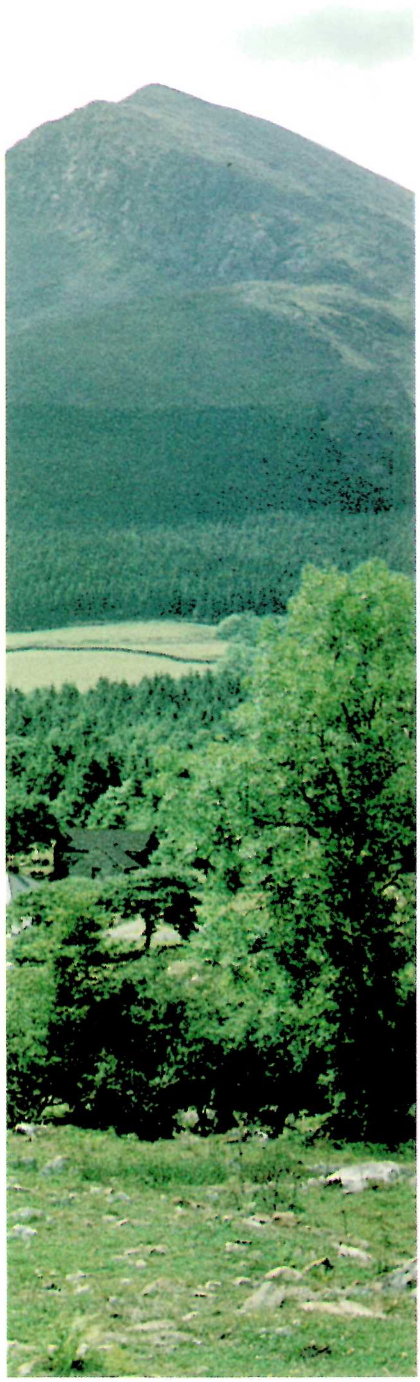
1988 – 1989

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

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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:

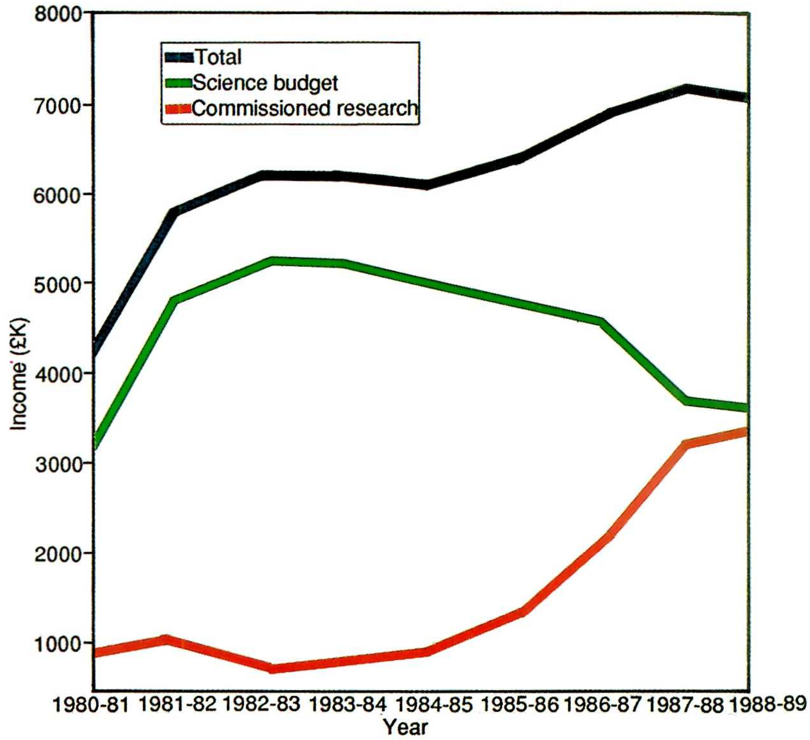
- increasing awareness of environmental issues – the 'green' movement
- increased demand for contract research
- re-organisation to meet the changing situation.

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.



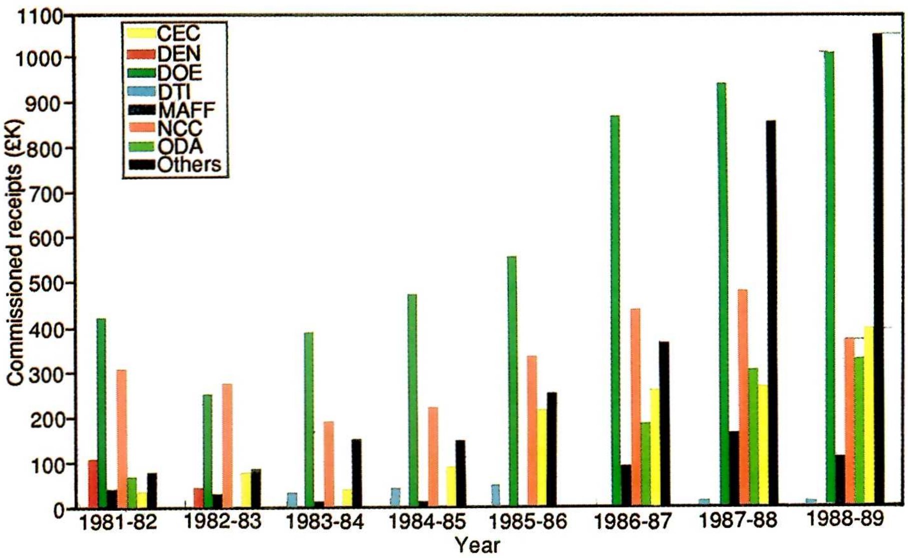
Demand for contract research

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 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.

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

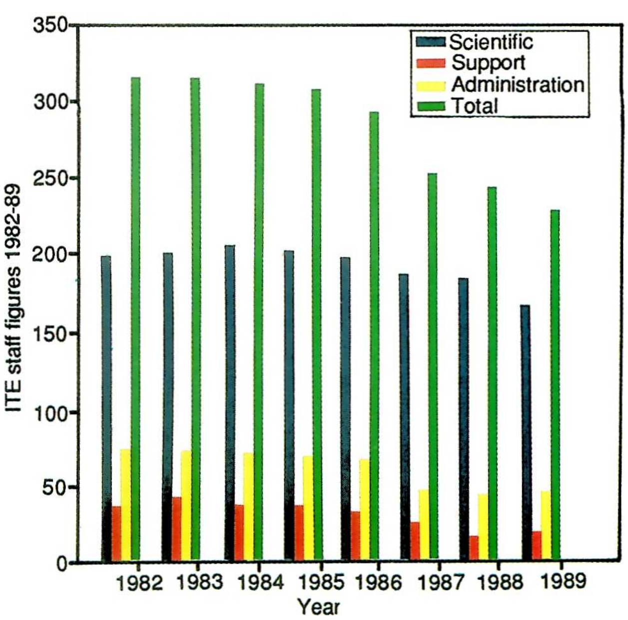
The re-organisation of the Institute into the Directorate of Terrestrial and Freshwater Sciences (TFS) in 1987 (along with the Institute of Hydrology, Institute of Virology, Freshwater Biological Association, and the Unit of Comparative Plant Ecology) and the subsequent restructuring of research work 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



Figures on the three graphs revalued to 1988-89 prices using GDP indices

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 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:

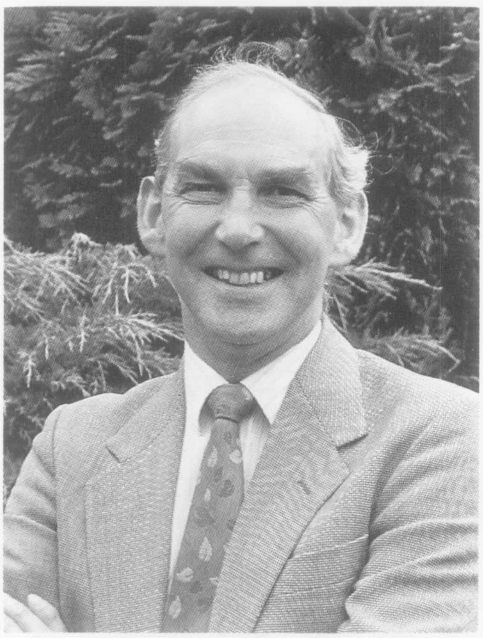
1. *Climatic change* and its effects are likely to be a central issue for some years to come. The subject is particularly relevant to ITE because of (i) its wide range of expertise, allowing integrated studies, (ii) its facilities, and (iii) its experience already developed in land/atmosphere interactions,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

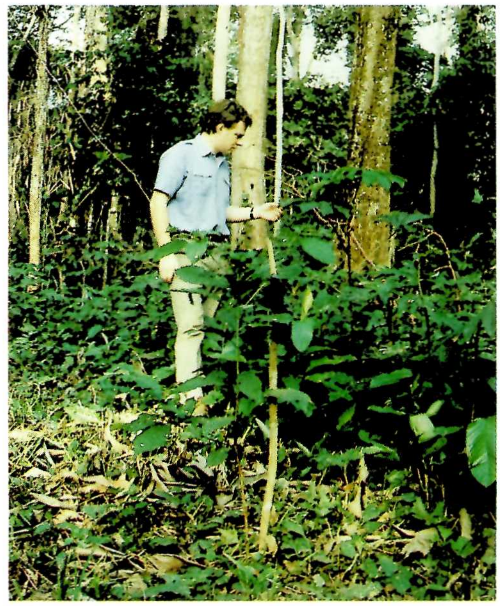


Plate 1. Assessing vegetation development on plots partially cleared by machine near Mbalmayo, Cameroon

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).

