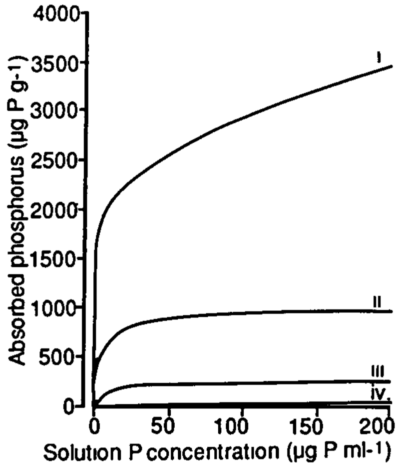

Figure 50 Adsorption curves fitted to data from (i) Headland Warren, Dartmoor – an area with high soil phosphorus adsorption capacity, but maintained as open heathland by grazing, (ii) Langford Heathfield, Somerset – an ungrazed site subject to invasion by trees (iii) Clayhiddon Turbary, Devon – an ungrazed site with areas invaded by gorse, (iv) Hartland Moor NNR, Dorset – an ungrazed heathland with low soil phosphorus adsorption capacity, where successional change is slow

adsorption maximum lies between about 70 and 700 $\mu g\ P\ g^{-1}$ soil Where it exceeds 700 $\mu g\ P\ g^{-1}$ soil, succession to birch wood is probable, if grazing or management is not maintained Sites, such as Dartmoor, Exmoor and the New Forest, that remain as open *Calluna* heathland despite phosphorus adsorption levels over 300 $\mu g\ P\ g^{-1}$ soil, are all still grazed, or managed by burning or mowing Climate might retard the development of woodland on Dartmoor and Exmoor, but it is unlikely that the New Forest would remain as open heathland, if grazing or management were discontinued

The range of phosphorus adsorption maxima shows that soils from Dorset are not typical of heathlands in general Whilst the concept and assumptions made in the model remain valid, it is probable that leaching of phosphorus will be lower on many other sites (Gimingham & de Smidt 1983) Thus, greater proportions of the phosphorus released by burning and decomposition would be retained in the soil Hence, the rate of change of vegetation, in the absence of grazing or management, might be more rapid than in Dorset

Heathlands in lowland Britain are, largely, the result of particular forms of land use on suitable soils Changes in land use have led to marked changes in both the structure and composition of the vegetation and associated fauna of many British heathlands The maintenance of representative areas of heathland in some areas of lowland Britain is an immediate problem

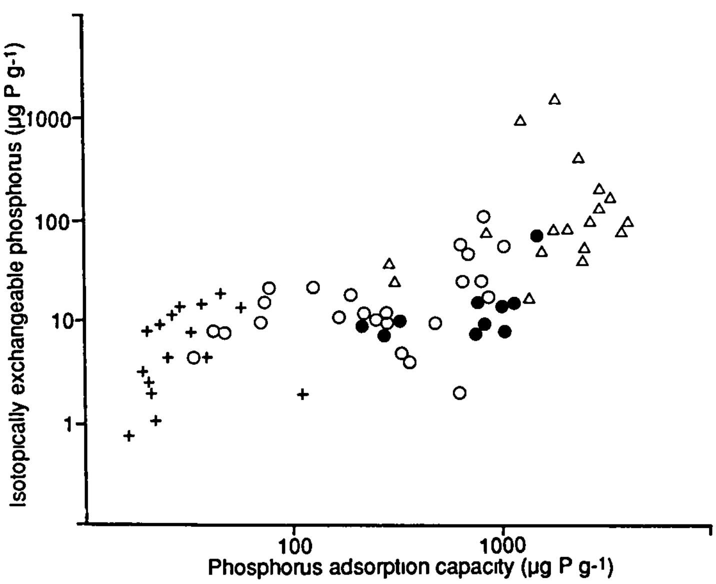

Figure 51 The relationship between the vegetational state of heathland sites in southern England, phosphorus adsorption capacity, and levels of isotopically exchangeable phosphorus in the soil
+ Ungrazed *Calluna* heathland with little or no invasion by scrub or trees
▲ Grazed heathland with little or no invasion by scrub or trees
O *Calluna* heathland with invasion by gorse
● Heathland with extensive invasion by birch and where *Calluna* now only survives in small areas

Decreased rabbit grazing and, in many areas, the decline of common rights have led to an invasion of heathland by gorse, birch, bracken *(Pteridium aquilinum)* and other species As suggested here, the rate of succession from open heathland to scrub and woodland will be related to nutrient status Several of these invasive species have been associated with improved soil nutrient status Thus, the control of such species is essential, if successional change is not to be further accelerated

Whilst the arrest of succession is important in the management of most heathland sites, the requirements of individual sites must be considered because of variations in soil and climate The loss of traditional forms of land use on some sites will require drastic alternatives The use of herbicides for the control of birch and bracken has been investigated by Marrs (1987), but methods of reducing the nutrient capital contained in some heathlands must be considered, if the long-term future of such sites is to be assured Mowing and the removal of the cut heather as bales, as has been done in the New Forest, may be more effective than burning for removing nutrients Mowing may be more practical on many smaller sites, where the nature of adjacent land may preclude the use of fire, it has the advantage that it is less dependent upon weather conditions, requires less manpower, and can be applied throughout a greater period of the year than heather burning

A more drastic, but even more effective, treatment in reducing nutrient capital is that of sod-cutting, as practised in the Netherlands However, the characteristics of the soil profile must be examined, especially with regard to phosphorus adsorption before any such disturbance is undertaken The removal of surface layers may deplete soil phosphorus, but, in some situations, the exposure of the deeper soil horizons may accelerate undesirable succession

Further work is required into the energy of adsorption, and into the relative availability of phosphorus in different heathland soils Similarly, the different forms of heathland management, such as burning, grazing and mowing, should be examined further for their effects upon maintaining the low nutrient status of lowland heathlands

S B Chapman and R J Rose

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Computer programs for identifying vegetation types

Suppose that you visit a Pennine moorland and find that it has dominant heather (*Calluna vulgaris*) and cloudberry (*Rubus chamaemorus*), with an admixture of hare's-tail and common cotton-grass (*Eriophorum* spp) This information about the vegetation can (if you are an ecologist) tell you a great deal about the environment Probably the soil has impeded drainage, with peat exceeding 30 cm thickness, the site sheds water in wet weather, so there are no permanent pools or runnels, the soil is exceedingly acid, with a pH of about 3 8, the climate is cool and moist, and sheep grazing, if present at all, is light

The ability of the experienced ecologist to 'read off' environmental information from vegetation is derived from years of field experience With simple vegetation such as that on a Pennine blanket bog, the signals may be quite easy to read, with complex vegetation, the signals may be apparently conflicting, and much harder to interpret Only a really good field ecologist can make sense of them How can his knowledge of vegetation be simplified so that it is available to an investigator with less experience?

The standard approach to this problem is to classify vegetation into types The subject of vegetation classification (as opposed to habitat classification) is called phytosociology In the past, authors such as Tansley (1939) used attributes both of vegetation and of habitat to define plant communities Nowadays, a phytosociological approach is favoured, whereby the vegetation is classified first and its environmental relations are investigated afterwards For example, a blanket bog is a physical object composed mainly of peat It is defined by its physical attributes, not in terms of its vegetation It may support any of several kinds of vegetation, some of which may also occur on other types of bog

In practice, the range of habitats that can support a given type of vegetation is quite limited Indeed, the species composition of most semi-natural vegetation conveys enough information to say how it should be managed for nature conservation, and sometimes for other purposes Approximate limits can also be put on its productivity

Vegetation classifications are often made automatically, by means of a computer The starting point is typically a phytosociological table of the occurrence of species in quadrat samples (Table 12) The classification seeks to group the samples so that like assemblages of species are classified with like Almost all current numerical methods for classification of vegetation are 'unsupervised', ie they do not use previous classifications as input data Each problem is examined afresh from first principles

Once a classification has been set up, there remains the problem of how to assign a new sample to a vegetation type that has been defined previously This is the problem of allocation or identification Identification has received far less attention from numerical ecologists than classification

Each numerical classification must be based on a set of data If the input data are comprehensive, then the resulting classification will suffice for all new samples of vegetation However, such an

Table 12 Phytosociological table specifying the occurrence and abundance of species in samples. Absence is denoted by a dot, numbers denote abundance on the Domin scale, which specifies categories of ground cover ranging in this example from 1 for a species with negligible cover to 8 for a species covering 50–75% of the ground

Species	Sample 1	2	3	4	5	6
Brown bent-grass (*Agrostis vinealis*)	3	1		2	3	3
Heather (*Calluna vulgaris*)	6	8	8	5	3	3
Common sedge (*Carex nigra*)		2	4	3	4	
Wavy hair-grass (*Deschampsia flexuosa*)	3	3	2	3	4	
Crowberry (*Empetrum nigrum*)	3	3	3	3	3	3
Common cotton-grass (*Eriophorum angustifolium*)	3	3	3			
Hare's tail (*E. vaginatum*)	4	5	5		5	5
Cloudberry (*Rubus chamaemorus*)	5					
Bilberry (*Vaccinium myrtillus*)				5	6	

Table 13 Association table summarising data in Table 12. Key to frequency classes I, 0.0–0.2, II, 0.2–0.4, III, 0.4–0.6, IV, 0.6–0.8, V, 0.8–1.0

Species	Frequency	Median Domin value
Brown bent-grass (*Agrostis vinealis*)	V	3
Heather (*Calluna vulgaris*)	V	5
Common sedge (*Carex nigra*)	IV	3
Wavy hair-grass (*Deschampsia flexuosa*)	V	3
Crowberry (*Empetrum nigrum*)	V	3
Common cotton-grass (*Eriophorum angustifolium*)	III	3
Hare's tail (*E. vaginatum*)	V	5
Cloudberry (*Rubus chamaemorus*)	I	5
Bilberry (*Vaccinium myrtillus*)	II	5

ideal is unattainable, as all knowledge and all data are partial.

