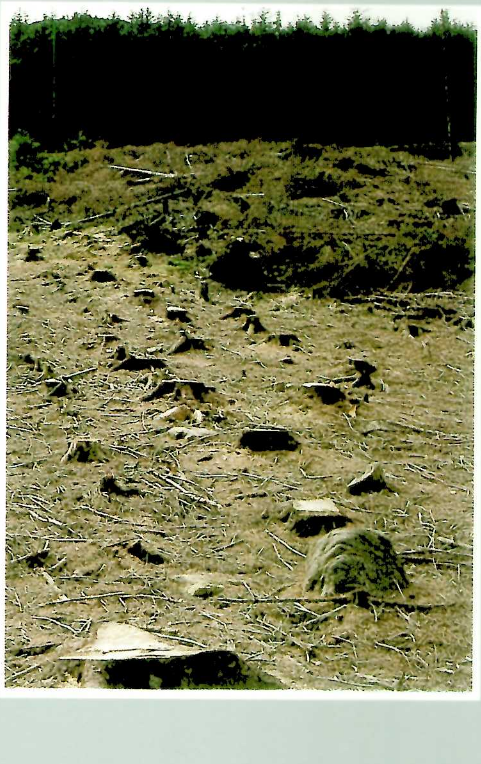
Institute of Terrestrial Ecology

Report for 1986/87



The Natural Environment Research Council

Institute of Terrestrial Ecology

Report for the period 1 April 1986 to 31 March 1987

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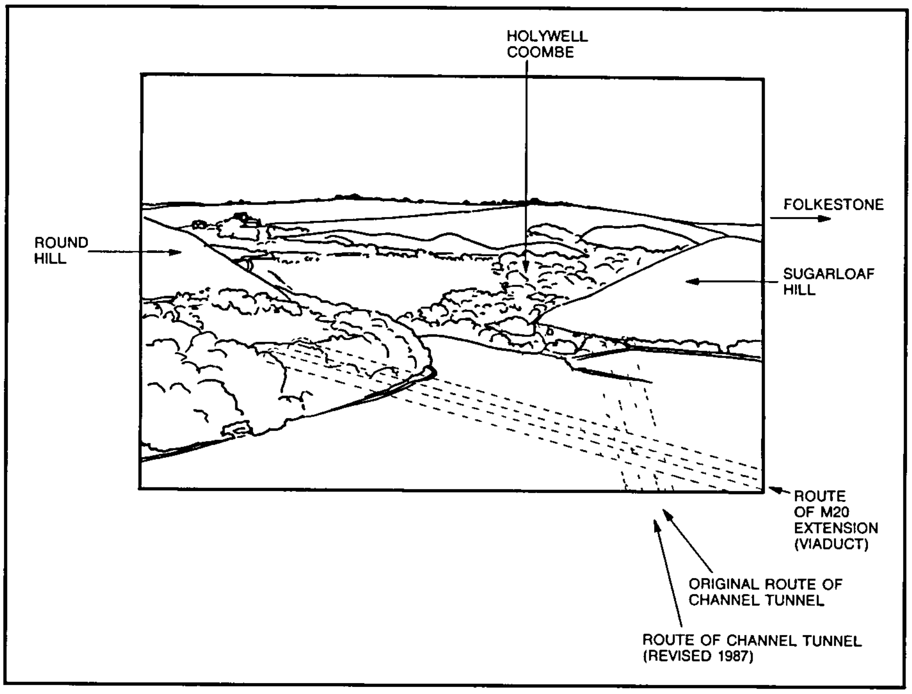
Introduction

The year 1986/87 was characterised by an increase of nearly 50% in commissioned research income and by changes in the management and organisation of the Institute, reflecting the major organisational changes which have taken place, with the establishment of the new Directorates, in the Research Council as a whole

Professor J N R Jeffers and Professor F T Last, formerly Director and Assistant Director of ITE, both retired during the year

John Jeffers was appointed Director of the Nature Conservancy's Merlewood Research Station in 1968 When ITE was set up in November 1973, he was appointed Assistant Director In that post and later, as Director of the Institute (from 1976), he was instrumental in bringing together its very different research stations, developing and channelling their strengths into a structured scientific programme and establishing an Institute identity His particular strengths lay in forestry, in systems analysis, statistics and modelling, and in his organisational ability, which enabled him to maintain the integrity of a dispersed, multi-disciplinary Institute capable of tackling ecological problems regionally, nationally and internationally The rigorous systematic approach and knowledge of statistics and computing, which provided the basis for his direction of ITE, also gained him an international reputation as a scientist

Professor Last joined NERC as Head of the Institute of Tree Biology, set up in 1972 to develop research on the biology of forest and woodland trees In 1973, when that Institute became part of ITE, he was appointed to the post of Assistant Director Professor Last was responsible for expanding and developing the research of the Edinburgh Laboratory of ITE, notably on atmospheric pollution and its effects, and on temperate and tropical forestry As Assistant Director he was responsible for research programmes across ITE which he sustained with an energetic and enthusiastic personal interest He combined an exceptionally wide participation in national, European and international research with a stream of publications emanating from active research on mycorrhizas