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.

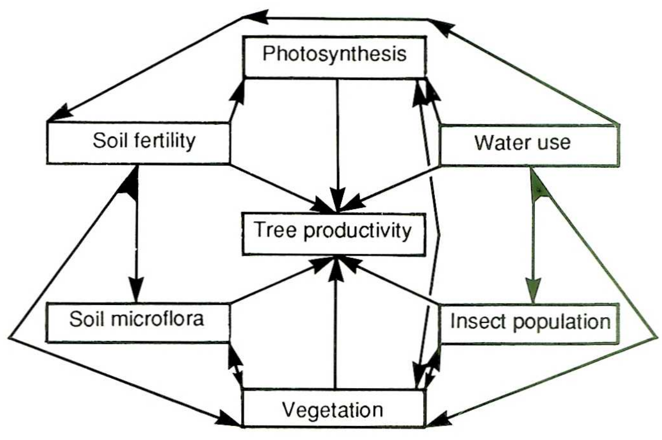


Figure 1. An ecosystem approach to the development of highly productive sustainable plantations of indigenous hardwoods in a moist deciduous forest in tropical Africa

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

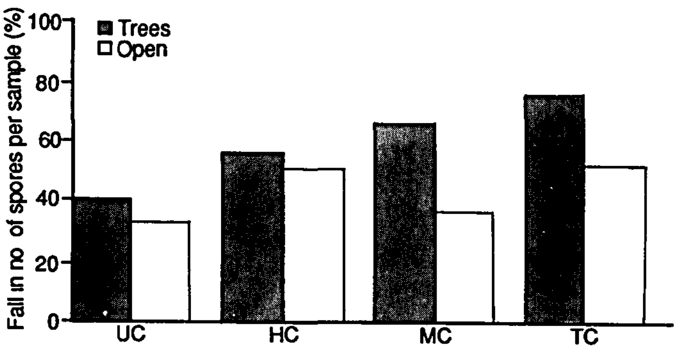


Figure 2 Effect of different methods of site preparation on the percentage reduction in numbers of mycorrhizal spores three months after site preparation. Samples were taken along transects between trees and in the open (UC = uncleared control, HC = clearance by hand, MC = partial clearance by machine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

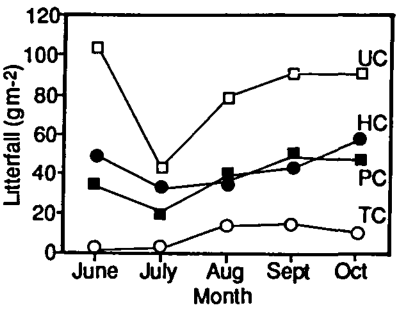


Figure 3 Seasonal variation (1988) in the mean total monthly litterfall in differently prepared planting sites (key as in Figure 2)

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 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

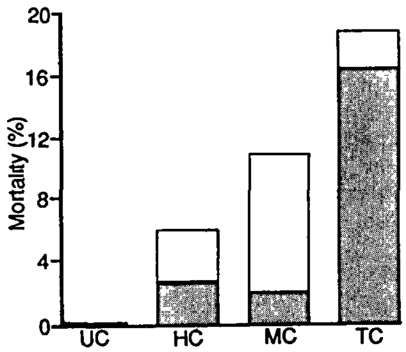


Figure 4 Tree mortality since planting recorded in February (shaded histogram) and July (unshaded) 1988 (key as in Figure 2)

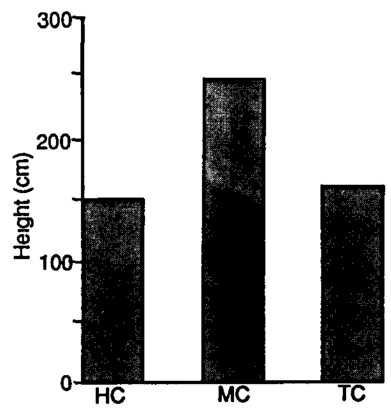


Figure 5 Effects of site preparation treatment on the height of planted *Terminalia ivorensis* trees one year after planting (key as in Figure 2)

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.

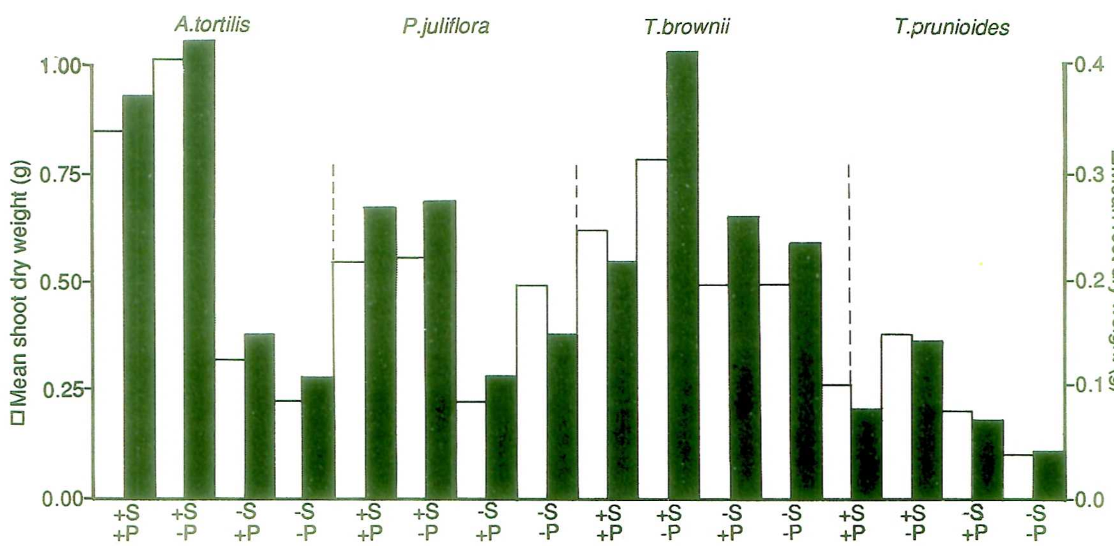


Figure 6. Mean shoot and root dry weights of plants with and without symbiont (+S,-S) and with and without polymer (+P, -P) at Olorgasailie and Marimanti at planting time

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

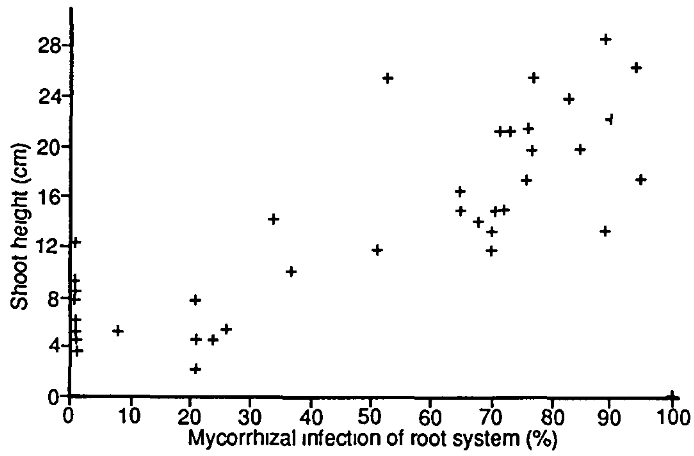


Figure 7 Growth of *Acacia tortilis* before planting at Marimanti relationship between shoot height and mycorrhizal infection (correlation significant at P<0 001)

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

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

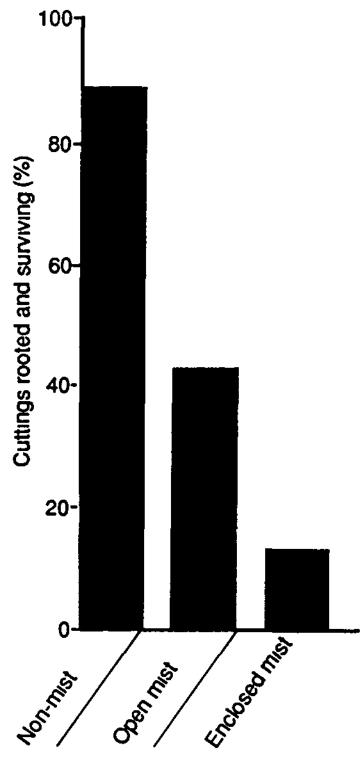


Figure 8 Vegetative propagation experiments effects of different environments on the rooting of *Prosopis juliflora* cuttings