A major problem now presents itself. Given that no scheme of classification is comprehensive, how can partial information be used? It is impracticable to maintain an ever-growing and increasingly bulky data base, which is repeatedly re-analysed. However, established vegetation types can be published in summary form as 'association tables' (Table 13). New samples can then be compared with association tables, rather as one compares a plant specimen with its description in a *Flora*. In the terminology of image classification, the association tables serve as a summarised training set of data to generate a 'supervised' classification of vegetation.

In order to produce repeatable results, the process of matching samples to association tables needs to be automated. ITE has recently developed a computer program called TABLEFIT (Hill 1989), designed for this purpose. Written in the FORTRAN programming language, it can run on most desktop and all larger computers. The input data are (i) a set of association tables describing vegetation types, and (ii) the composition of a vegetation sample (either a complete species list, or a list with measures of species abundance, or just the dominant species). From these data, TABLEFIT calculates a measure of the goodness-of-fit of the sample to the vegetation type.

The measure used is a composite, consisting of the mean of three coefficients which answer the following questions.

1 How closely do the species present match those that would be expected in the vegetation type?

2 How well does species abundance coincide with that described for the type?

3 Taking the four most abundant species in the sample, what is their frequency in the vegetation type (the best score being when all four occur in frequency class V)?

The best-fitting vegetation types are then listed in descending order of preference.

The new thing about TABLEFIT is that it provides a numerical method of generating supervised classifications from published data. It can be applied to any vegetation classification for which association tables are available. It is just as suitable for use with traditional non-numerical systems of classification as it is for computer-generated numerical classifications. It has been tried on the mire types defined in NCC's *National vegetation classification* (Rodwell 1986–87). User reaction has been favourable, and it is hoped to develop it further.

Automated identification of vegetation types presents exciting possibilities for the future. For each vegetation type, it is possible to specify the likely soil, grazing pressure, management history and successional trends, together with the type's rarity, geographical distribution and conservation value. Given a data base with this information, TABLEFIT can be used for site evaluation by suggesting whether vegetation present at the site is unusual or rare in a given district, and whether the site is likely to be a habitat for valuable species. It can also be used for site management, either by suggesting species suitable for introduction or by indicating how the vegetation is likely to change if the management regime is altered.

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Assessing effects of climatic change on vegetation

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If current forecasts of climatic change are accurate, then there will be significant effects on the structure and species composition of many natural and semi-natural plant communities within the next 100–150 years Clearly, these changes must be identified before they occur (prediction), or as they occur (measurement) Studies have begun in ITE to identify the possible areas where change is most likely to be detected This work has highlighted some of the difficulties in detecting change *per se* and the subsequent problems in determining cause/effect relationships

Change: where will it be most easily detected?

Basically, for the purposes of monitoring the effects of climate, vegetation change can be classified into three main groups (i) where the mean regional climate has a direct effect on species, (ii) where climatic extremes affect vegetation change through disturbance, and (iii) where the climate exerts an indirect effect through other ecosystem processes, such as increasing net primary production, modifying competitive interactions between species, or accelerating habitat change through succession

Direct climatic effects on species

Vegetation change will involve either the colonisation of new species typical of warmer climates, or the extinction of species typical of colder climates It is difficult to predict which species are likely to be the best indicators of climatic change, because distribution maps show a plethora of species whose British distribution is apparently limited by some aspect of climate (Perring & Walters 1962) However, there are three broad groups of species which are likely candidates for initial study the Lusitanian flora, alien species with a southern distribution, and the Arctic-alpine flora

Lusitanian species, such as the Cornish and Dorset heaths (*Erica ciliaris* and *E vagans*), reach their northern limits in the south-west of England and/or western Ireland, and may expand their British range if the climate becomes warmer and wetter Introduced alien species from warmer climates, such as the holm oak (*Quercus ilex*) and the Hottentot fig (*Carpobrotus edulis*), are already established in the south-west of Britain, and are obvious candidates for study Arctic-alpine species, on the other hand, are found mainly in montane areas, where the climate is harsh, and the British distribution of these species is likely to contract if the climate becomes warmer, with the possible extinction of some species

An example of one group of plants that could be considered for further study are the saxifrages (*Saxifraga* spp), because of their current British distributions

1 Lusitanian species the kidney saxifrage and St Patrick's cabbage (*Saxifraga hirsuta, S spathularis*),

2 widely distributed/lowland species meadow and rue-leaved saxifrage (*S granulata, S tridactylites*)

3 Arctic-alpine/montane species starry, mossy, yellow and purple saxifrage (*S stellaris, S hypnoides, S aizoides, S oppositifolia*)

The distribution of one member from each of these groups shows the clearcut nature of the distributions, and there is obvious potential for mapping their spread as climate changes (Figure 52) Although it may be possible to predict the likely change in distribution of the Lusitanian and Arctic-alpine species in response to climate change, it is much more difficult to forecast what might happen to *S granulata* or *S tridactylites*

Gross change in these species may be detected by mapping their distributions at regular intervals, as is done within the Biological Records Centre (BRC) at ITE Monks Wood However, accurate assessments of the effects of climatic change will require detailed autecological studies of existing populations, so that range expansion and contraction can be measured For example, a detailed baseline study of the Dorset heath (*Erica ciliaris*) (a Lusitanian species) and its hybrid with the cross-leaved heath (*Erica tetralix*), a widely distributed species, has already been established, and has indicated that these species are expanding their ranges (Chapman 1975)

Effects of extreme events

When extreme climatic events occur, there is often catastrophic death of individuals and populations Recent examples in Britain include the October gales of 1987 affecting the southern woodlands, and the hot dry summer of 1976 affecting heathlands, directly through heather (*Calluna vulgaris*) death (Marrs 1986), and indirectly through increased 'accidental' fires The important feature of such a catastrophe is that it is an initiator of change, and the community regenerates, either cyclically to replace the original community (cyclic regeneration), or by the invasion of new species Good examples of such change occur in Breckland where heather death started in 1976 during the hot summer, and increased in the following two to three years after outbreaks of insect herbivores In the affected area, there was immediate large-scale invasion by birch (*Betula* spp) (Marrs 1986) Such data emphasise the importance of catastrophes in initiating new successions Studies of patch dynamics in sensitive communities, where the normal periodicity and return interval of such catastrophes is known, may help detect important influences of climate Moreover, this type of catastrophic disturbance may be an important factor allowing bursts of invasion by species typical of warmer habitats As information is already available on the Breckland heaths, a southern habitat with a continental climate (by British standards), and the cycles are not too long (15 years), these heaths are likely 'pressure point' communities Baseline monitoring and extensive study of community dynamics are currently in progress

Indirect effects through ecosystem processes

These vegetation changes are likely to be much more subtle than those described above, because the same species may persist, but at markedly altered rank abundance As the productivity of most ecosystems is likely to increase, because of higher temperatures, higher or modified rainfall, at least in some areas, and higher CO_2 concentrations, an approximation can be obtained of the likely effects of increased vegetation growth, using experiments where other growth-limiting factors are alleviated, as a model Fertiliser addition is often used to increase vegetation