Environmental impact assessment of Channel Tunnel construction extension of A20 through part of Folkestone — Etchinghill Escarpment

Following the retirement of Professor Jeffers and Professor Last, the Institute was divided for management purposes, into two, ITE North and ITE South, each with its own Director (Dr O W Heal and Dr J P Dempster respectively) responsible to Dr P B H Tinker, recently appointed to the new post of Director of NERC Terrestrial and Freshwater Sciences (TFS) and notional Director of the Institute as a whole ITE North and South each comprise three stations, all with some degree of regional specialisation and particular areas of scientific expertise, but with the capability of combining their different strengths to tackle a variety of environmental problems at both national and regional levels The ability of the Institute to respond to environmental problems at the national level was demonstrated in the immediate aftermath of the accident at the Chernobyl nuclear reactor in the spring of 1986, a response which is described in the first of the research reports which follow

At the regional level, ITE expertise has been in demand for the assessment of the environmental implications of developments, such as the Channel Tunnel and its associated road link, various road, barrage and land reclamation schemes, and the extraction of oil in southern England During the last few years, ITE Furzebrook has won a number of contracts for research on the effects of proposed barrages on shorebirds ITE's advice has also been widely sought in relation to the management of habitats, including the restoration of physically damaged or ecologically impoverished sites and the reinstatement of indigenous species

ITE has gained an international reputation for research on acid deposition and its effects During the last year, the Institute has won contracts from the Commission of the European Communities for research on the dry deposition of acid pollutants and for work aimed at developing methods for the early diagnosis of forest decline in Europe The US Department of Agriculture has also awarded a contract to ITE, to undertake an investigation of the possible association of the decline of red spruce in the Eastern United States with reduced winter hardiness and the effects of exposure to air pollutants This project is part of the US National Acid Precipitation Assessment Programme In these three pollution projects, as in many others, ITE is collaborating with university scientists and staff from other institutes, both in the UK and abroad

One of the most ambitious of the collaborative programmes in which ITE has been involved is the Regional Hardwood Improvement Programme for West and Central Africa, based on the common commercial interest of seven African countries in a number of hardwood species ITE was instrumental in drawing up the research proposals, and provides one of two European research co-ordinators for the programme, which has received funds from UNEP, UNESCO and the European Development Fund, as well as from the participating African countries ITE is independently involved in research on tropical trees, and other crop species, in Cameroon, Kenya and Malawi, some of these projects are described in this report

There have been changes in the organisation of the Institute research programmes during the past year, in line with the setting up of the TFS Directorate ITE's research programmes have provided the basis for the new programme structure, which encompasses the work of all TFS institutes There are 13 programmes, for each of which there is a co-ordinating group, led by a senior scientist from one of the institutes, members are drawn mainly from within TFSD, but there are also some university scientists Although the system has been in operation for less than a year, there are already indications that it will facilitate greater collaboration between ITE and its sister institutes

Over the last three years, the level of Science Budget funds allocated to ITE has declined in real terms, with a consequent reduction in effort on basic scientific research The reduction in Science Budget support has, however, been compensated by an increase in income from commissioned research to the extent that, in 1986/87, commissioned income represented about a third of ITE's total budget This income came mainly from work on radionuclides, atmospheric pollution and environmental impact assessment The indications for the future are that the Science Budget will continue to decline and that ITE will need to increase still further its income from other sources

Some areas of work in which ITE has developed a particular expertise, and which were previously supported almost entirely on the Science Budget, are now beginning to attract funding from outside agencies In addition to the research on tropical forestry mentioned above, one such area is that of land use classification and survey Interest in recent land use change in the UK, in the potential for further change, and in the environmental consequences of such changes, is likely to be an important national issue in the immediate future and has attracted a major commission from the DoE during the last year In addition to the existing land use data bases and the digital cartographic service based at Bangor, ITE is developing its capability in remote sensing, aided by the NERC decision to base one of three UK Remote Sensing Application Centres at ITE Bangor

Events during the year included the successful Open Days in Summer 1986 at ITE Edinburgh, when the new laboratory building, completed in 1985, was formally opened by Michael Ancram, Minister of State at the Scottish Office There was a fire at Monks Wood in March 1987, when one of the chemistry laboratories was gutted It cost about £150k to make good the damage

Almost all the senior staff changes during 1986/87 were the result of retirements, some of these early retirements in response to the financial circumstances whose effects have been felt throughout NERC At the end of the reporting year, with the appointment of Dr Heal to the post of Director (North), and the retirement of Dr Jenkins, neither Merlewood nor Banchory had a permanent Head of Station

The scientific achievements of a number of individual members of staff were rewarded during the year Drs Melvin Cannell and Hans Kruuk were awarded the degree of D Sc, Dr Ian Newton received the Gold Medal of the British Ornithological Union for Services to ornithology and Dr Caroline Sargent received the Ness Award of the Royal Geographical Society for her work in Bhutan These awards reflect the quality of the individual scientists who form the basic strength of ITE