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*

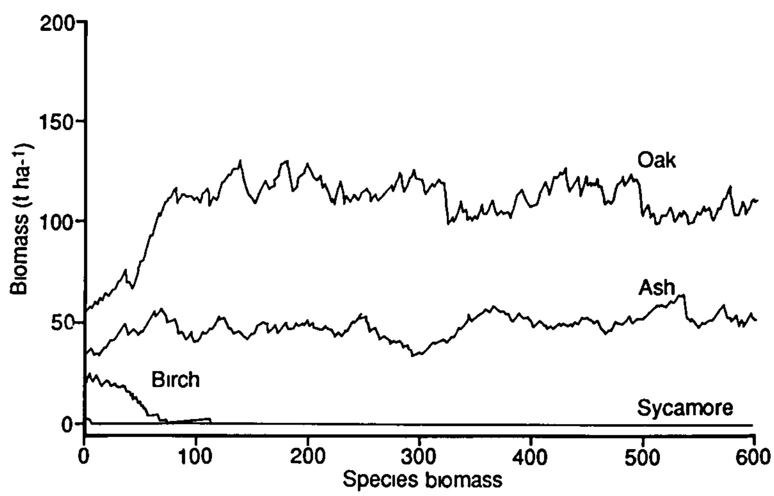

Figure 9 Biomass predictions of the main tree species in Meathop Wood over a 600 year period made by the FORET model

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		

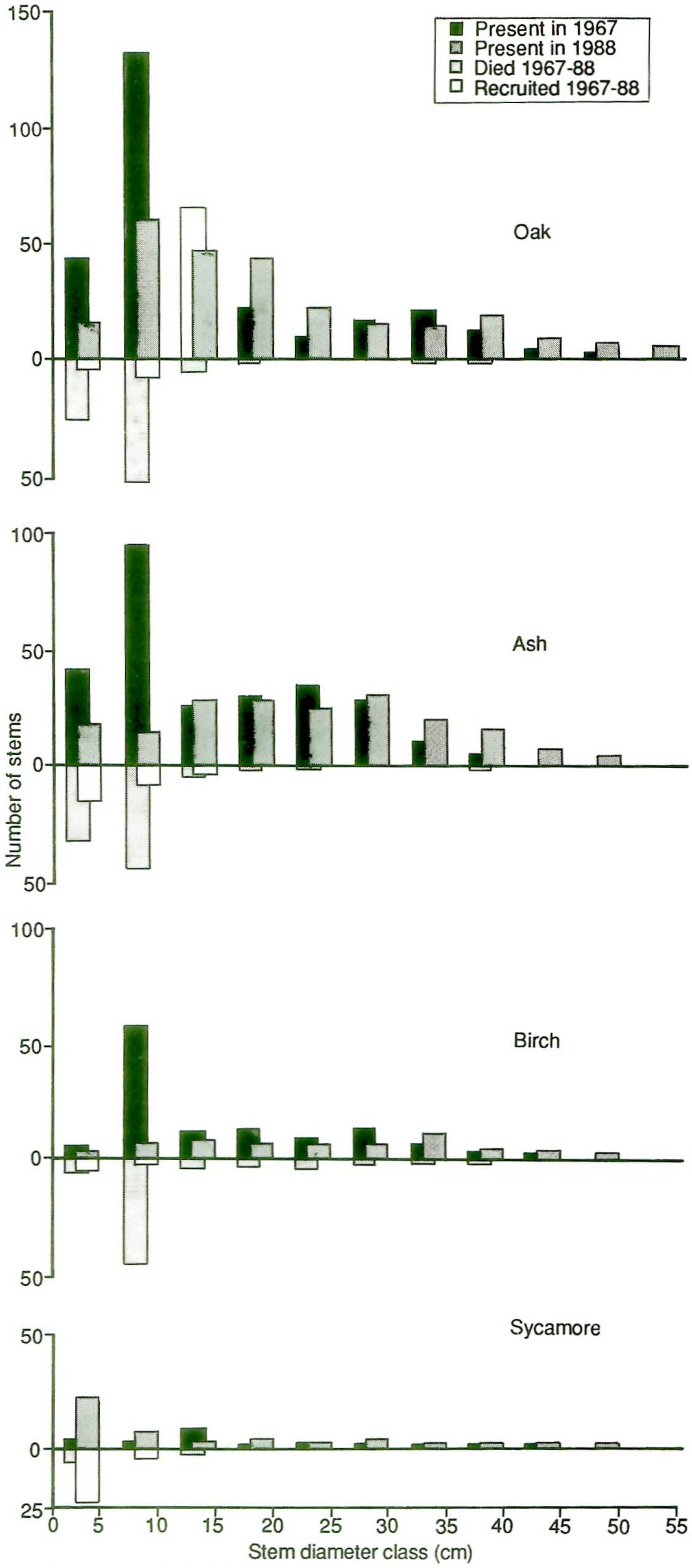

Figure 10. Frequency distributions of tree stem and diameter in Meathop Wood, measured in 1967 and 1988, and of stems dying and recruited

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 ıs clear that thıs sımulatıon accords reasonably wıth the facts, as far as bırch ıs concerned This pıoneer specıes ıs relatıvely short-lıved and, whılst ıt ıs able to regenerate followıng clearfellıng or heavy coppıcıng, as ın 1892 and 1939, the smaller gaps created naturally by the deaths of trees may be ınadequate to allow regeneratıon Predıctıons about the future role of sycamore seem more doubtful, although ıt ıs stıll only a mınor contrıbutor to the stand, ıts aggressıve nature ıs well known and ıt could be expected to play an ıncreasıng role ın the wood It ıs obvıous that some of the assumptıons made ın the model need to be re-examıned more crıtıcally, as do some of the parameter values used, for ınstance to control the growth rates of dıfferent specıes, to establısh whether and at what rate a specıes may regenerate from seed or by vegetatıve means, and to determıne the expected maxımum age of a specıes at the sıte Nevertheless, predıctıons whıch dıffer from known facts help to ıdentıfy areas where knowledge needs to be strengthened or ımproved

J M Sykes

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Biogeochemistry of afforestation in upland Wales

(Thıs work was partly supported by funds from the Department of the Envıronment and the Welsh Offıce)

Much of upland Wales ıs underlaın by slowly weatherıng bedrock of lower Palaeozoıc age, contaınıng small amounts of base catıons such as calcıum and magnesıum The soıls developed from these rocks are acıd, and contaın large quantıtıes of readıly exchangeable alumınıum Naturally, acıd peats and peaty topsoıls are wıdespread, resultıng from a combınatıon of hıgh raınfall and relatıvely low temperatures lımıtıng the decomposıtıon of organıc matter These upland areas are, therefore, naturally acıdıc and susceptıble to further acıdıfıcatıon by acıdıc deposıtıon and certaın land management practıces (Fıgure 11)

In the rural uplands of Wales, raınfall has a low solute content and ıs moderately acıdıc (pH c4 7) Sea-derıved sodıum, chlorıde and magnesıum are the major constıtuents, and concentratıons of non-sea sulphate and nıtrate are amongst the lowest ın the UK However, the hıgh annual raınfall leads to relatıvely hıgh rates of solute deposıtıon, especıally ın north Wales

Large-scale afforestatıon wıth exotıc conıfer specıes ın the UK has been concentrated, for the last 40 years, ın the uplands The streams and rıvers of these areas are ımportant as plentıful supplıes of pure water and as sports fısherıes Recently, much concern has been expressed over the possıble envıronmental effects of wıdespread conıfer afforestatıon on upland stream ecosystems In Wales, ITE has been studyıng these problems ın collaboratıon wıth the Instıtute of Hydrology, the Forestry Commıssıon and the Welsh Water Authorıty at three maın sıtes Beddgelert forest, Plynlımon and Llyn Brıanne (Fıgure 11) The research has focused on how afforestatıon has changed soıl and stream water chemıstry ın the uplands, and studıes of the processes controllıng nutrıent cyclıng have led to the development of forest management optıons to mınımıse effects on water qualıty

Interactions between the forest canopy and the atmosphere

The development of the forest canopy ın the moıst wındy uplands ıncreases the amount of water lost by evaporatıon (ınterceptıon loss), thus reducıng the amount of raınfall whıch reaches the ground At Plynlımon and Beddgelert, thıs loss amounts to approxımately 24% of the ıncomıng precıpıtatıon Any solutes contaıned wıthın the evaporated precıpıtatıon stay on the needles to be washed off by the remaınıng water as ıt passes to the ground as throughfall and stemflow

The tree canopy also acts as an effıcıent fılter of the atmosphere, capturıng aerosols, mıst and cloud droplets The latter usually contaın very hıgh concentratıons of solutes, representıng an ınput addıtıonal to the evaporatıve/ concentratıon effects already mentıoned Dry deposıtıon of gases on to and ınto leaves also occurs For nıtrogen gases, dry deposıtıon wıll be greater to the forest canopy, whereas sulphur dıoxıde deposıtıon wıll be sımılar for both forest and grassy vegetatıon (Fowler, Cape & Unsworth 1989)

The combıned effect of these processes ıs to ıncrease the concentratıon of most solutes reachıng the ground ın throughfall beneath, for example, Sıtka spruce *(Pıcea sıtchensıs)*, compared wıth the pre-exıstıng mat-grass/fescue (*Nardus/ Festuca*) vegetatıon or an open raıngauge (Table 3) Thıs comparıson ıs an oversımplıfıcatıon, however, as the age and specıes of tree wıll obvıously ınfluence the concentratıon of solutes ın throughfall (Table 3) Independent of deposıtıon, canopy leachıng of nutrıents, such as potassıum, whıch have been cycled by the vegetatıon, wıll further supplement solute concentratıons ın throughfall compared wıth an open raın collector