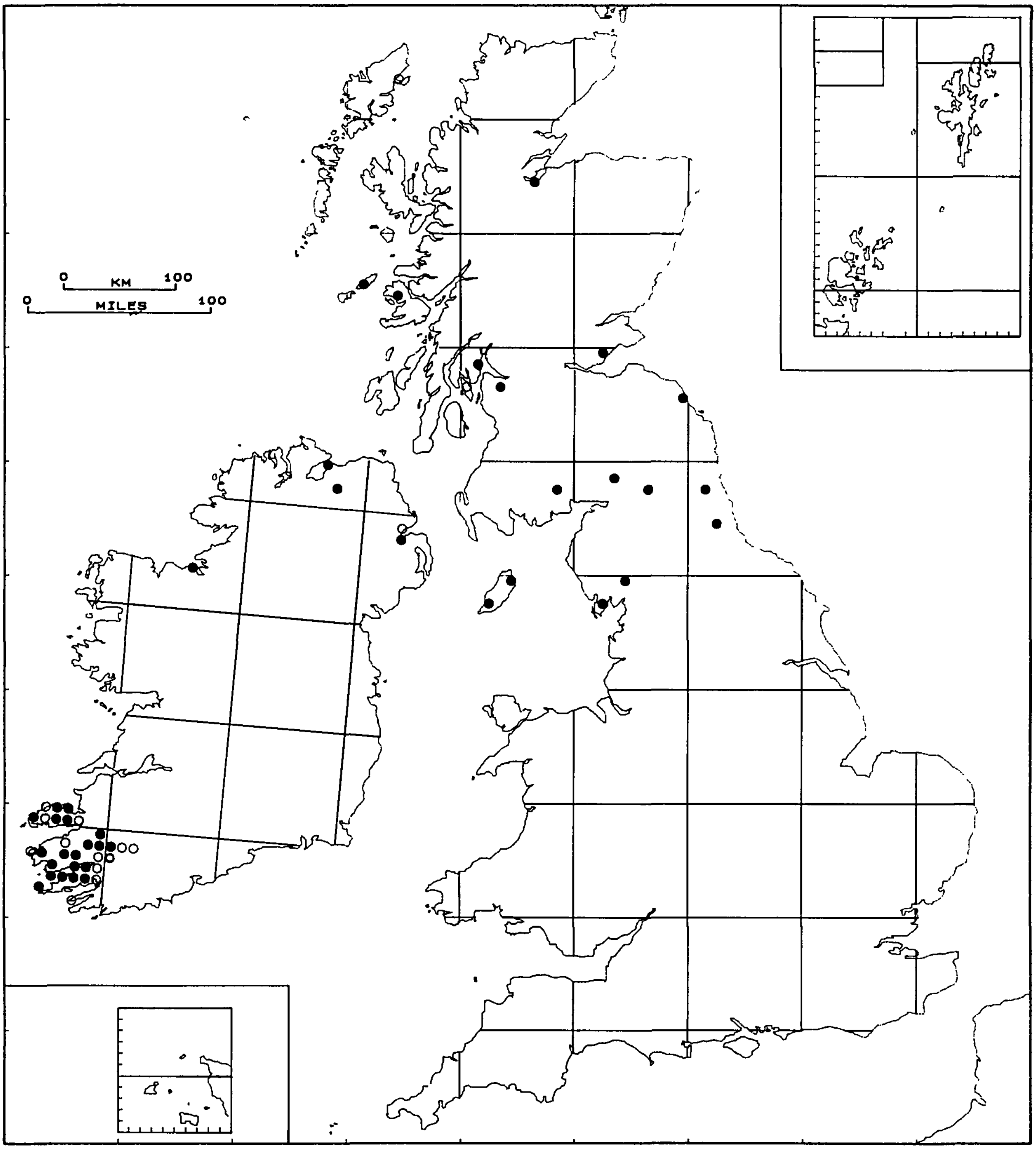

Figure 52 The current distribution of three saxifrages from the data base held in the ITE Biological Records Centre These species would be ideal candidates for studying response to changing climate because of their contrasting distributions (i) a Lusitanian distribution

productivity, and, when applied to semi-natural communities at high rates (agricultural rates), the growth of aggressive productive species has been promoted at the expense of subordinate ones which do not respond to fertiliser addition However, recent research in Europe suggests that, even where much lower amounts of nutrients are added in polluted rain, similar effects occur, with increasing dominance of competitive grasses on infertile heathlands and chalk grasslands (Heil & Diemont 1983, Bobbink & Willems 1987), and a dramatic loss of bryophytes and lichens (During & Willems 1986) Thus, if climate does tend to increase the productivity of natural and semi-natural vegetation, then some competitive species are likely to flourish, but at the expense of the understorey species, and especially the lower plants

Problems in detecting vegetation change

There are two fundamental problems in detecting vegetation change first, the separation of significant directional change (ie the signal) from background fluctuations (noise), and, second, the identification of cause/effect relationships These two problems are illustrated using real data collected in a long-term monitoring scheme at Moor House International Biosphere Reserve, an upland reserve which is likely to be vulnerable to climate change The data presented here are from one experiment (heath rush (*Juncus squarrosus*) grassland experiment) in a set of ten established between 1954 and 1972 by the Nature Conservancy, and continued first by NCC, and, since 1982, by ITE (Marrs *et al* 1986) The experiments were set up to cover the range of upland vegetation found on the Reserve, and, in each experiment, the effects of sheep grazing *versus* no sheep grazing are compared

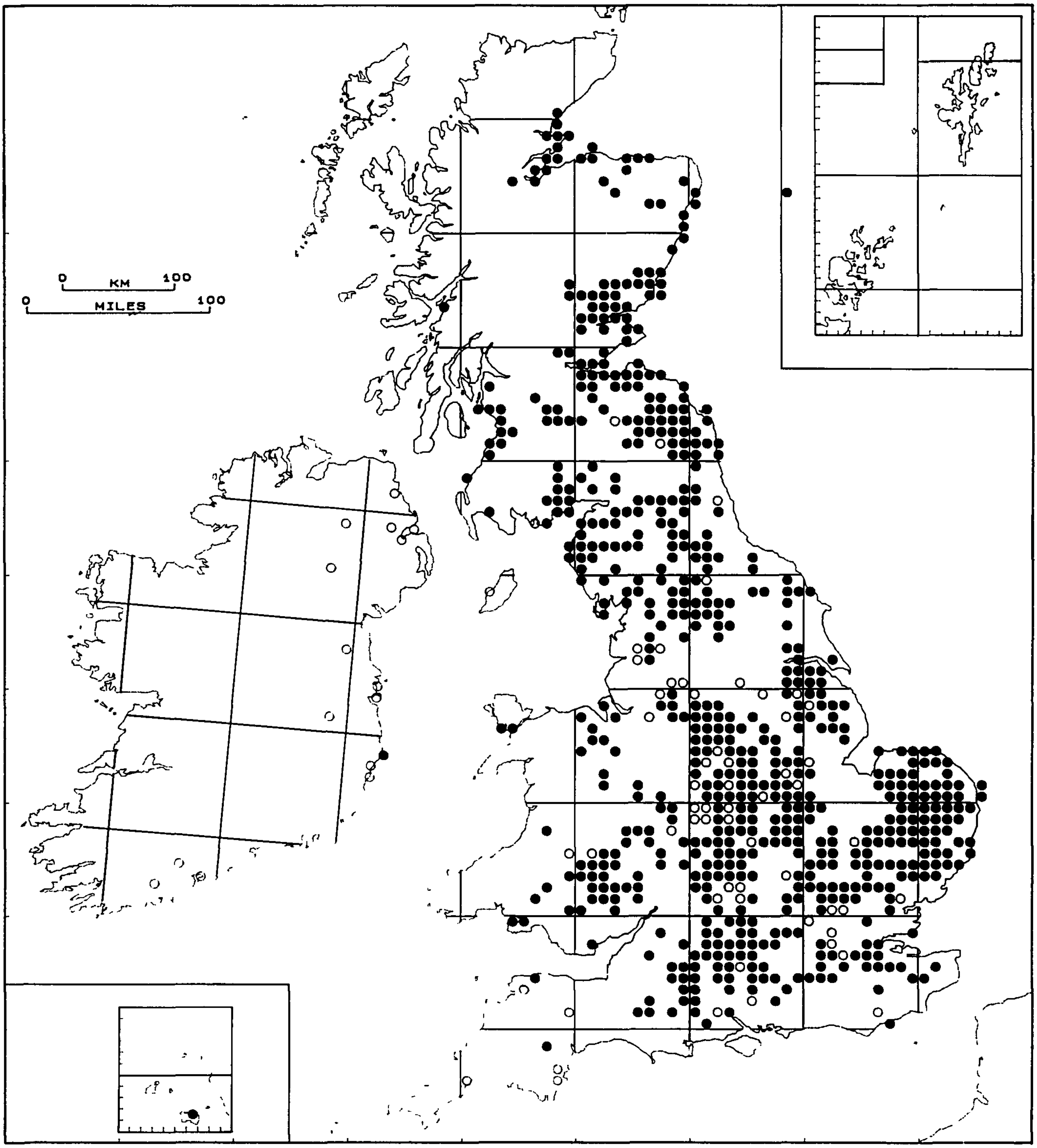

Figure 52 The current distribution of three saxifrages from the data base held in the ITE Biological Records Centre These species would be ideal candidates for studying response to changing climate because of their contrasting distributions (ii) a widely distributed species

At one blanket bog site, a rotational burning sequence is also included The general aim of the study is to measure vegetation change, and identify important signals (ie changes induced by management) from background noise (species fluctuations in abundance that are not accounted for by known events)

Separation of signal from noise

In the heath rush grassland experiment, four typical examples of species response through time are shown in Figure 53 Obviously, common sedge (*Carex nigra)* was increasing and common cotton-grass (*Eriophorum angustifolium)* was decreasing, but *Pohlia nutans* showed a curvilinear response and bilberry (*Vaccinium myrtillus)* was erratic Clearly, the first two species are showing a consistent directional change over the period examined, but the latter two must be viewed as noise Where such noise occurs, measuring change in abundance from a few points is impossible (Figure 54), and, moreover, long-term data are essential even to determine that they are noisy! Thus, the current classification of common sedge and cotton-grass may prove erroneous when data for a longer period become available

It is possible to use multivariate ordinations for data from all species to assess change, and comparisons can be made between sites (Figure 55) In this example, the grazed *versus* ungrazed plots are changing in both treatments in the same direction, but at different rates, the enclosed plots are changing towards blanket bog much faster Rates of change on the ordination axes may provide a useful, albeit crude, method for assessing climatic change impacts