J P D
O W H

The Distribution and Fate of Radionuclides from Chernobyl in Vegetation in Britain

The explosion at the Chernobyl nuclear reactor exposed the graphite moderator, working at a temperature of about 700 °C, to oxygen in the air The fire which followed vapourised some of the ruptured fuel rods, the resulting cloud of radionuclides was carried by weather systems across parts of western Europe, reaching the United Kingdom in the first few days of May 1986 Most deposition in the United Kingdom occurred during a series of heavy, thundery rainstorms over the west and north-west

The temperature of the reactor fire at Chernobyl was such that only certain radionuclides were present in the fallout which reached the United Kingdom, there was an almost total absence of the heavy actinide elements, such as plutonium, which emit alpha radiation Important among those elements deposited were isotopes of caesium and iodine, which emit gamma radiation Iodine was largely in the form of I-131, which has a half-life of about eight days Although this radio-isotope decays quickly, there was concern because it can pass rapidly through the grass/cow/milk foodchain and is accumulated in the human thyroid Caesium, represented by two isotopes, Cs-137 (half life *ca* 30 years) and Cs-134 (half life *ca* 2 years), present greater problems because of the long half life of these isotopes and their potential mobility in biological systems, where caesium can be an analogue for potassium Caesium-137 is present in fallout from atomic weapons testing and releases by the nuclear industry, but the Chernobyl deposit can be distinguished from previous depositions by the ratio between the isotopes Cs-137 and Cs-134, a ratio of 2·1 in the Chernobyl deposits, but of the order of 30 1 for other releases

It was a matter of urgency to determine the deposition pattern of the radioactivity over the United Kingdom and the potential fate of the radionuclides, particularly those with longer half lives Because of the importance of grazing animals in the foodchain, it was decided to sample grassy vegetation, including the sedges and rushes which are common components of grassland in many areas of upland Britain In choosing the location of sampling areas, advantage was taken of the country-wide spread of ITE Research Stations The ITE land use classification system, developed by Institute scientists (Barr 1988, see page 00), was used to select sites (20 from each of 16 land classes in the United Kingdom) A more detailed survey was carried out in Cumbria, where deposition was known to have been high Samples of all the grassy vegetation clipped from an area of 1 m^2 were collected ten days after peak deposition (3 May 1986) by scientists from each of the Institute's Research Stations and returned to Merlewood for analysis Caesium-137 was determined in all samples and both the concentrations and deposition per unit area were calculated

Pre-Chernobyl determinations had established that the levels for Cs-137 on vegetation were generally less than 5 becquerels per square metre (Bq/m^2), even in the vicinity of the Sellafield reprocessing plant, the values found were only 10-20 Bq/m^2 Caesium-137 deposition in north-west England following the Windscale fire in 1957 had been mostly between 100 and 1000 Bq/m^2, although iodine deposition was about 50 times higher The highest figure recorded following Chernobyl was 6670 Bq/m^2 at sea level near Barrow-in-Furness, Cumbria and was probably associated with an exceptionally heavy rainfall on the afternoon of 3 May 1987 Several values of over 3000Bq/m^2 of Cs-137 were obtained from the western fells of Cumbria In North Wales the highest recorded value was 1785 Bq/m^2 near Dolgarrog, and in the north of Scotland 2080Bq/m^2 near Ben Alder forest In the south of Scotland a value of 1940Bq/m^2 was recorded from a sample collected between East Kilbride and Kilmarnock The western and northern Isles of Scotland were not covered by the initial survey, but opportunistic sampling by a staff member on holiday in Shetland revealed a level of activity of 2390Bq/m^2; the possibility of higher deposition levels in remote upland areas cannot be excluded The highest value for eastern England was near Kings Lynn, where 165Bq/m^2 was recorded

The results were incorporated into deposition maps for the United Kingdom and for Cumbria using contouring packages available through the NERC computing network. These maps were used extensively, particularly by MAFF, to determine areas where restrictions on the movement and slaughter of sheep might be necessary The deposition recorded by ITE closely matched that in MAFF reports for crops and animals and confirmed deposition patterns predicted by computer models run by the Meteorological Office and Imperial College, London University

The initial survey work has been followed up in later surveys The first of these, completed in October 1986, repeated the initial work, but extended it to include soils, upland vegetation and some wild animals Soil sampling enabled the weathering loss from the vegetation to be followed over the summer period, and the plant soil transfers to be assessed for a wide range of British soil types under different climatic conditions

The upland vegetation samples were of heather, an evergreen plant of high collecting ability, and bracken, a deciduous plant whose fronds, having grown after the Chernobyl accident, would give an indication of plant uptake and surface deposition during the growing season Animal samples were taken from two species of economic importance, red deer and grouse, and two animals representing the plant-herbivore-carnivore foodchain, fox and rabbit More than 1400 samples are being prepared and analysed

A further repeat survey of 100 sites with previously high concentrations of Cs-137, is being made with the aim of examining the potential movement of Cs-137 into the new season's growth and of following movements in the soil

Other research activities following the Chernobyl incident include a study of the retention of fallout on vegetation Regular samples taken from heavily contaminated sites in Cumbria, at Corney Fell, Ennerdale and Wastwater, indicate that the residence half life of the caesium from Chernobyl is in the range 30-50 days This residence time would justify the need for restrictions on animal sale and movement in areas of upland Britain.