Soils and soil water chemistry

Afforestatıon has ıncreased the concentratıon of most ıons ın the soıl solutıon compared wıth soıls under grassland, wıth the largest ıncreases observed for alumınıum, sulphate, chlorıde and organıc anıons (Table 4) Ion exchange, drıven by the ıncreased anıon concentratıons, may be the proxımal source of alumınıum, although some ıncrease ın weatherıng must also

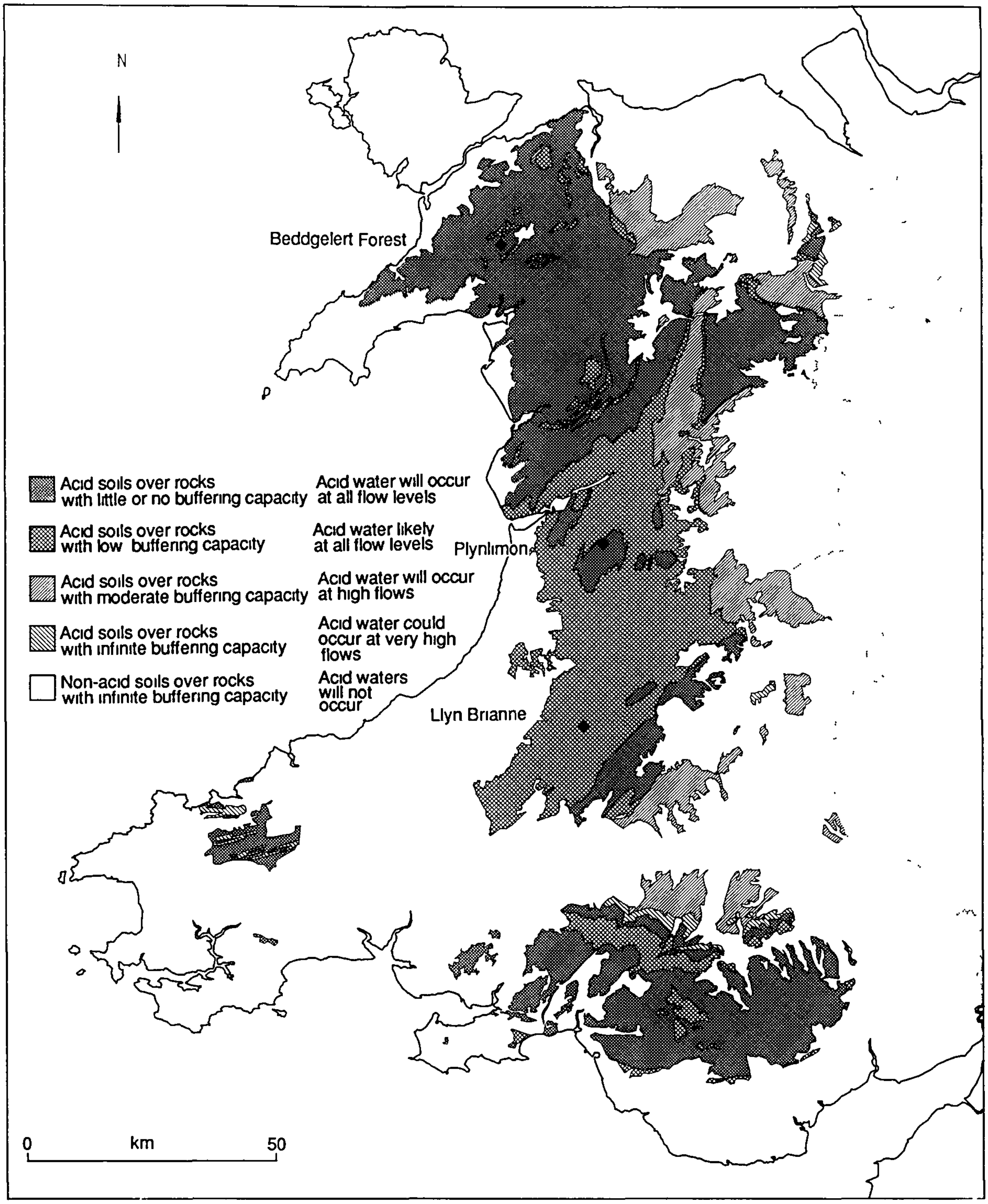

Figure 11 Location of ITE study sites in Wales shown in relation to the predicted occurrence of acid waters in Wales (Hornung *et al* 1989)

Table 3 Volume weighted mean solute concentrations ($\mu eq\ l^{-1}$, 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 (μeq 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

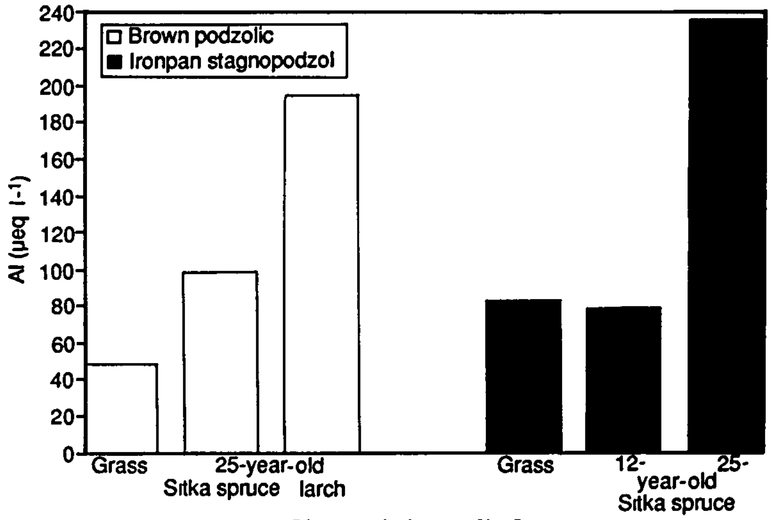

Figure 12. Aluminium concentrations in B-horizon soil solutions at Llyn Brianne

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).

Table 5 Mean stream water solute concentrations (μeq l^{-1}, except pH and Si = μmol 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

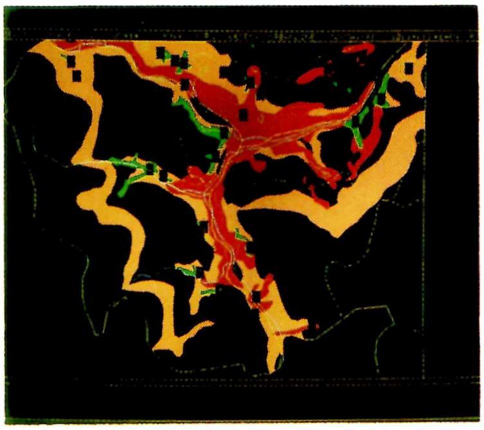

Plate 5 Use of a geographic information system for assessing land capability amber areas indicate sites in Calderdale with high potential for reforestation

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).

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

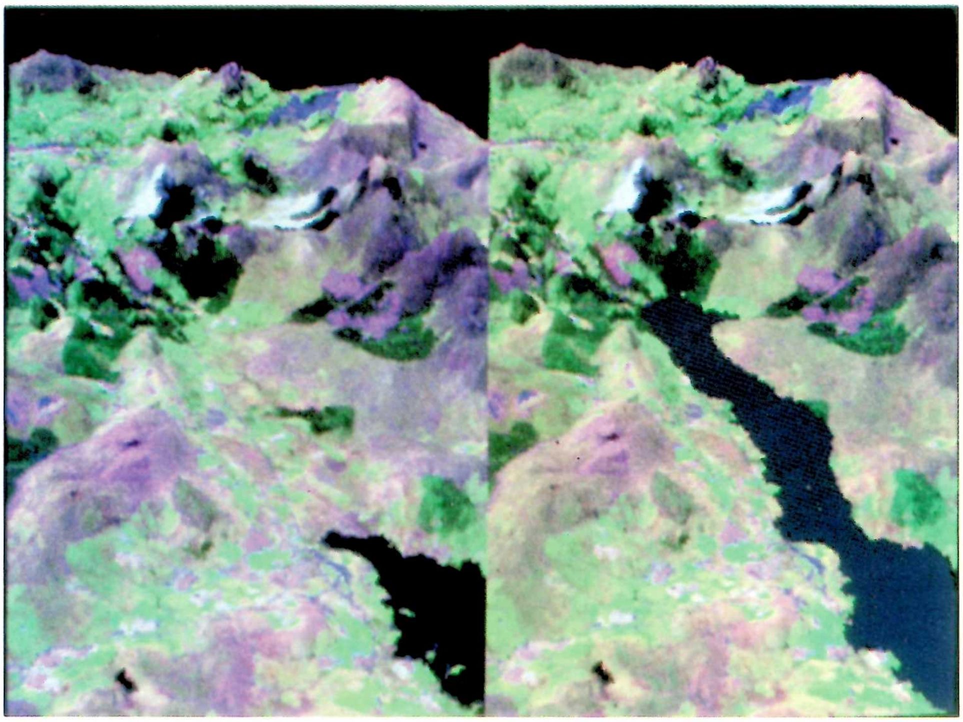

Plate 6. Simulation studies using remote sensing and digital elevation data: visualisation of landscape effects of reservoir development in Snowdonia