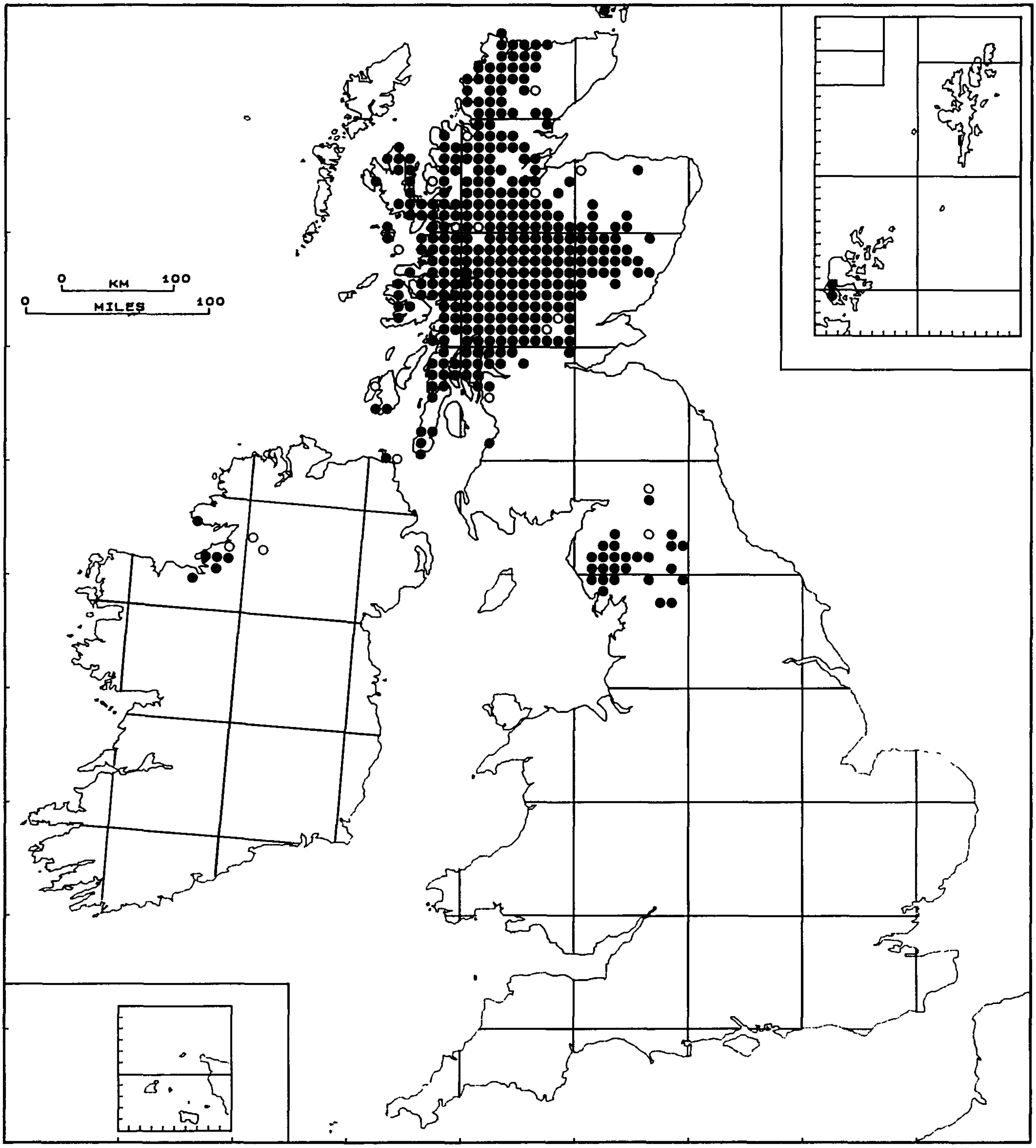

Figure 52 The current distribution of three saxifrages from the data base held in the ITE Biological Records Centre These species would be ideal candidates for studying response to changing climate, because of their contrasting distributions (iii) a montane/northern species

Cause/effect relationships

It is impossible to separate cause/effect relationships without detailed experiments where the causal factors of interest are manipulated For example, the results in Figure 55 show that both grazed and ungrazed heath rush grassland changed towards blanket bog between 1966 and 1984, but the trend was faster when grazing was removed However, directional change in other unknown environmental factors may also have occurred during this period, and these covariates with time complicate the interpretation of cause/effect relationships Thus, the general trend in the grazed plots towards blanket bog could be the result of

- unknown vagaries of the climate, eg individual extreme events, some periods favouring certain species at the expense of others,
- a possible increase of nutrient inputs, particularly nitrogen, through rainfall deposition and cloud capture,
- possible slight reductions in grazing pressure on the grazed site, through changes in stocking density or animal preferences,
- changes in unknown variables

What has been determined is that this background change is slower if sheep grazing is continued

Clearly, the best way of separating cause/effect relationships is through experiments where the causal factors are manipulated However, it may be possible to obtain pointers using the newer methods of multivariate analysis (Ter Braak 1986), where community trends can be related to measured environmental variables, eg time To be successful, this approach requires measurements of the environmental factors of interest throughout the study period

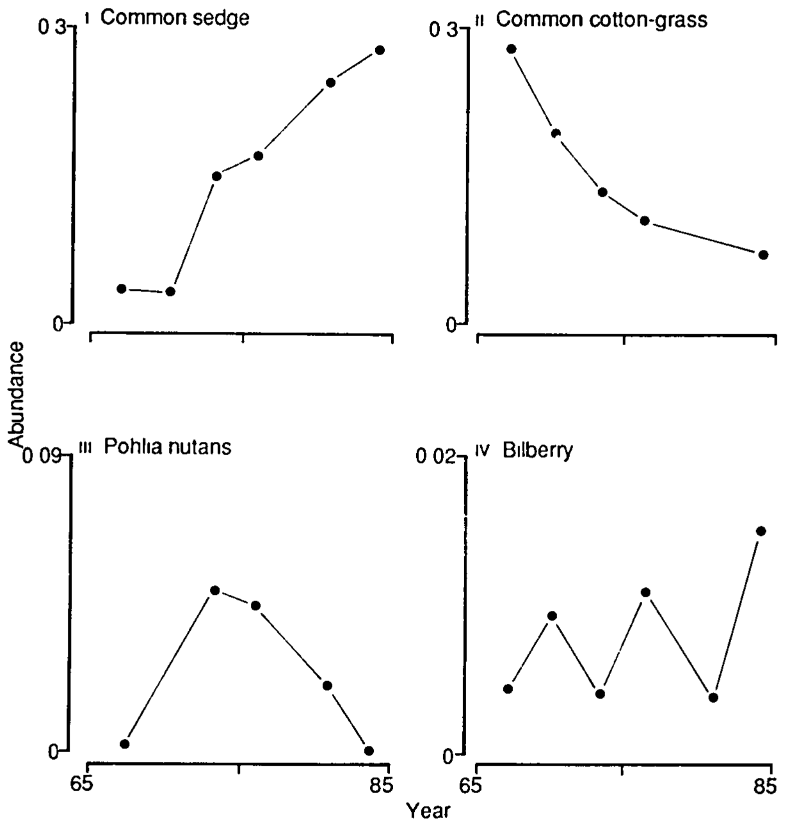

Figure 53 Observed change in abundance of four species in the heath rush grassland experiment at Moor House International Biosphere Reserve between 1965 and 1985 showing examples of directional change (i ii) and fluctuations/noise (iii iv)

So far, the difficulties in showing that vegetation change has been caused by changes in major driving variables have been considered However, change can also be initiated by secondary effects that may be promoted by climatic change or its interaction with other major driving variables, such as pollution and grazing pressure Secondary effects that might occur are the increased productivity of dominant species, and hence a lower resource availability (light and nutrients) for subordinate species, or responses induced by changed invertebrate herbivory

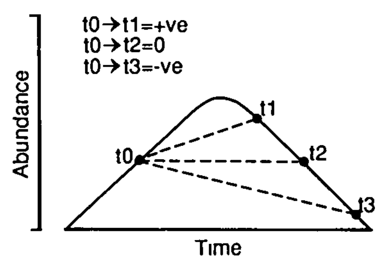

Figure 54 Hypothetical diagram illustrating the problem of detecting change when there are few sampling points and change is curvilinear Opposite results are obtained depending on the time interval between sampling points

Conclusions

Although it is possible to detect the effects of climatic change for certain 'pressure point' communities where species may be gained or lost, for most communities separation of signal from noise and the isolation of causal factors are likely to be major problems In order to detect the subtle effects of climate change on vegetation, an expanded system of long-term site monitoring must be set up, and linked intimately to (i) experimental studies of comparative plant ecophysiology, the competitive relationships between species under various management scenarios, and (ii) simulation modelling

R H Marrs

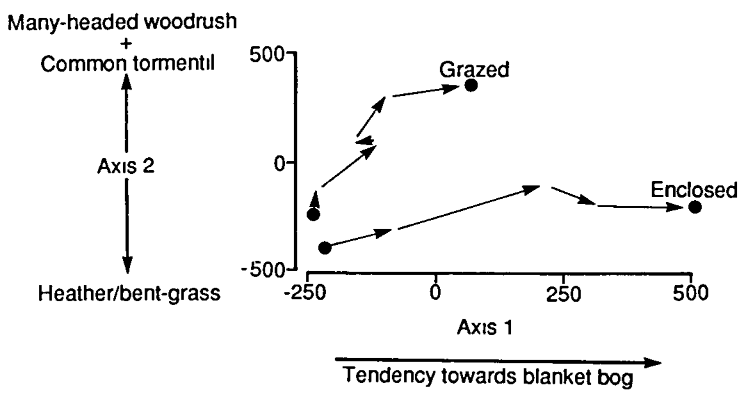

Figure 55 Trajectories through time for the sheep grazed and enclosed (no sheep grazing) plots of the heath rush grassland experiment at Moor House International Biosphere Reserve between 1965 and 1986 using multivariate analysis

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AO	Mrs Holgate A (PT)
TYP	Miss Cottam S
TYP	Mrs Wilson M (PT)
TYP	Miss Benson C
BAND 8	Mr Lethbridge R

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Grade 7	Mr Brown A H F
Grade 7	Dr Bunce R G H
Grade 7	Dr Callaghan T V
Grade 7	Dr Harrison A F
Grade 7	Dr Hornill A D
Grade 7	Mr Howard P J A
Grade 7	Mr Lindley D K
Grade 7	Mr Sykes J M
SSO	Dr Dighton J
SSO	Dr Howard B J
SSO	Dr Ineson P
SSO	Mr Lawson G J
SSO	Mr Parkinson J A
SSO	Mr Quarmby C
SSO	Mr Roberts J D
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Grade 6	Dr Watson A
Grade 7	Dr Harris M P
Grade 7	Dr Kruuk H
Grade 7	Dr Miller G R
Grade 7	Dr Miles J
Grade 7	Dr Moss R
Grade 7	Mr Welch D
SSO	Dr Bayfield N G
SSO	Mr Cummins R P
SSO	Mr French D D
SSO	Dr Marquiss M
SSO	Mr Parr R A
SSO	Mr Paterson I S
SSO	Mr Picozzi N
HSO	Mr Catt D C
HSO	Mr Conroy J W H
HSO	Mr Young W F
SO	Mr Scott D
SO	Mr Trenholm I B
PTO	Mr Morris J A