A factor which might contribute to the continuing high levels recorded in upland vegetation is the presence of a large component of dead material, which has been shown to accumulate up to five times the radioactivity of live material. A second factor is that caesium from Chernobyl appears to be much more mobile than expected; it is therefore available in the soil for further uptake by plants. Experimental work to be carried out during 1987 will be concerned with the retention of material on plant surfaces, the rate at which the material passes into the soil system, and its eventual fate in that system.

A D Horrill

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Radioactive Caesium in Upland Sheep Pastures

(This work was supported by the Ministry of Agriculture, Fisheries and Food.)

Caesium-137, which has a half-life of 30 years, and caesium-134, with a half-life of two years, were the principal long-lived radioactive isotopes in the fallout that reached Britain after the accident at the Chernobyl nuclear reactor in the spring of 1986. These isotopes were deposited in soil and vegetation, especially in the upland areas of north and west Britain, where there was heavy rain during the period that the air mass containing radioactive material was passing over those parts of the country.

A few weeks later, the Ministry of Agriculture (MAFF) and the Scottish Office restricted the movement and slaughter of sheep in the most affected areas. It was expected that these restriction orders would be in place for only a limited period, the prediction being that radioactive caesium would soon become bound in the soil and would not be taken up by plants and thence by grazing animals. However, the levels of radioactivity in vegetation remained persistently high in the contaminated upland areas and the tissues of sheep feeding on the vegetation still contained unacceptably high concentrations of the radio-isotopes (above the permitted level of 1000Bq kq^{-1} fresh weight); hence the restrictions were still in place twelve months later.

The mathematical models which forecast the effective removal of radioactive caesium within a relatively short space of time had been based on field observations and experimental data mainly from lowland sites and did not, therefore, take account of the differences in the nature of upland soils. Further information about the behaviour of radio-isotopes in upland areas, particularly in relation to grazing animals, was clearly necessary. MAFF commissioned a number of research projects to investigate the behaviour of caesium in these ecosystems.

In the summer of 1986, ITE was commissioned by MAFF to undertake a study of an upland farm within the restricted area of west Cumbria. The farm has about 70ha of improved pasture land, and the grazing rights on the nearby open fell, where the flock of about 800 ewes grazes for much of the year. Animals are brought on to the improved pasture near the farmhouse for lambing, shearing, weaning and mating; also for worming and dipping. Store lambs (mostly male) are sold in early autumn for fattening on lowland farms (in Eskdale and in Dorset) to spend their first winter. At the time of the Chernobyl accident the ewes were in improved pasture for lambing; they returned to the fell with their lambs a month later (Figure 1).

Grazing experiment Cumbria

Intensive sampling of vegetation has been carried out in a small (0.7ha) improved paddock, where samples have been taken at monthly intervals since the work began. During the late summer and early autumn of 1986, the mean Cs-137 activity in the paddock was between 2000 and 2500Bq kg^{-1} dry weight, rising slightly (but not significantly, $p < 0.05$) to between 2600 and 3100Bq kg^{-1} during the winter months. By the end of March 1987, there had been no noticeable decline. There was considerable spatial variability in the levels of activity in the paddock, which preliminary investigations of the soil adhering to vegetation, of the moss content and of the moisture levels of the underlying soil have not fully explained.

Samples of fell vegetation taken in November 1986 had levels of Cs-137 which were generally higher than those taken from improved pasture; the highest activity was 4810Bq kg^{-1} dry weight.

The differences in levels of radioactivity between vegetation from the fell and from the improved pasture could be accounted for by a number of factors: initial deposition may have been greater on the fell; grazing pressure is not so heavy as on the pasture; new growth, which may 'dilute' the concentration of radioactivity, does not occur so quickly, nor to the same extent, on the fell; the availability of caesium may be