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

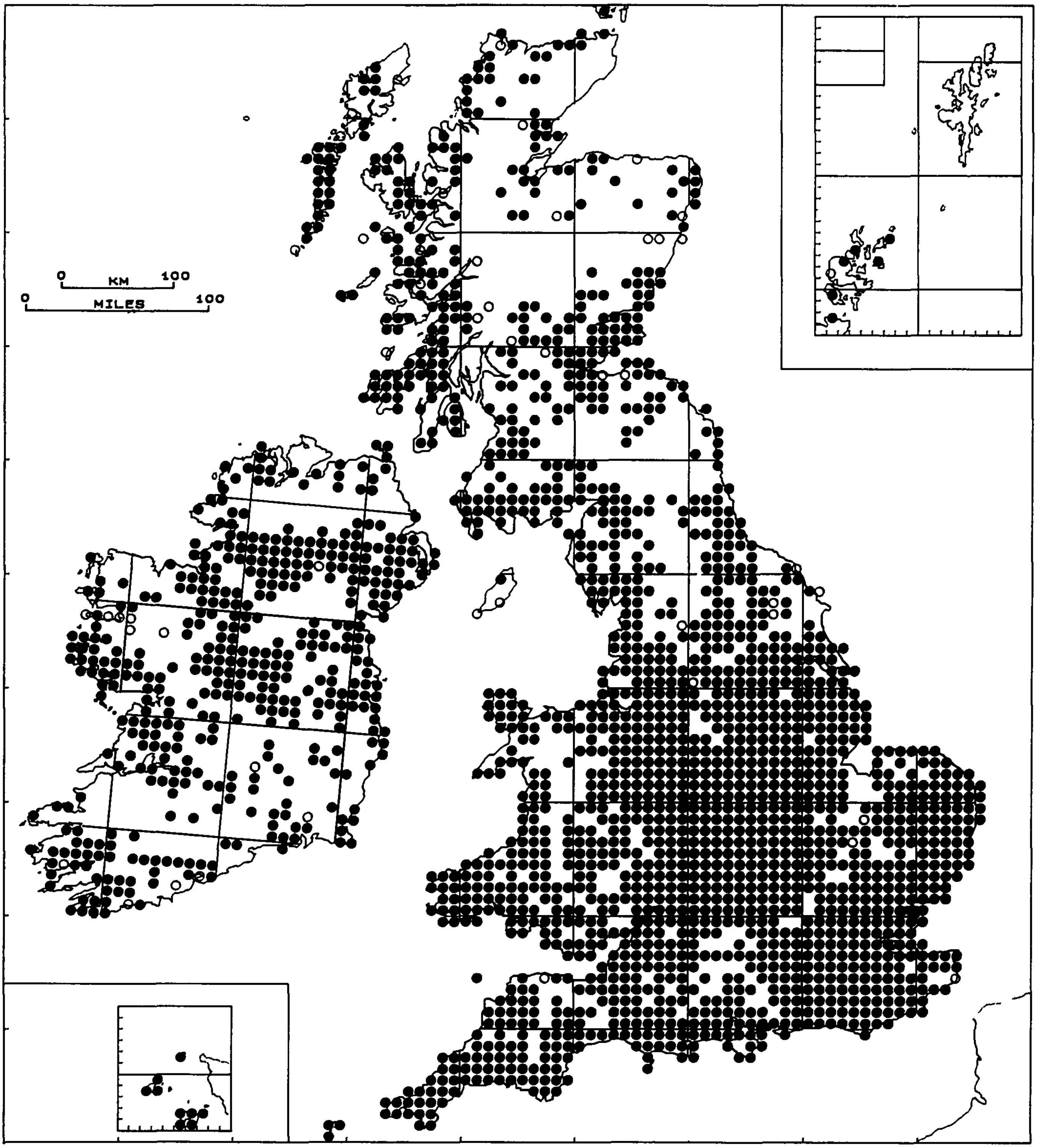

Figure 13 Distribution map of the blue tailed damselfly pictured in Plate 7

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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

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)

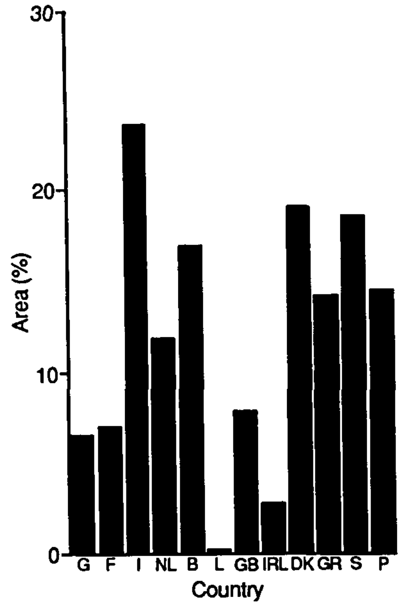

Figure 14 Percentage of the land surface of each European Community Member State covered by sites recorded in the CORINE biotopes project

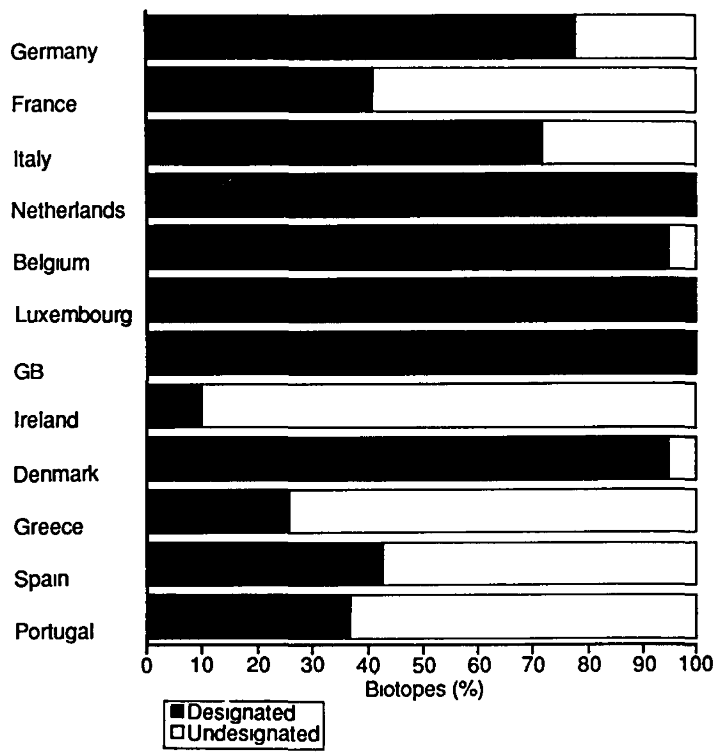

Figure 15 Percentage of CORINE biotopes in each Member State which have some form of statutory designation

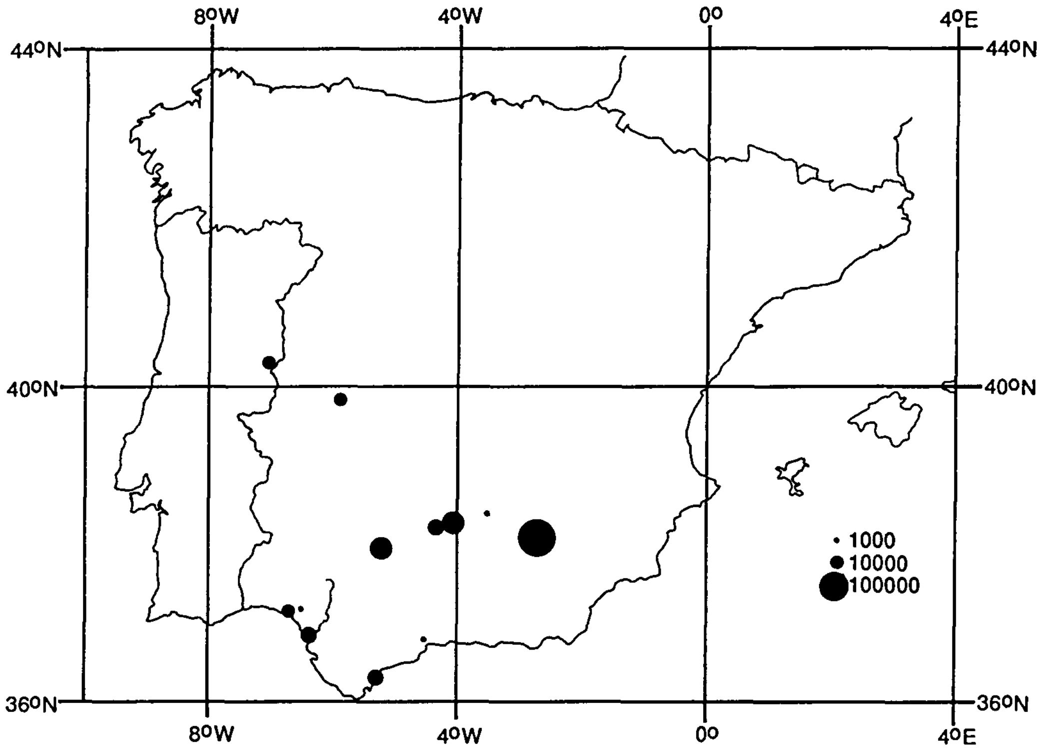

Figure 16 Biotopes where the Pardel lynx (*Lynx pardina*) an endangered species has been recorded. Areas of circles represent biotope areas in hectares as shown in the key