Appendix 2 **Research projects at ITE stations at 31 March 1989**

ITE (S) MONKS WOOD EXPERIMENTAL STATION

Programme 2 Land use, agriculture and the environment

T02052–5	**EIC Remote sensing**	***B K Wyatt***
T02052a2	Remote sensing techniques for habitat surveys	R M Fuller
T02052e1	Remote sensing in the Less Favoured Areas models for rural land use planning	B K Wyatt
T02052f2	Characterisation of grassland type and condition using remotely sensed data	B K Wyatt
T02052g5	Use of remote sensing for mapping and monitoring Sahelian rangelands	B K Wyatt
T02053–5	**EIC GIS and cartography**	***B K Wyatt***
T02053a2	Digital cartographic service	G L Radford
T02053b1	CORINE Biotopes project	D Moss
T02053c1	Scientific co-ordination of the CORINE programme	B K Wyatt
T02053e2	Ecological Data Unit	G L Radford
T02054–5	**EIC Biological Records Centre**	***P T Harding***
T02054a5	Biological Records Centre botanical recording schemes	C D Preston
T02054b5	Biological Records Centre vertebrate recording schemes	H R Arnold
T02054c2	The distribution and ecology of non-marine isopoda	P T Harding
T02054d5	Biological Records Centre terrestrial and freshwater invertebrate recording schemes	B C Eversham
T02054e5	Biological Records Centre general	P T Harding
T02054f2	Population fluctuations in annual legumes	C D Preston
T02054g5	Biological Records Centre data bank	C Appleby
T02054h5	Butterfly monitoring scheme	T J Yates
T02055–1	**Environmental impact assessment**	***M D Hooper***
T02055a1	Avalon Lakes design studies	M D Hooper
T02055b1	Channel Tunnel construction – monitoring terrestrial (and freshwater) ecology	R C Welch
T02055c1	Folkestone terminal – specialist advice	M D Hooper
T02055d1	Ecological appraisal of a potential power station site	M D Hooper
T02056–5	**Grassland ecology**	***T C E Wells***
T02056a2	Monitoring floristic changes	T C E Wells
T02056b1	Cutting of chalk grassland	T C E Wells
T02056c2	Population studies on orchids	T C E Wells
T02057–5	**Historical ecology**	***J Sheail***
T02057a5	Historical aspects of environmental perception	J Sheail
T02058–5	**Vegetation dynamics**	***T W Parr***
T02058a2	Roadside vegetation dynamics	T W Parr
T02058b2	Modelling competition in grass swards	T W Parr
T02058c1	Effects of growth retardants on the ecology of roadside vegetation in west Sussex	T W Parr
T02058d1	*Phragmites* seedlings – their use in RBTS sewage treatment	T W Parr
T02058e1	Factors affecting the establishment and performance of reeds (*Phragmites australis*) in RBTS systems a survey in the UK of reed bed treatment	T W Parr
T02058f1	Experimental studies on the management of reed beds for RBTS sewage treatment	T W Parr
T02059–5	**Wetland dynamics and management**	***T Parish/ J O Mountford***
T02059a2	Modern agriculture and wildlife	T Parish
T02059b2	Land use and ecology of Swavesey Fens – the fauna and flora in relation to both established and changing management	T Parish
T02059c5	Environmental impact of flood protection measures on the water regimes of wildlife habitats	J O Mountford
T02059d1	The effects of nitrogen on species diversity and agricultural production on the Somerset Moors	J O Mountford
T02059e5	British Rail-sponsored grassland experiments	J O Mountford
T02061–3	**Agriculture and the environment (special topic programme)**	***J Sheail***
T02061f3	Reducing residual soil fertility of abandoned agricultural land for the restoration of native vegetation	R H Marrs

Programme 4 Management of aquatic ecosystems

T04053k1	Physical habitat simulation in rivers – model calibration (PHABSIM)	J O Mountford

Programme 7 Environmental pollution

T07061–5	**Hazard assessment**	***S Dobson***
T07061a1	Hazard assessment on chemicals	S Dobson
T07061b1	Pesticides 'call-off' consultancy to DOE	S Dobson
T07061d1	Pesticide drift and impact	B N K Davis
T07061e2	Insecticide spray drift and bioassay	B N K Davis
T07061f5	Birds and pollution	I Newton
T07062–5	**Aquatic ecology and ecotoxicology**	***K R Bull***
T07062a1	Classification and comparison of river and lake catchments using computing techniques	K R Bull
T07062c5	Remote sensing of Eskdale and Dunnerdale	K R Bull/ B K Wyatt
T07062d2	Life history of the common frog	C P Cummins
T07062e1	Froglet production related to water chemistry and tadpole density in semi-natural pools	C P Cummins
T07062f2	Modelling of atmospheric deposition into catchments	K R Bull
T07063–5	**Toxicology**	***D Osborn***
T07063a2	Heavy metals in bats	R F Shore
T07063b1	Bats and pollution	R F Shore
T07063c2	Hedgehogs and pollution	R F Shore
T07063d2	Heavy metal metabolism in wild small mammals	R F Shore
T07063e2	The effects of liming moorland on small mammal populations (proposal)	R F Shore
T07065–3	**Animal ecotoxicology (special topic programme)**	***A S Dawson***
T07065c3	Interactive effects of pesticides on reproduction in birds	C Walker/ A S Dawson

Programme 8 Population ecology

T08054–5	**Population dynamics**	***I Newton***
T08054a5	Population ecology of sparrowhawks (*Accipiter nisus*)	I Newton
T08055–5	**Farmland birds**	***A Village***
T08055a2	Kestrels in farmland	A Village
T08055b5	Birds on arable farmland	A Village
T08056–5	**Bird physiology**	***A S Dawson***
T08056a2	Physiological factors causing deferred sexual maturity in birds	A S Dawson
T08056c2	Reproduction in rabbits	A S Dawson
T08057g1	Sediment classification of the Rivers Stour and Orwell	M G Yates

Programme 9 Community ecology

T09051–5	**Coastal systems**	***L A Boorman***
T09051a2	Sand dune studies in East Anglia	L A Boorman
T09051b2	Plant establishment in woodland	L A Boorman

T09051d1	Studies on salt marsh erosion in Essex	L A Boorman
T09051e2	Invertebrates of Scottish sand dunes	R C Welch
T09051f5	Comparative studies of salt marsh processes (proposal)	L A Boorman

T09052–2	**Heath and moorland systems**	***R H Marrs***
T09052a2	Heathland management research	R H Marrs
T09052b2	Long-term studies of vegetation change at Moor House NNR	R H Marrs
T09052c2	Effects of grazing in Snowdonia	M O Hill

T09053–2	**Ecological processes in farm woodland**	***M O Hill***
T09053a2	Autecology of selected species on farm woodland	M O Hill
T09053b2	Farm woodland – primary and secondary effects of tree planting on soil (proposal)	J M Sykes
T09053c2	Modelling succession in farm woodland	M O Hill
T09053d2	Invertebrate fauna of native and introduced broadleaved trees in Britain	R C Welch
T09053e1	Management guidelines for the conservation of invertebrates, especially butterflies, in plantation woodlands	R H Marrs
T09053f2	Nitrogen mineralisation in tropical forest soils	R H Marrs
T09053i2	Artificial intelligence applied to ecological and distributional information systems	M O Hill
T09053j2	A survey of sand dunes in relation to grazing	L A Boorman

Programme 11 Freshwater biology and chemistry

T11053m2	The numbers of Atlantic salmon in some Scottish rivers	K H Lakhani

Programme 13 Scientific services

T13060–2	**Statistical services in ITE South**	***K H Lakhani/ M D Mountford***
T13060a2	Estimation of population parameters	K H Lakhani
T13060b2	Statistical consultancy	K H Lakhani
T13060c2	Population regulation and estimation	M D Mountford
T13060d2	Statistical consultancy in ITE	M D Mountford

T13061–1	**ITE South consultancies**	***T M Roberts***
T13061a1	Small consultancies at ITE Monks Wood	M D Hooper

ITE (S) FURZEBROOK RESEARCH STATION

Programme 8 Population ecology

T08057–5	**Migratory wader ecology**	***J D Goss-Custard***
T08057a2	Predator/prey interactions between the oystercatcher, *Haematopus ostralegus*, and its prey, particularly the mussel, *Mytilus edulis*, on the Exe estuary and adjacent coastal areas	J D Goss-Custard
T08057b2	Winter feeding ecology of juvenile oystercatchers on the Exe estuary	J D Goss-Custard
T08057c2	Habitat contraction, breeding density and reproductive output in waders, a feasibility study	J D Goss-Custard
T08057d1	Wash birds and invertebrates	J D Goss-Custard
T08057e1	Predicting post-barrage densities of invertebrates and shorebirds birds	J D Goss-Custard
T08057f1	Cardiff Bay barrage feasibility study: Rhymney alternative feeding grounds	C J Reading

T08058–5	**Resident vertebrate ecology**	***R E Kenward***
T08058a2	Grey squirrel damage and management	R E Kenward
T08058b1	Goshawk population dynamics	R E Kenward
T08058c2	Foraging and reserve storage in red and grey squirrels	R E Kenward
T08058d1	Raptor ecology of Kluane Valley	R E Kenward
T08058e2	Breeding success and survival in the common toad	C J Reading
T08058f2	Ecology and population dynamics of the grass-snake (*Natrix natrix helvetica*)	C J Reading