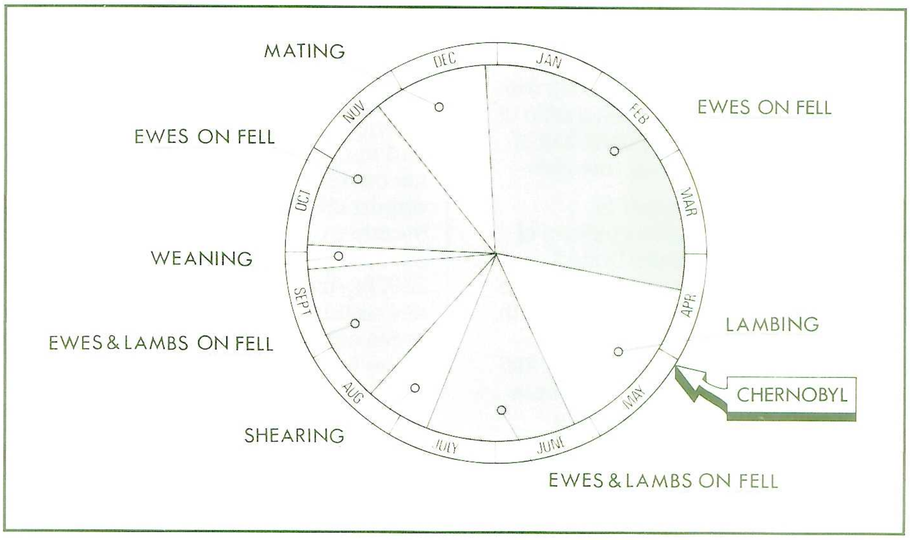
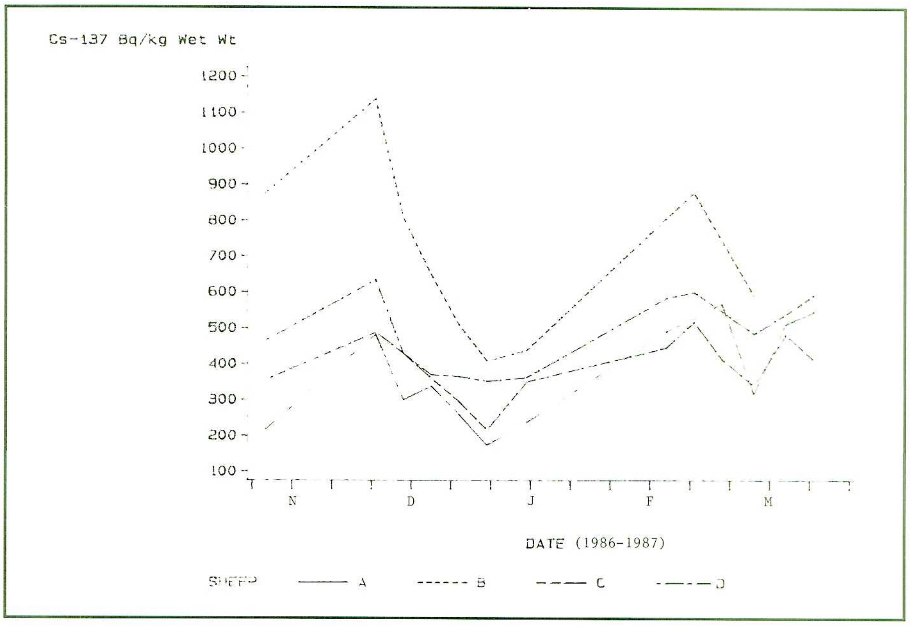


Figure 1

Figure 3
Cs-137 concentrations measured in upland ewes



greater from soil on the fell, perhaps because it is more acidic and contains less clay than the soils of the enclosed pastures.

The Cs-137 activity in a group of 20 individually marked ewes was measured in late October before they returned to the fell (after the lambs had been weaned) and again in late November, when they were brought

Fell in Winter

down to the improved pasture for mating. Measurements were made on several occasions during December, before the flock returned to the fell at the end of the year. While the flock was on the fell during the winter, regular observations were made of grazing behaviour. Between three and eight ewes were caught and monitored on six occasions during February and March, when the farmer put out feed blocks. Most of the marked ewes were monitored when the flock was brought down from the fell for worming at the end of February.

Figure 2 shows the changes in the level of Cs-137 activity during the period from late October 1986 to early April 1987. These changes reflect the movement of the animals between improved pasture and fell. However, the number of sheep sampled varied considerably over the period and was less than ten on each occasion when monitoring was carried out on the fell. The results from individual ewes (Figure 3) give a more realistic picture.

Caesium levels were also followed in two groups of hoggs which were sent

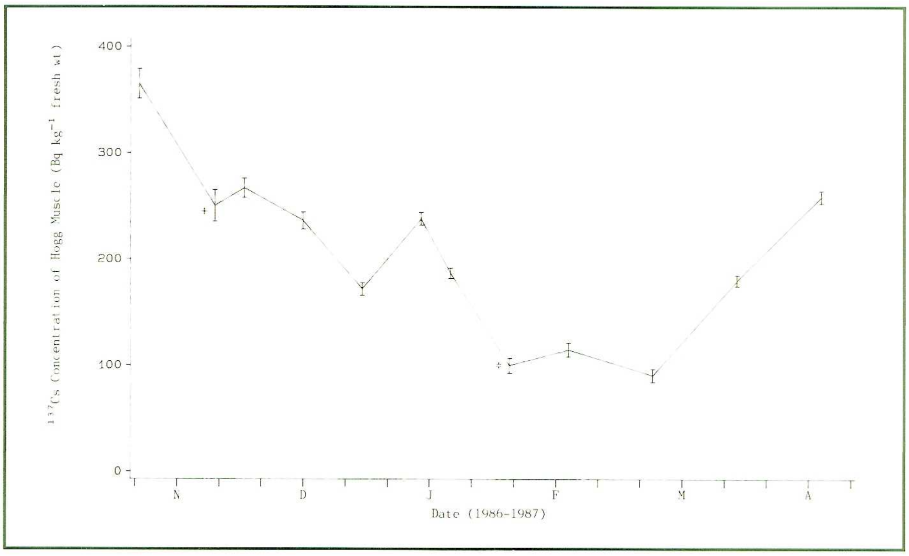


Figure 4.
Changes in the ^{137}Cs activity in the muscle of hoggs removed to Eskdale. (n = 50 except at + n = 25 and + n = 32).