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)

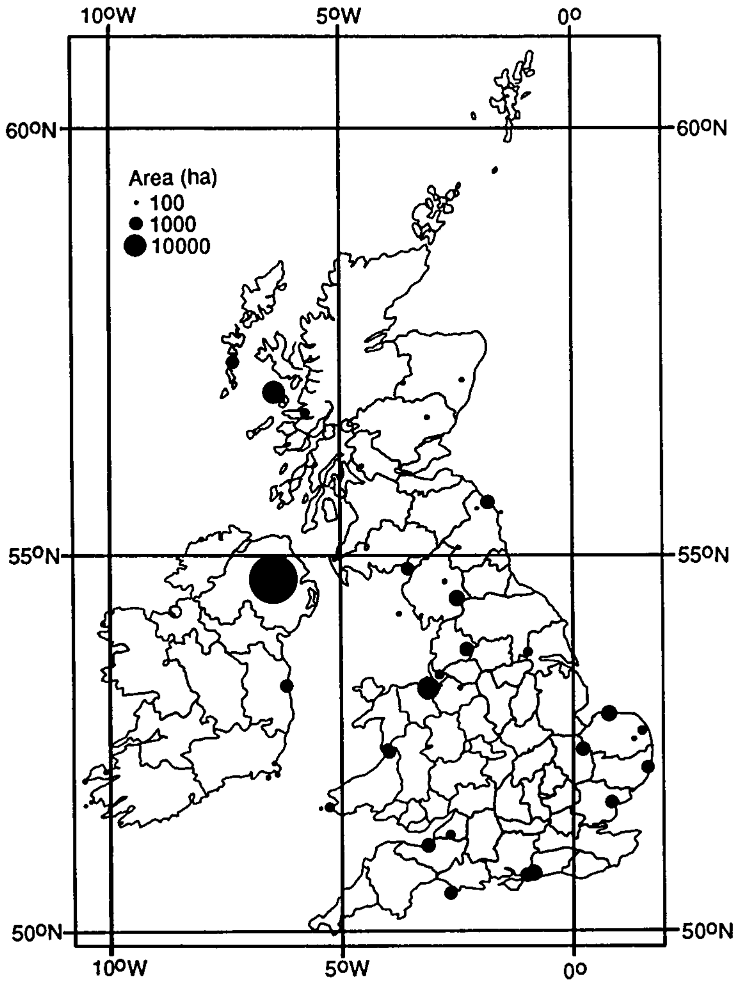

Figure 17 Location and extent of Special Protection Areas in Great Britain and Ireland under the European Community Bird Directive

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

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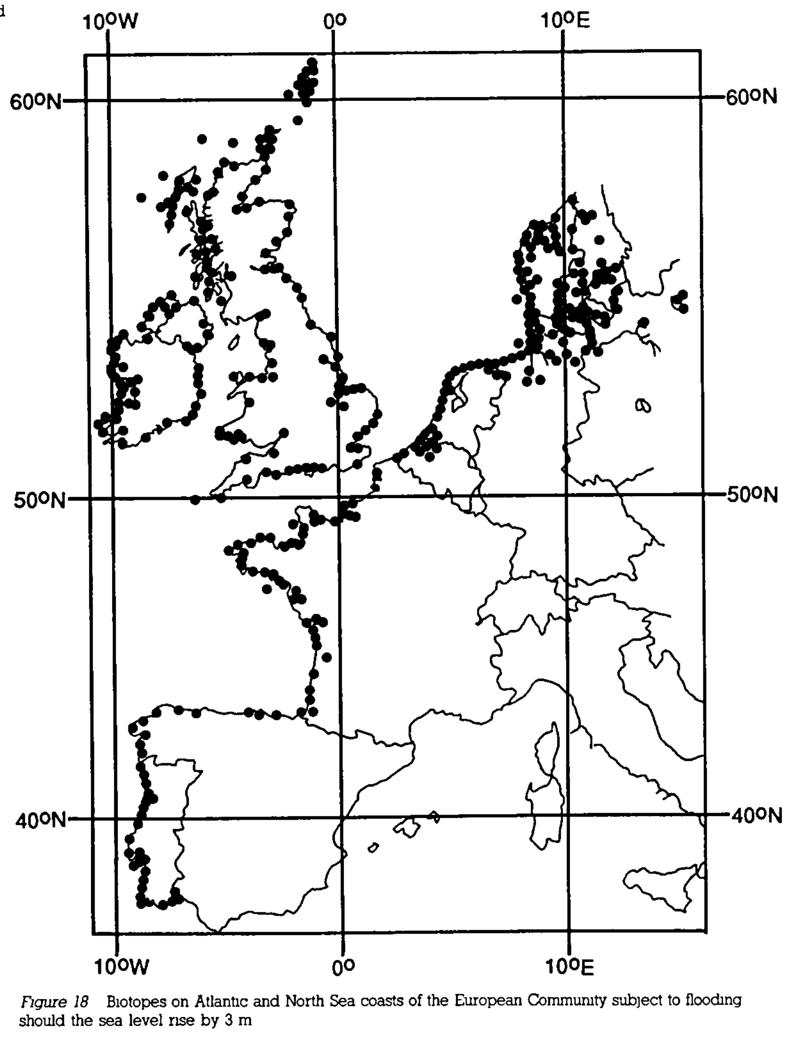

Figure 18 Biotopes on Atlantic and North Sea coasts of the European Community subject to flooding should the sea level rise by 3 m

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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.

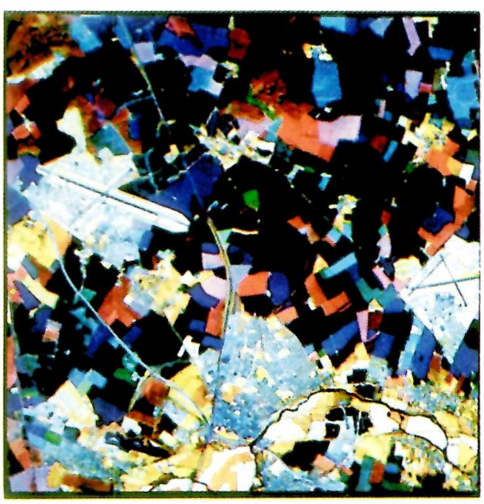

Plate 8. A LANDSAT Thematic Mapper multi-temporal image of a 10 km x 10 km part of Cambridgeshire. infra-red bands 4 of October and 5 of July 1984 are displayed to the red and green channels of the display; the red band 3 of July 1984 uses the blue channel. The section shows Monks Wood (top left) with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

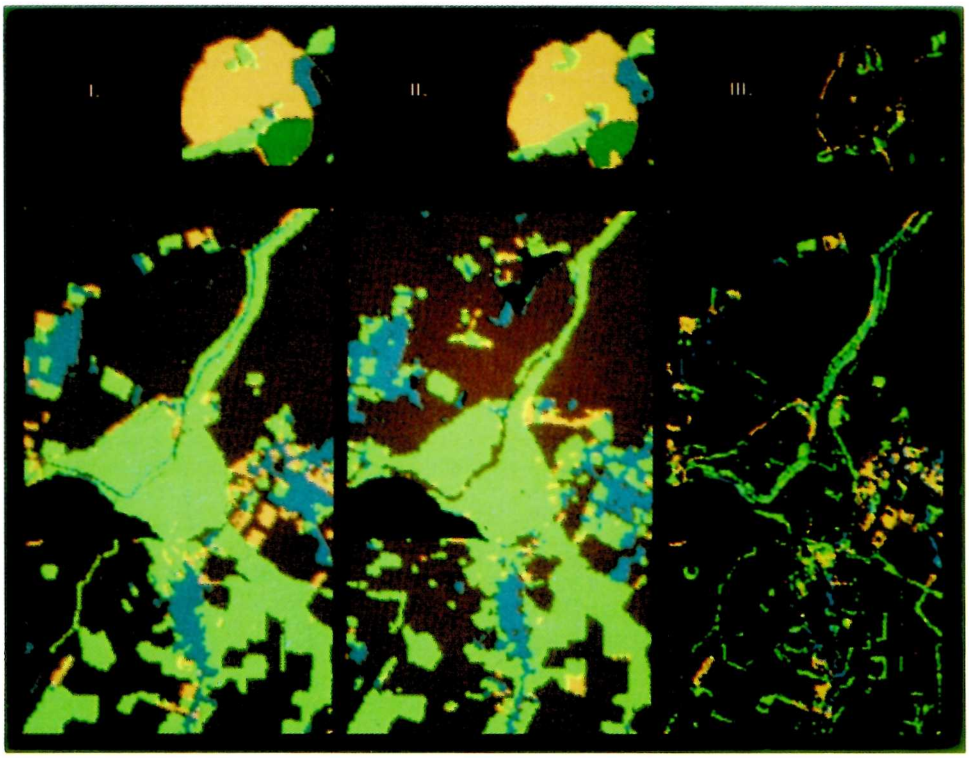

Plate 10. Check areas used in pixel-by-pixel tests of classification accuracies: (i) a digitised map produced by air photo-interpretation; (ii) the maximum likelihood classification of LANDSAT imagery; (iii) the differences between map and classification, coloured according to the 'true' class, ie that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