T08059–5	**Plant genecology**	***A J Gray***
T08059a2	Iso-enzyme studies in *Sphagnum*	R E Daniels
T08059b2	*Spartina* population ecology	A J Gray
T08059c5	Genetic variation in *Phragmites australis*	R E Daniels
T08059d2	Nitrogen economy of *Drosera* species	R E Daniels
T08059e1	*Spartina* niche model marginal vegetation in a post-barrage environment	A J Gray
T08059f1	Poole Bridge environmental enhancement	A J Gray
T08059g1	Poole Bridge replacement environmental impact assessment	N R Webb
T08059h5	Culture and supply of reed plants	R E Daniels
T08059i2	Population biology in peatland angiosperms	R E Daniels

T08060–5	**Butterfly and ant studies**	***J A Thomas/ G W Elmes***
T08060a5	The conservation of the large blue butterfly	J A Thomas
T08060b1	The ecology of woodland fritillary butterflies	J A Thomas
T08060c2	Social biology of *Myrmica* species	G W Elmes
T08060d2	Large blue butterfly/*Myrmica* ant interactions	G W Elmes/ J A Thomas
T08060e2	Population ecology and adaptive speciation of *Myrmica*	G W Elmes

Programme 9 Community ecology

T09055–5	**Heathland impacts**	***N R Webb***
T09055a1	Wytch farm development biological monitoring	R E Daniels
T09055b1	Purbeck–Southampton pipeline biological monitoring	R E Daniels
T09055c1	Hinkley Point public enquiry	R E Daniels
T09055d1	Rehabilitation of oil well sites	R E Daniels
T09055e2	Heathland invertebrates	N R Webb
T09055f1	Restoration of heathland	N R Webb
T09055g1	Restoration experiments for New Forest gas pipeline	N R Webb
T09055h2	Dorset heathland survey	N R Webb
T09055m1	Survey at Sandford Heath	N R Webb

T09056–5	**Grassland and scrub dynamics**	***M G Morris***
T09056a2	Grassland management – invertebrates	M G Morris
T09056b2	Study of scrub succession on chalk at Aston Rowant NNR	L K Ward
T09056c2	Rotational management of scrub at Castor Hanglands NNR	L K Ward
T09056d5	Demography and conservation of scrub	L K Ward
T09056f2	Weevil studies	M G Morris
T09056g5	National survey of natural ecosystems in Korea (proposal)	M G Morris
T09056h2	Invertebrate geographical ranges and climate	L K Ward

T09057–5	**Heathland vegetation dynamics**	***S B Chapman***
T09057a2	Nutrient cycles in lowland heath	S B Chapman
T09057b2	Autecology of the marsh gentian	S B Chapman

Programme 13 Scientific services

T13060e2	Statistical and computing services at Furzebrook	R T Clarke
T13060f2	Statistical and computing services for the River Laboratory	R T Clarke
T13060g2	Statistical research	R T Clarke

T13061–1	**ITE South consultancies**	***T M Roberts***
T13061b1	Small consultancies at ITE Furzebrook	M G Morris

ITE (S) BANGOR RESEARCH STATION

Programme 2 Land use, agriculture and the environment

T02060–5	**Biogeochemistry and land use**	***J E G Good***
T02060a1	Nature conservation in upland conifer forests	J E G Good
T02060b2	Clonal selection in *Betula* and *Salix*	J E G Good
T02060c1	Ecological survey of Capel Cynon	G L Radford

T02060d2	Geochemical cycling in the uplands	B Reynolds
T02060f2	Effects of clearfelling plantation forests – extension	P A Stevens
T02060g1	Cwm Dyli pipeline consultancy	J E G Good
T02060h5	The role of mires as sinks for N, P and S	B Emmett

Programme 7 Environmental pollution

T07062c5	Remote sensing of Eskdale and Dunnerdale	K R Bull/ B K Wyatt
T07064–5	**Ecosystems' response to pollution**	**K C Walton**
T07064a5	Pollution study of Wales	T W Ashenden
T07064b1	Effects of nitrogen dioxide on bryophytes and ferns	T W Ashenden
T07064c2	Effects of acid mist on arctic-alpine plant species	T W Ashenden
T07064d2	Trace metals in terrestrial ecosystems	K C Walton
T07064f2	Trace metals in rabbit bones from England and Wales, 1971–72	K C Walton
T07064g2	Engineering development (mechanical and electronic)	C R Rafarel
T07064h2	Development and maintenance of site of Bangor glasshouse unit	T W Ashenden
T07064i2	Fluorine pollution studies	D F Perkins
T07064j2	Radiocaesium in the Snowdonia sheepwalk ecosystem	D F Perkins
T07064k2	Radiocaesium cycling in *Nardus stricta*	D F Perkins

Programme 9 Community ecology

T09054–2	**Montane ecology**	***C Milner***
T09054b2	Ecology of arctic-alpine plant species in Snowdonia	C Milner

Programme 13 Scientific services

T13061–1	**ITE South consultancies**	***T M Roberts***
T13061c1	Small consultancies at ITE Bangor	C Milner

ITE (N) EDINBURGH RESEARCH STATION

Programme 1 Forest science

T01057–5	**Temperate tree biology**	***A D Watt/ M G R Cannell***
T01057a2	Evaluation of conifer clones and progenies	M G R Cannell
T01057b2	Evaluation of red alder	L J Sheppard
T01057c1	Genetic improvement of tea	M G R Cannell
T01057d2	Frost hardiness of *Nothofagus procera*	J D Deans
T01057e1	Agroforestry experimental assessment of novel biomass systems	G J Lawson
T01057f2	Assimilate partitioning in branches	M G R Cannell
T01057g2	Light use efficiency of trees	M G R Cannell
T01057h2	Cones and tree carbon balance	J McP Dick
T01057i2	Silviculture of re-spacing Sitka spruce	J D Deans
T01057j2	Mechanics of windthrow	R Milne
T01057k5	Tree stability interactions among trees	R Milne
T01057l5	BES special symposium ecology of mixed species stands of trees	M G R Cannell
T01057m2	The population ecology of the pine beauty moth	A D Watt
T01057n2	The population ecology of the winter moth in Sitka spruce plantations	A D Watt
T01057o2	Population dynamics of forest insects conference	A D Watt
T01059–5	**Mycorrhizas and tree production**	***J Wilson***
T01059a2	Mycorrhizas and tree growth	P A Mason
T01059b2	Characterisation of sheathing mycorrhizas	P A Mason
T01059c2	Occurrence of fruitbodies of mycorrhizal fungi in field plantings of different provenances of *Picea sitchensis* and *Pinus contorta*	J Wilson
T01059d1	Mycorrhizal research links with India	J Wilson
T01059e1	Large-scale production of mycorrhizal inocula (proposal)	J Wilson
T01059f2	Influence of mycorrhizas on root growth potential	P A Mason
T01060–5	**Tropical forestry and tree improvement**	***R R B Leakey***
T01060a2	Domestication of tropical hardwoods	R R B Leakey
T01060b1	Seed production and tree improvement in Cameroon	R R B Leakey
T01060c1	World Bank forestry – EFG and ONAREF	R R B Leakey/ K A Longman
T01060d1	Vegetation propagation of *Eucalyptus grandis*	R R B Leakey
T01060e1	Propagation of *Lovoa trichilioides* in Cameroon	R R B Leakey
T01060f1	Consultancy for CATIE, Costa Rica (proposal)	R R B Leakey
T01060g1	Agroforestry and mycorrhizas in E Africa	R R B Leakey
T01060h1	Comparative ecology of endomycorrhizas and nutrient cycling in indigenous species plantations in Cameroon	R R B Leakey/ P A Mason
T01060i1	UNESCO MAB contracts	O W Heal

Programme 2 Land use, agriculture and the environment

T02051f1	Environmental constraints on the UK wind energy resource	B G Bell
T02051h2	Long-term environmental reference sites	O W Heal
T02051i2	Data base of research sites	M A Booth/ P A Ward

Programme 7 Environmental pollution

T07055–3	**The effects of atmospheric pollutants on forests and crops (special topic programme)**	***B G Bell***
T07055l3	Exchange of NO_x and other gases before and after exposure to wind, ozone and polluted cloud water	D Fowler/ J Grace
T07056–5	**Ecological effects of climatic change**	***M G R Cannell***
T07056a1	Impact of the mild winter 1988–89 a review for DOE	M G R Cannell
T07056b2	The occurrence of extreme winds	R Milne
T07056d2	Response of trees to elevated CO_2 concentrations and temperature	D Eamus
T07056e2	Relationship between tree growth and temperature analyses of tree-ring	R Milne
T07057–5	**Atmospheric pollutants and trace gases**	***D Fowler***
T07057a1	Land/atmosphere exchange of NO_x, O_3 and NH_3 (dry deposition)	D Fowler
T07057b1	Variation of acidic deposition with altitude	D Fowler
T07057c1	Rural O_3, N_o and NO_x concentrations	D Fowler
T07057d2	Land/atmosphere exchange of methane (proposal)	D Fowler
T07057e5	Land/atmosphere exchange of ammonia (proposal)	M Sutton
T07057f1	Cloud deposition (proposal)	D Fowler
T07057g5	Pollution climate at Dunslair (proposal)	A Crossley
T07057h5	Deposition of lead-210	R Mourne
T07057i1	N deposition effects on plant communities (proposal)	C Pitcairn
T07058–5	**Atmospheric pollution modelling and chemistry**	***J N Cape***
T07058a2	The chemical composition of rainfall	J N Cape
T07058b5	Scavenging of pollutants by snow (proposal)	T Dore
T07058c1	Nitrogen chemistry on Great Dun Fell (proposal)	D Fowler
T07058d1	Physical properties in open-top chambers (proposal)	D Fowler
T07058e2	Modelling UK deposition (RGAR and GDF) (proposal)	J N Cape
T07059-5	**Effects of atmospheric pollutants on trees**	***D Fowler/ J N Cape***
T07059a5	Frost hardiness of red spruce in relation to forest decline and effects on red spruce of winter exposure to SO_2 and NO_2	M G R Cannell
T07059b1	Open-top chamber studies on spruce and beech (proposal)	D Fowler
T07059c2	Responses of conifer trees to artificial acid mist	C G M Henderson
T07059d5	Wind and cloud effects on Norway spruce (proposal)	D Fowler