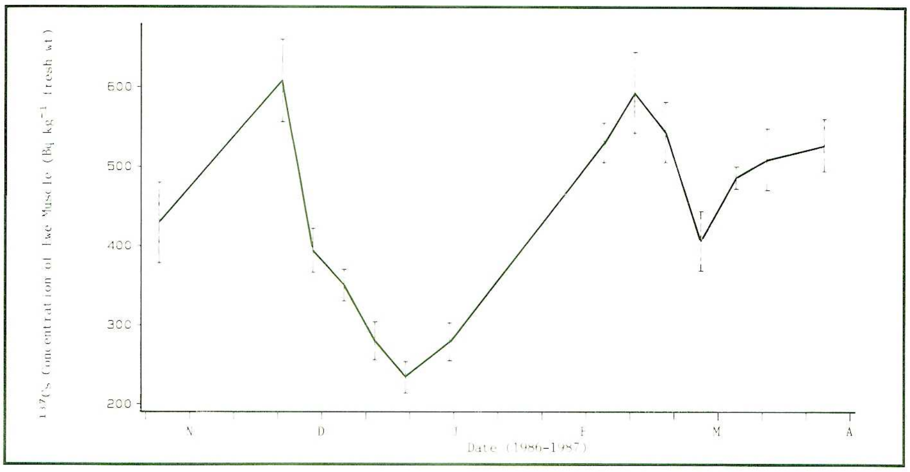


Figure 2. Changes in the ^{137}Cs activity of muscle as the ewes are moved between improved pasture and fell

to lowland farms to overwinter. Fifty hoggs sent to Eskdale (west Cumbria) were monitored before their transfer in late October and at regular intervals through the winter. A further fifty which were sent to Dorset were monitored before, and ten weeks after, their removal. Vegetation samples were taken from the areas grazed by the hoggs during the winter. The Cs-137 activity of muscle of the group of hoggs sent to Dorset had fallen in some individuals below the limit of detection when the animals were monitored, ten weeks after their departure from Cumbria (the highest level recorded was 178Bq kg^{-1} dry wt). The hoggs sent to Eskdale were grazing vegetation with a comparatively high level of Cs-137,

Figure 6
Annual mean concentrations of NO_2 in rural areas of Wales for 1986

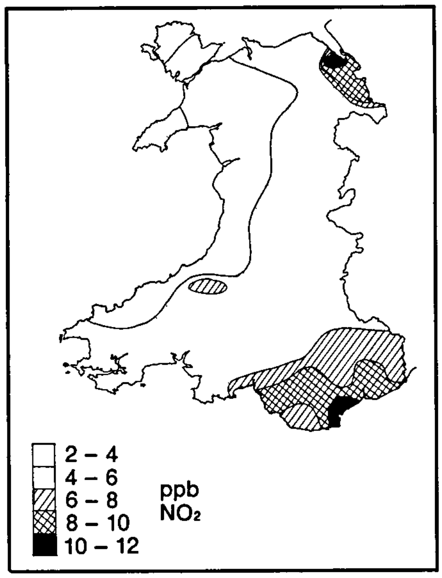
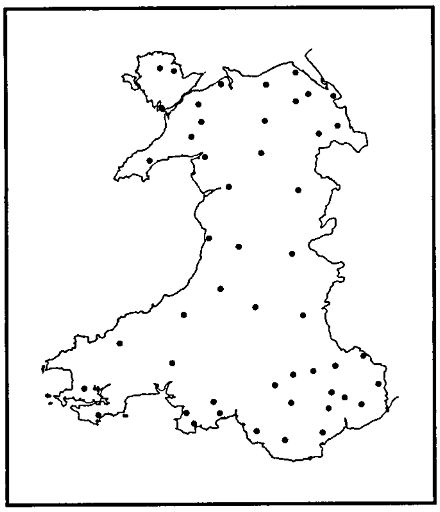


Figure 5
Outline map of Wales showing the distribution of sites used in the NO_2 survey



ranging from 78 to 1085Bq kg- dry wt in the different fields grazed Hence, although they lost Cs-137 activity overall, the rate of loss and the activity on each sample day was influenced by the contamination of vegetation in the field currently being grazed (Figure 4)

It is clear that the levels of caesium in sheep tissues respond rapidly to changes in the level of activity in the vegetation they are grazing The caesium activity of vegetation, particularly that of the new growth in spring and summer, will determine the levels of activity in this year's lambs when they go to market