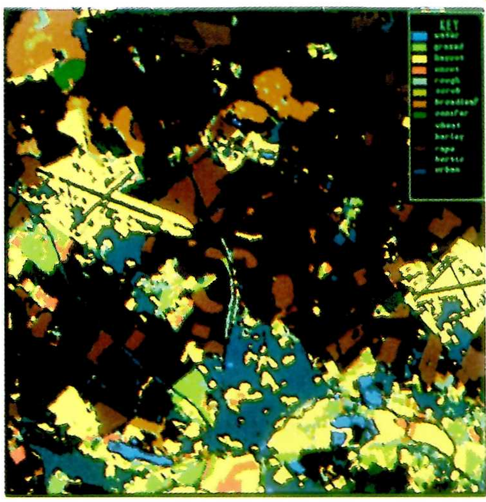

Plate 9. A 10 km x 10 km section of the Cambridgeshire 13-class map, produced by maximum likelihood classification of a summer/autumn multi-temporal composite of LANDSAT TM data. The section shows Monks Wood (top left), with Huntingdon (bottom centre) and the floodplains of the River Great Ouse (bottom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

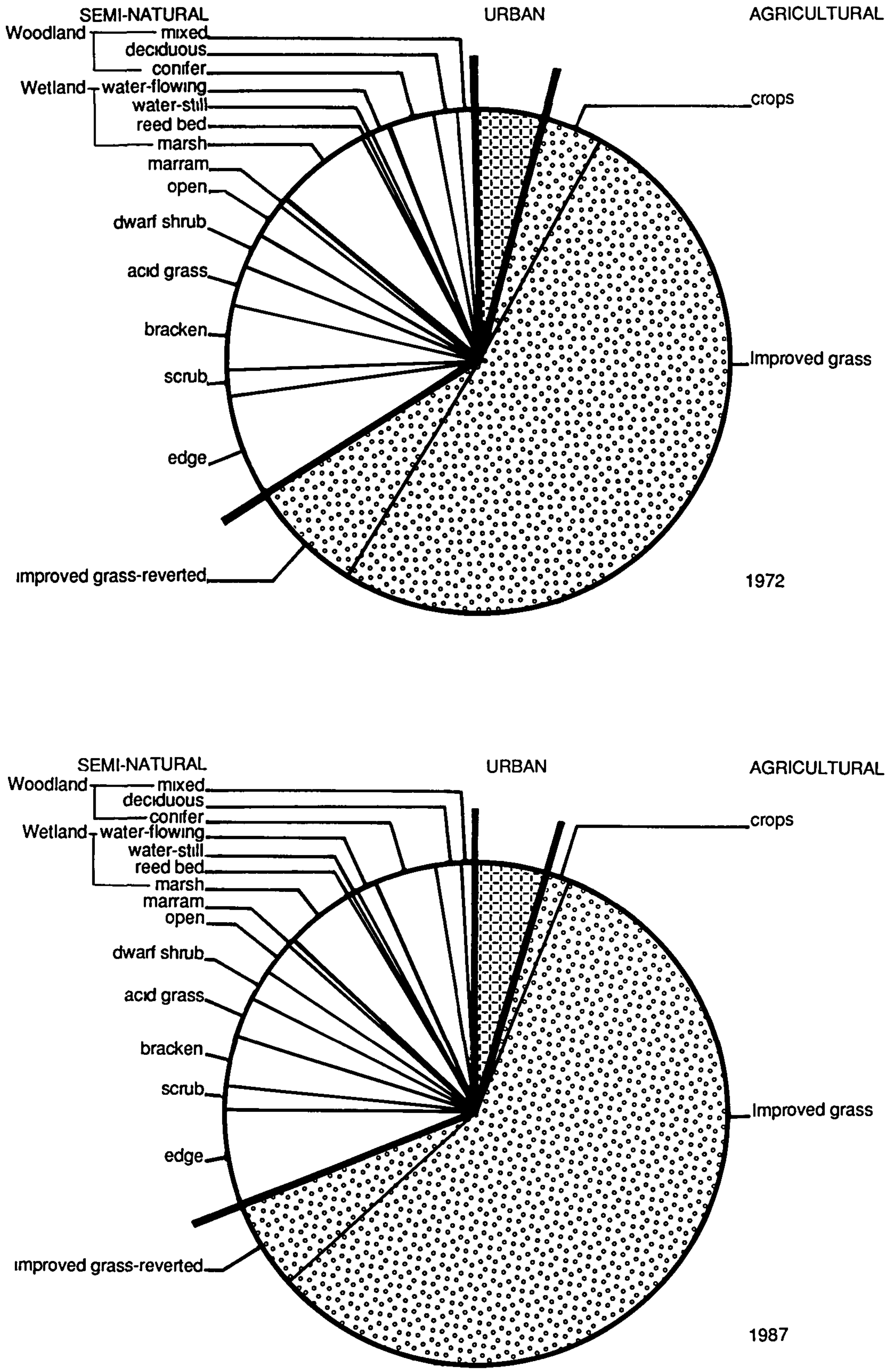

Figure 19 A comparison of the area of Lleyn covered by various habitats in 1972 and 1987

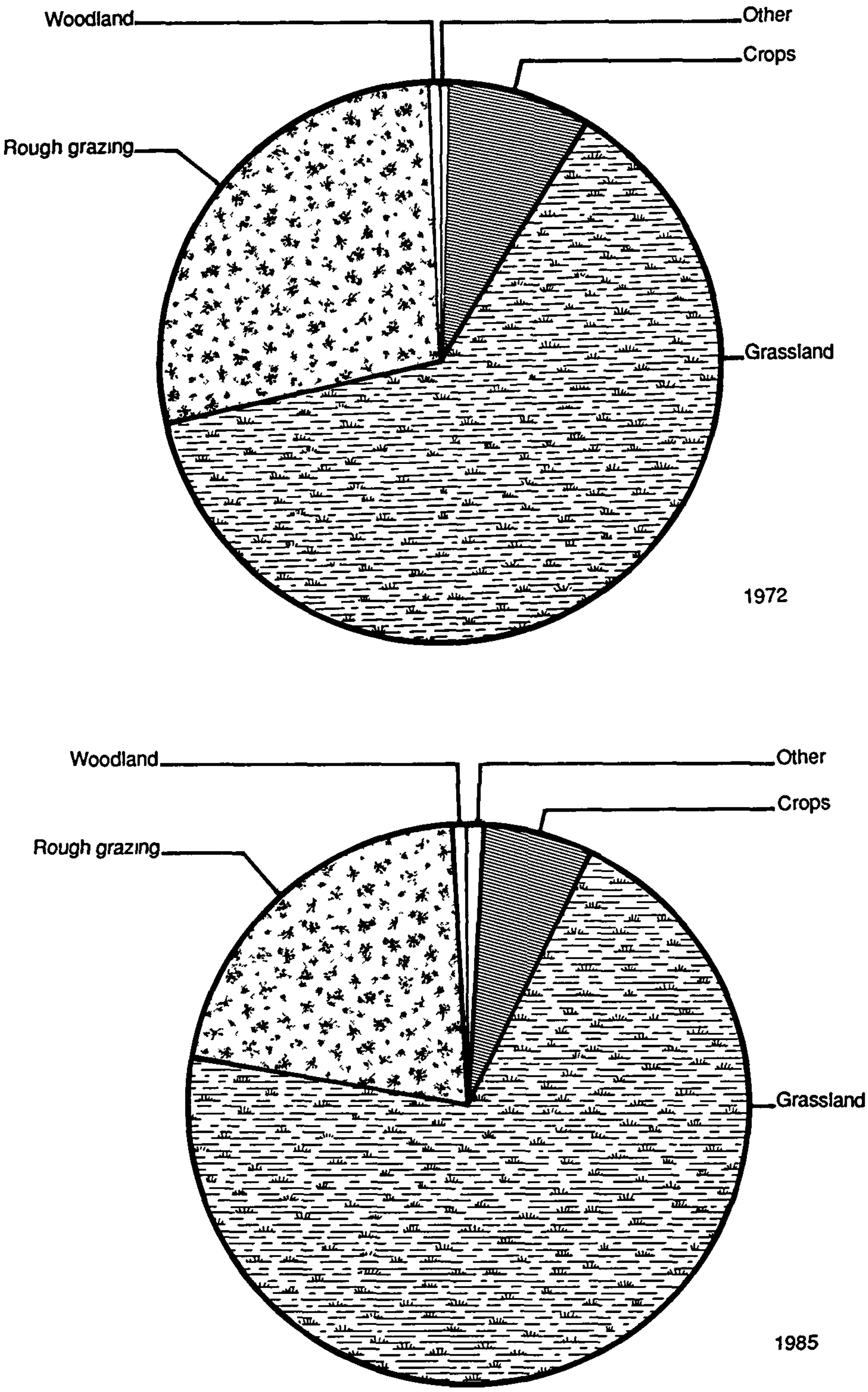

Figure 20 A comparison of the area of Lleyn covered by various agricultural land uses in 1972 and 1985