T07059e2	Effects of acid mist on mature trees	A Crossley
T07059f5	Accumulation and effects of atmospheric particulates on forests	A Crossley
T07059g5	Early diagnosis of forest decline	J N Cape
T07059h1	Throughfall, stemflow and 35S experiment	J N Cape

Programme 12 Atmospheric science and hydrological extremes

T12056–3	**Atmospheric chemistry (special topic programme)**	***J N Cape***
T12056a3	Atmospheric chemistry Phase 1 (special topic programme)	J N Cape
T12056f3	Atmospheric chemistry Phase II	J N Cape
T12056m3	The surface/atmosphere exchange of gaseous ammonia (Phase 2)	J Moncrieff

Programme 13 Scientific services

T13054a2	Utilisation of STATUS in ITE libraries cataloguing	S M Adair

T13059–5	**Edinburgh scientific support services**	***M G R Cannell***
T13059a2	Glasshouses and nursery support and development	R F Ottley
T13059b1	Plant culture for Inveresk Research International – winter wheat II	R F Ottley
T13059c1	Glasshouse consultancy to IRI (proposal)	R F Ottley
T13059d1	Apple culture for IRI	R F Ottley
T13059e5	Controlled environmental facilities at ITE Edinburgh	R Milne
T13059f2	Operation of the Rivox field site	R Milne
T13059g2	Biometrics research and consultancy at ITE Edinburgh	R I Smith
T13059h2	Graphics, photography and scientific illustrations (proposal)	R H F Wilson
T13059i1	Plant culture for IRI – potatoes II	R F Ottley
T13059j1	Plant culture for IRI – onions	R F Ottley

ITE (N) MERLEWOOD RESEARCH STATION

Programme 1 Forest science

T01051–2	**Ecology of woodland soil fungi**	***J Dighton***
T01051a2	Role of fungi in nutrient cycling with special reference to *Mycena galopus* in forest soil	J C Frankland
T01051b2	An assessment of the status of mycorrhizas in the soil ecosystem	J Dighton
T01051c2	Faunal/microbial interactions related to nutrient cycling and agricultural stocking of the uplands	J C Frankland

T01052–5	**Soil nutrient dynamics**	***A F Harrison***
T01052a5	A comparison of biological and chemical assessments of the fertility of soils	A F Harrison
T01052b2	Cycling of key nutrients in forest soils and their inter-relationships	A F Harrison
T01052c5	Field methods in terrestrial nutrient cycling studies (proposal)	A F Harrison
T01052d1	Effects of vitamin addition on nutrient mineralisation	J Dighton
T01052e5	Assessment of P & K fertiliser responses of Sitka spruce (proposal)	A F Harrison
T01052f5	Assessment of P–deficiency in Sitka spruce, Pen-y-bont, Wales (proposal)	A F Harrison
T01052g1	Application of nutrient bioassays to *Eucalyptus* forest management	J Dighton
T01052h1	Investigation of nutrient deficiency of citrus plantations in Cheju, Korea (proposal)	J Dighton

T01053–5	**Forest nutrient dynamics**	***P Ineson***
T01053a2	A comparison of denitrification in felled and unfelled plots of Sitka spruce	P Ineson
T01053b5	Nutrient cycling in European forests (proposal)	P Ineson
T01053c2	Biological manipulation of coniferous forest soils	C H Robinson
T01053d5	Rehabilitation of *Acacia* fallow systems and nutrient dynamics in the Blue Nile region, eastern Sudan	D K Lindley
T01053e5	The scientific management of renewable natural resources in China	D K Lindley
T01053f1	Effect of forest management on soil (proposal)	M Hornung

T01054–2	**Ecological effects of forest management**	***J M Sykes/ A H F Brown***
T01054a2	Effects of pure and mixed stands on soils and vegetation	A H F Brown
T01054b2	The effects of management in lowland coppices	A H F Brown
T01054d2	Soil and water acidity under different trees	A H F Brown
T01054e2	Effects of clearfelling in pure and mixed stands on soil water chemistry (proposal)	S M C Robertson
T01054f2	Effects of afforestation on fauna and flora	J M Sykes
T01054g2	Long-term dynamics of semi-natural forest ecosystems	J M Sykes
T01054h2	Floristics of secondary woodlands and their manipulation (proposal)	J M Sykes
T01054i2	Rehabilitation of riparian zones in coniferous forests (proposal)	J K Adamson

Programme 2 Land use, agriculture and the environment

T02051–5	**Land use change and ecological impacts**	***R G H Bunce***
T02051a2	An ecological survey of Britain	R G H Bunce
T02051b1	The environmental and socio-economic effects of the CAP	M Bell
T02051c1	Countryside implications of changes in CAP	R G H Bunce
T02051d1	Environmental issues, agriculture and forestry land use options in Devon	R G H Bunce
T02051e1	Ecological consequences of land use change	R G H Bunce
T02051g1	Mapping heather in England and Wales (proposal)	R G H Bunce
T02051i2	Data base of research sites	M A Booth/ P A Ward

T02060e5	Review of catchment work in the COST countries (proposal)	M Hornung

T02061h3	The future environmental implications of a possibly less intensive agricultural industry in England and Wales	R G H Bunce

T02064–5	**Environmental impact assessment – ITE(N) Merlewood**	***J M Sykes***
T02064a1	Botanical survey – British Gas Barrow onshore terminal (proposal)	J M Sykes

Programme 7 Environmental pollution

T07050–5	**Radionuclides in vegetation and soil**	***A D Horrill***
T07050a1	The distribution and dynamics of radionuclides in relation to land use in west Cumbria	A D Horrill
T07050b2	The concentrations and movement of americium in a coastal ecosystem in Cumbria	A D Horrill
T07050c1	Post-Chernobyl radiation levels in soils and vegetation	G R Miller/ A D Horrill
T07050d1	Radioactivity and wildlife a desk study	A D Horrill/ V H Kennedy
T07050e1	Evaluation of data on the transfer of radionuclides in the foodchain (proposal)	A D Horrill
T07050f1	The influence of mycorrhizas, potassium nutrition and microbial activity on radiocaesium cycling in heather-dominated ecosystems	A F Harrison
T07050g2	Selenium inputs, distribution and cycling in upland grassland ecosystems (proposal)	A F Harrison

T07051–5	**Radionuclide/animal transfers**	***B J Howard***
T07051a1	Sheep feeding trials	B J Howard
T07051b1	Recycling of radiocaesium	B J Howard
T07051c2	Comparative radioecology of Ag–110m and Cs–137	N A Beresford
T07051d1	The dynamics of radionuclide uptake by sheep	B J Howard

T07052–5	**Geochemistry of radionuclides**	***F R Livens***
T07052a5	Relationships between soil organic matter and the actinide elements (actinides in soil organic matter)	F R Livens
T07052b2	Terrestrial geochemistry of transuranic elements	A S HurstHouse
T07052c1	Radionuclides in freshwater systems	F R Livens
T07052d2	Radiochemical development	F R Livens
T07053–5	**Soil microbial response to pollutants**	***P Ineson***
T07053a1	Effects of forest fumigation with SO_2 and O_3 on roots and mycorrhizas of trees	J Dighton
T07053b1	Effects of air pollution (proposal)	P Ineson
T07053c2	Effects of atmospheric pollution on mycorrhizas (proposal)	J Dighton
T07053d2	Effects of sulphur dioxide on litter-decomposing fungi in deciduous woodland	J C Frankland/ P Ineson
T07053e5	Liming and faunal inoculation of forest soils protection from acidification (proposal)	P Ineson
T07054–5	**Acid deposition and its effects**	***M Hornung***
T07054a1	Acidification of waters in Wales	M Hornung
T07054c1	Subcontract to Aberdeen University	M Hornung/ M Cresser
T07054d1	Subcontract to Lancaster University	M Hornung/ T A Mansfield
T07054e1	Subcontract to Nottingham University	M Hornung/ J Colls
T07054f5	Solutes beneath larch and Sitka spruce at three sites (proposal)	J K Adamson
T07055h3	Effects of elevated inputs of nitrogen on the uptake metabolism, retention and allocation of nitrogen in tree crops	G R Stewart/ A F Harrison
T07055k3	Interaction of enhanced N loading on soil nutrient dynamics and forest growth	M Hornung
T07056f2	Phenology in the spring of 1989 (proposal)	J M Sykes
T07056g2	Modelling the impact of climatic change on the productivity, species composition, and decomposition in a UK mixed deciduous forest (proposal)	P Ineson/ A F Harrison
T07056h2	Evaluating the response of upland organic soils to CO_2-induced climatic change (proposal)	P Ineson
T07056i2	Evaluating the response of soils to increases in the CO_2 content of the atmosphere (proposal)	P Ineson
T07056j2	Determination of the impact of CO_2-induced climatic change on forest decomposition processes (proposal)	P Ineson
T07066–3	**Environmental radioactivity (special topic programme)**	***V H Kennedy***
T07066b3	Uptake of radiocaesium by plants and the role of mycorrhizal fungi in mediating uptake	J Dighton
T07066c3	Effects of sward conditions on radiocaesium cycling in hill and upland sheep systems	R Mayes/ B J Howard
T07066d3	Dynamic modelling of pathways for radionuclides from the atmosphere to grazing animals	M H Unsworth/ B J Howard
T07066g3	Migration and retention of radionuclides in soils	A G O Donnell/ D Rimmer/ P Ineson