B J Howard and N A Beresford

ACID PRECIPITATION AND ITS EFFECTS

Nitrogen Dioxide Pollution in Wales

(This work was partially supported by the Welsh Office)

The most commonly occurring acidic pullutant gases in Britain are sulphur dioxide (SO_2) and nitrogen oxides (NO_X) While levels of SO_2 have been monitored for more than 20 years in a national survey by Warren Spring Laboratory (reports are published annually), few measurements have been made of NO_X, except in city centres and near to major roads, because nitrogen oxides were generally considered to be urban pollutants, posing little threat to rural areas However, Martin and Barber (1981) found the combined concentrations of NO and NO_2 to be greater than that of SO_2 at a rural site in England, remote from known sources of pollution Several investigators have since measured the concentrations of oxides of nitrogen in rural areas, but only at a few individual sites This report gives some preliminary data from the first national survey of rural concentrations of NO_2

The major objective of the survey was to determine differences in rural concentrations of NO_2 throughout Wales and to follow changes in levels of the pollutants at different times of the year Sites were selected to give a good general geographical distribution, with additional sites in the 'more polluted' areas of the south-east and north-east, where there was assumed to be a greater variability in pollutant concentrations The location of sites within the basic framework was dependent on the availability of secure sites which could be visited on a regular basis As far as possible, all monitoring points were located at least 1km from major trunk roads and 0 5km from minor roads or buildings which could be local sources of pollution The monitors were sited well away from obvious obstructions, such as trees or hedgerows, which could filter pollutants from the air being sampled, and placed at a height of 1m above ground level Forty-nine sites were set up in October 1985, their distribution is shown in Figure 5

The sampling method, orginally developed by Palmes *et al* (1976) involved the use of simple diffusion tubes (costing approximately 30p each) This technique has been found to give results which compare well with those obtained by using expensive chemiluminescent monitors (Atkins, personal communication) The tubes are about 7cm × 1cm in diameter, made of acrylic material and fitted with air-tight polythene end-caps Stainless steel mesh discs, previously coated with triethanolamine, are fitted inside one end of the tube, where they act as highly efficient collectors of NO_2 During exposure, the polythene end-cap at the opposite end of the tube to the mesh collector is removed and the tube is mounted vertically, with the open end pointing downwards to prevent entry of rain and dust particles Duplicate tubes were exposed at each site for periods of about 14 days, after which the open ends of the tubes were re-sealed and the tubes dispatched for analysis

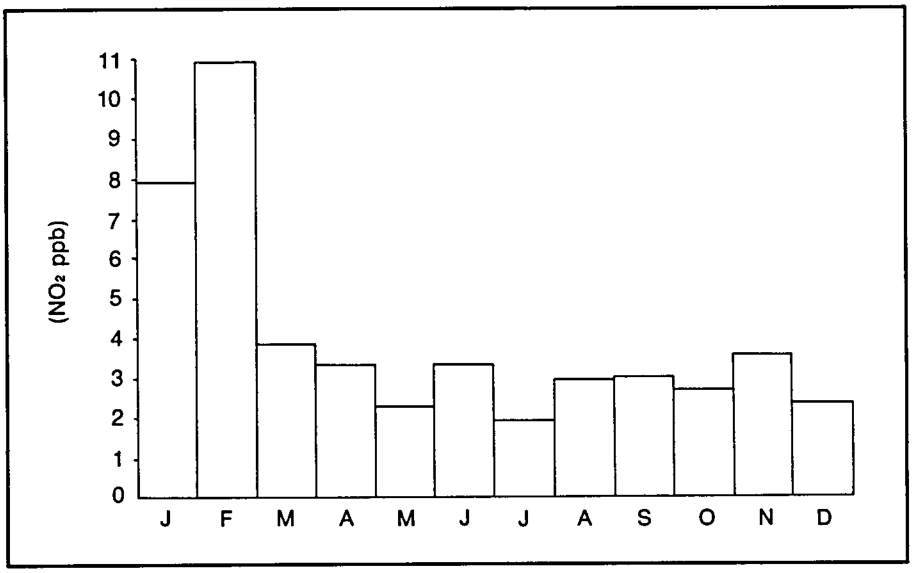


Figure 7
Changes in mean monthly concentrations of NO_2 for rural locations in Wales during 1986 The concentrations quoted are an average of all sites used in the survey

Nitrogen dioxide absorbed by the collectors is determined colorimetrically as NO_2^- by adding a mixed reagent of sulphanilamide in dilute phosphoric acid and N-1-napthylethylene diamine (NEDA) to the tubes The nitrite ion diazotizes

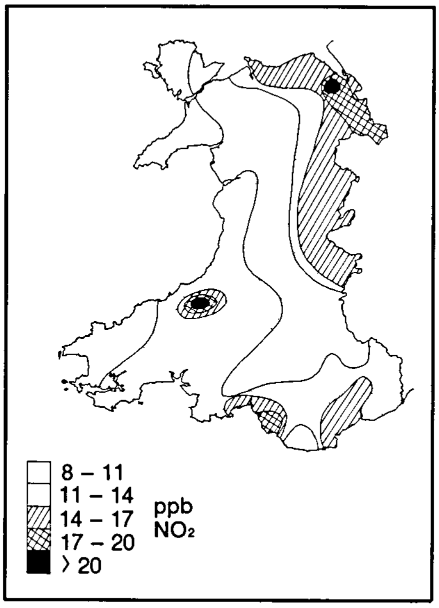


Figure 8
Mean concentrations of NO_2 for February 1986 at rural locations throughout Wales