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 oocupied 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

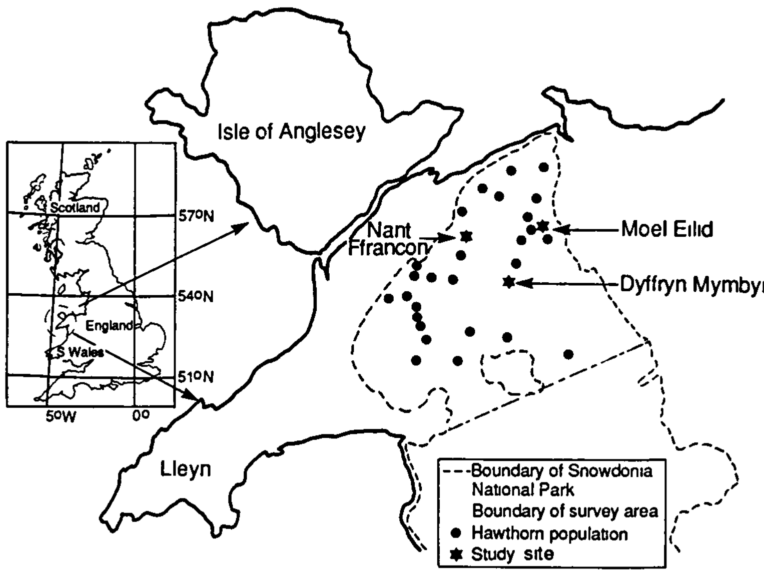

Figure 21 Map of north Wales showing the boundary of the survey area in the Snowdonia National Park and the distribution of hawthorn populations over one ha in extent

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

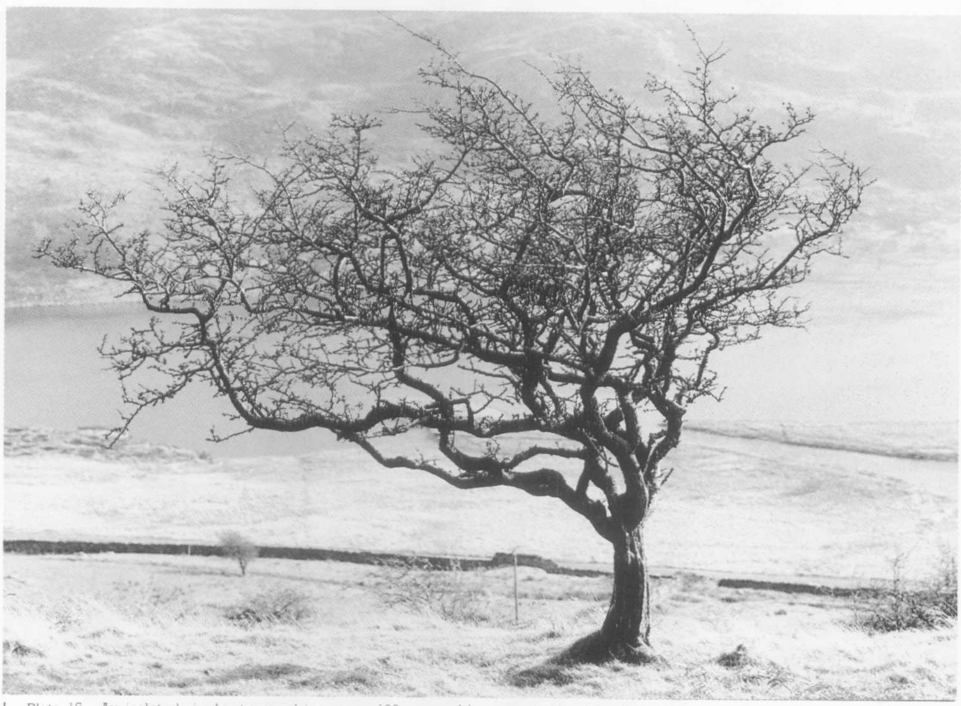

Plate 15. An isolated single-stemmed tree over 100 years old at the Dyffryn Mymbyr site

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*) + Tufted hair-grass (*Deschampsia cespitosa*) + Rough-stalked meadow-grass (*Poa trivialis*) + Mat-grass (*Nardus stricta*) –	Heath bedstraw (*Galium saxatile*) + Brown bent-grass (*Agrostis canina*) + Rock/stone +	Purple moor-grass (*Molinia caerulea*) + Common bent-grass (*Agrostis capillaris*) Deer-grass (*Scirpus cespitosus*)
Constancy tables (ranked by cover abundance)	Common bent-grass (*Agrostis capillaris*) Sweet vernal-grass (*Anthoxanthum odoratum*) Tufted hair-grass (*Deschampsia cespitosa*) Sheep's fescue (*Festuca ovina*) Bracken (*Pteridium aquilinum*) Rough-stalked meadow-grass (*Poa trivialis*) Smooth-stalked meadow-grass (*Poa pratensis*) Red fescue (*Festuca rubra*) Yorkshire fog (*Holcus lanatus*)	Sheep's fescue (*Festuca ovina*) Common bent-grass (*Agrostis capillaris*) Sweet vernal-grass (*Anthoxanthum odoratum*) Heath bedstraw (*Galium saxatile*) Bracken (*Pteridium aquilinum*) Common tormentil (*Potentilla erecta*) Pill-headed sedge (*Carex pilulifera*) Field woodrush (*Luzula campestris*)	Purple moor-grass (*Molinia caerulea*) Sheep's fescue (*Festuca ovina*) *Sphagnum* spp Deer-grass (*Scirpus cespitosus*) Brown bent-grass (*Agrostis canina*) Mat-grass (*Nardus stricta*) Common tormentil (*Potentilla erecta*) Common bent-grass (*Agrostis capillaris*) 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

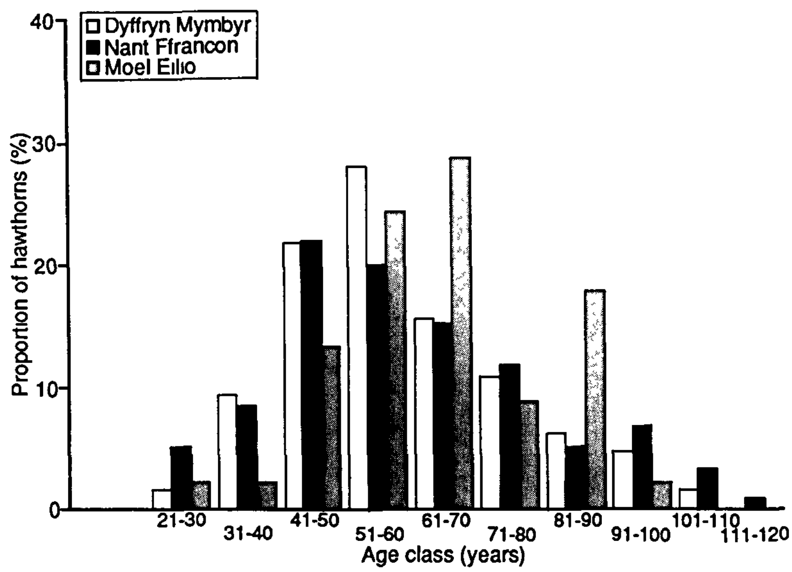

Figure 22 Age class distributions of sampled hawthorns at each of the three study sites in 1979

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

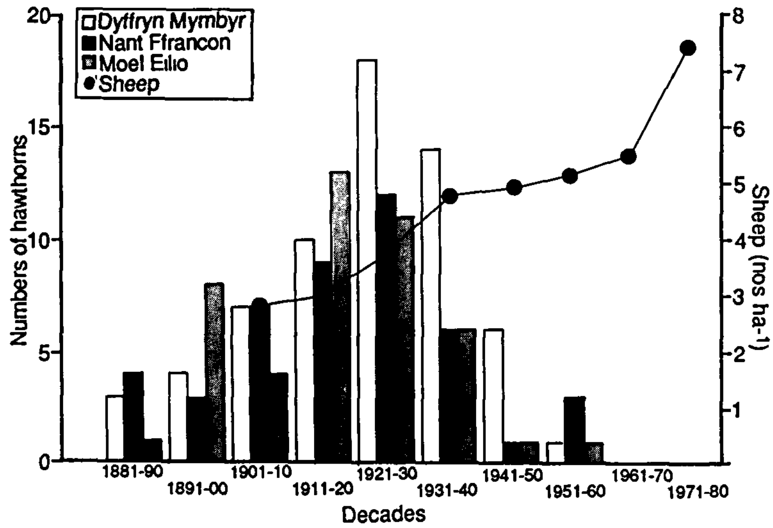

Figure 23. Relationship between recruitment of new hawthorns (seedlings plus root suckers) to the populations at each of the three sites and sheep density in June. Sheep densities are averaged for the three parishes in which the study sites occur. *Note the sharp decline in new bushes from* about the 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.

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