Programme 8 Population ecology

T08050g2	Population genetics of mute swans	P J Bacon
T08052–5	**Plant strategies: response to environmental stress**	***T V Callaghan***
T08052a2	Plant responses to environmental stress at high latitudes	T V Callaghan
T08052b5	Strategies of growth and population dynamics of tundra plants related to climatic change	T V Callaghan

Programme 9 Community ecology

T09053b2	Farm woodland – primary and secondary effects of tree planting on soil (proposal)	J M Sykes
T09056g5	National survey of natural ecosystems in Korea (proposal)	M G Morris

Programme 10 Environmental microbiology

T10055g3	Modelling intra- and interspecific competition of ectomycorrhizal fungi on tree root systems	F Sanders/ J Dighton

Programme 13 Scientific services

T13054–2	**ITE library services**	***J Beckett***
T13055–5	**ITE chemical research and development**	***J A Parkinson***
T13055a2	Chemical support studies	J A Parkinson
T13055b5	Analyses for certification of EEC international tree leaf reference materials	J A Parkinson
T13055c1	Chemical analyses for Nature Conservancy Council i Orkney waters ii Speyside lochwater	J D Roberts
T13055d1	Chemical analyses for universities	J A Parkinson
T13055e5	Standardisation scheme for chemical analysis of plant material for TSBF programme (proposal)	A P Rowland
T13055f1	Chemical analyses for private organisations	J A Parkinson
T13056–4	**NERC mass spectrometer service**	***C Quarmby***
T13056a2	NERC mass spectrometer service	C Quarmby
T13057–5	**Merlewood scientific support services**	***D K Lindley***
T13057a2	Graphics and publications	C B Benefield
T13057b2	Biometrics and modelling support services at Merlewood	D K Lindley
T13057c1	ITE advice and services to NCC	J M Sykes

ITE (N) BANCHORY RESEARCH STATION

Programme 2 Land use, agriculture and the environment

T02050–5	**Human impact, erosion rehabilitation**	***A Watson***
T02050a1	Human impact in the Cairngorms	A Watson
T02050b1	Revegetation after disturbance	J Miles
T02050c2	Ecological impact of downhill skiing developments in north-east Scotland	G R Miller
T02050d1	Aonach Moor development plan	N G Bayfield
T02050e1	Footpath rehabilitation studies for the Yorkshire Dales National Park Committee	N G Bayfield
T02050f2	Soil erosion on north-east Scottish farmland	A Watson
T02050g1	Effects of past management on the potential of upland soils to support plant growth (proposal)	G R Miller
T02050h1	Restoration of upland vegetation	N G Bayfield
T02050i1	Path revegetation trials on the Pennine Way	N G Bayfield/ G R Miller
T02050l1	Environmental impact assessment of Intake 8 (proposal)	N G Bayfield
T02050m2	Manipulation of plant successions on disturbed ground (proposal)	N G Bayfield
T02050n1	Erosion control on the North/South Highway, Malaysia (proposal)	N G Bayfield

Programme 7 Environmental pollution

T07050c1	Post-Chernobyl radiation levels in soils and vegetation	G R Miller/ A D Hornll
T07056c5	Summer and autumn snow patches on Scottish mountains in relation to climate	A Watson

Programme 8 Population ecology

T08050–5	**Vertebrate population dynamics and upland habitat geometry**	***R Moss***
T08050a2	Population dynamics of red grouse	R Moss
T08050b5	Demographic effects of nest predation on golden plovers and other moorland waders	R A Parr

T08050c5	Population ecology of capercaillie	R Moss
T08050d1	Effects of afforestation on moorland birds and their predators	R A Parr
T08050e1	Park Hall grazing survey (proposal)	R Moss
T08050f5	Adaptation of capercaillie to novel environments (proposal)	R Moss

T08051–5	**Population ecology of predators**	***H Kruuk***
T08051a2	Herons and pollutants in aquatic ecosystems	M Marquiss
T08051b2	Occurrence of some heavy metals and PCBs in otters in Shetland	H Kruuk
T08051c5	The effects of environmental factors on populations of otters and fish in the north of Scotland	H Kruuk
T08051d5	Piscivorous birds in Scottish salmon rivers	M Marquiss
T08051e5	Ecology of the pine marten	D Balharry
T08051f5	Effect of water temperature on the behaviour and ecology of the European otter (*Lutra lutra*)	P S Taylor
T08051h5	Monitoring of seabird populations and performance in the North Sea	M P Harris
T08051i2	Feeding ecology and energetics of high- and low-latitude shags	M P Harris

Programme 9 Community ecology

T09050–5	**Dynamics of upland and montane plant communities**	***G R Miller***
T09050a2	Quantity and quality of seeds produced by montane plants	G R Miller
T09050b5	Effects of grazing on *Nardus* and *Calluna* moorland	D Welch
T09050c2	Development of subalpine scrub at northern Corries, Cairngorms SSSI	G R Miller
T09050d1	Response of *Gentiana nivalis* population to withdrawal of sheep grazing	G R Miller
T09050e1	Modelling the agricultural and environmental consequences of sheep and red deer grazing heather moorland (proposal)	B W Staines/ D Welch
T09050f2	Vegetation dynamics and soils	J Miles
T09050g2	The effects of birch on moorland soils and vegetation	J Miles
T09050h2	Early changes in soils under birch and heather	A J Ramsay
T09050i2	Dynamics of *Macchia* (proposal)	J Miles
T09050j5	Effects of sheep withdrawal on upland vegetation and wildlife (flora and fauna) and landscape	R Moss
T09050k2	Deer in production forests	B W Staines/ D Welch
T09050l2	Response of Sitka spruce to browsing and bark-stripping damage	D Welch/ B W Staines

Programme 13 Scientific services

T13053–5	**Services at ITE Banchory**	***B W Staines***
T13053a1	Ecological advisory appointment with SDD	J Miles
T13053b5	Caring for the high mountains – conservation of the Cairngorms	J W H Conroy
T13053c1	Brathens consultancies	B W Staines
T13053d2	Computing and statistical advice	D D French
T13053e1	Scottish Office consultancy	J Miles

Appendix 3 **Publications by ITE staff in 1988–89**

Ashenden, T W & Bell, S A. 1988 Growth responses of birch and Sitka spruce exposed to acidified rain *Environ Pollut*, **51,** 153-162

Ashenden, T W & Williams, J H. 1988 Differences in the spectral characteristic of birch canopies exposed to simulated acid rain *New Phytol*, **109,** 79-84

Bailey-Watts, A E. 1987 Fluctuations in the population density of Aphanizomeno in a small eutrophic lake (Coldingham Loch, Scotland) before and after de-stratification by aeration *Schweiz Z Hydrol*, **49,** 387-388

Bailey-Watts, A E. 1988 The abundance, size distribution and species composition of unicellular Centrales assemblages at mainly late winter-early spring maxima in Loch Leven (Kinross, Scotland) 1968-1985 *Proc 9th int Symp Living and Fossil Diatoms*, 1-16

Bailey-Watts, A E. 1988 Studies on the control of the early spring diatom maximum in Loch Leven 1981 In *Essays in phycology algae and the aquatic environment*, edited by F E Round, 53-87 Bristol Biopress

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Bell, M. 1988 Integration and evaluation of rural policy in a period of rapid change In *Rural information for forward planning*, edited by R G H Bunce & C J Barr, 33-39 (ITE symposium no 21) Grange-over-Sands Institute of Terrestrial Ecology

Bell, M. 1988 Methods for the identification of priorities in rural planning (Workshop report) In. *Rural information for forward planning*, edited by R G H Bunce & C J Barr, 108 (ITE symposium no 21) Grange-over-Sands Institute of Terrestrial Ecology

Boorman, L A. 1989 The influence of grazing on British sand dunes In *Perspectives in coastal dune management*, edited by F van der Meulen, P D Jongerius & J H Visser, 121-124 The Hague SPB Academic Publishing

Boyd, I L, Myhill, D G & (Mitchell-Jones, A J). 1988 Uptake of gamma-HCH (lindane) by pipistrelle bats and its effect on survival *Environ Pollut*, **51,** 95-111

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Brown, A H F & Howson, G. 1988 Changes in tensile strength loss of cotton strips with season and soil depths under 4 tree species In *Cotton strip assay an index of decomposition in soils*, edited by A F Harrison, P M Latter & D W H Walton, 86-89 (ITE symposium no 24) Grange-over-Sands Institute of Terrestrial Ecology

Brown, N J & Norris, D A. 1988 Early applications of geographical information systems at the Institute of Terrestrial Ecology *Int J geogr Inf Systems*, **2,** 153-160

Bull, K R. 1988 Classification models and water resource planning In *Rural information for forward planning*, edited by R G H Bunce & C J Barr, 82-84 (ITE symposium no 21) Grange-over-Sands Institute of Terrestrial Ecology

Bull, K R, Hall, J R & Bunce, R G H. 1988 The use of physical parameters for selecting representative samples of river catchments *J environ Manage*, **27,** 405-420

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