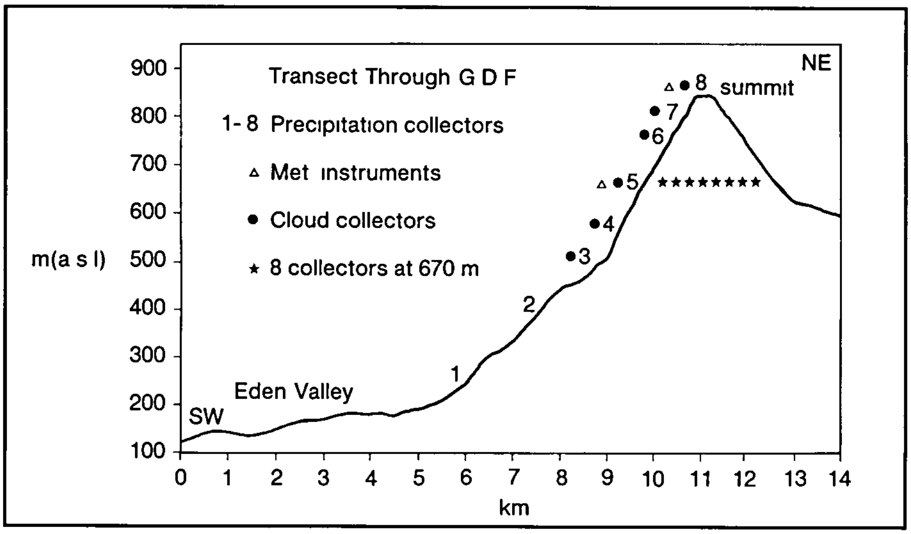


Figure 9
Distribution of sampling sites on the hillside at Great Dun Fell

sulphanilamide and the resulting salt is coupled with NEDA to give a purple-red azo dye whose absorbance is measured at 520nm Using the known sampling rate of the tubes ($76cm^3 h^{-1}$), it is possible to calculate the mean concentration of NO_2 in air during exposure periods

Preliminary analyses of the data have been carried out for 1986 Annual mean concentrations of NO_2 for the 49 sites were between 3 and 12ppbv (parts per billion (10^{-9} by volume), with the highest levels being found, as predicted, in the north-east and south-east part of Wales (see Figure 6) The lowest concentrations, were found along the west coast, probably reflecting the predominance of westerly winds

Monthly mean concentrations of NO_2 (expressed as an average of measurements from all sites) reveal substantial changes in pollutant loads over the year It can be seen from Figure 7 that levels were much higher in January and February than at other times of the year and were low in July (only 18% of the February concentration) Mean concentrations of NO_2 for individual sites during February ranged from 8ppbv in eastern Anglesey to 26ppbv in north-east Wales (see Figure 8) In contrast, the highest level for July was 5 5ppbv for a site near Swansea and the lowest a mere 1ppbv for a site in mid-Wales Pollutant concentrations are generally higher in winter months when there is a greater use of fossil fuels However, the particularly high concentrations for February were, at least in part, due to a prolonged period of easterly winds which brought polluted air into the Welsh counties from the industrial parts of Britain and Europe A shorter period of easterly winds occurred in January

In this survey, the sites were specially chosen to avoid the influence of local sources and the concentrations measured are considered to be minimum levels for the different regions NO_2 concentrations will be substantially higher in rural areas near to towns, villages and roads Similarly, isolated homes, the use of agricultural machinery and straw burning will affect local pollution levels Furthermore, all concentrations quoted are for NO_2 and no account has been taken of the other oxides of nitrogen (primarily NO) The proportion of NO NO_2 in the air for rural areas has been little studied, but Martin and Barber (1981) reported concentrations of the two pollutants to be approximately equal for a site in mid-Wales Thus, the concentrations quoted are likely to be only half of the NO_X pollution present in rural Wales

Acknowledgements
This survey could not have been conducted without the help of Welsh Water Authority staff at Bangor, Carmarthen, Haverfordwest, Hereford, Llandegfydd, Llanelli, Mold, Nelson and Swansea, Nature Conservancy Council wardens based at Bangor, Aberystwyth and Swansea, and Mr A Broughall of the Severn-Trent Water Authority Thanks are also due to Mr R O Page (Welsh Office) for his enthusiastic interest in the work
T W Ashenden

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Rain and Cloud Chemistry and Acid Deposition on Mountains

(This work was supported by the Department of the Environment)

Contemporary interest in the chemical composition of rain was largely stimulated by Scandinavian studies in the 1950s and 1960s which linked the acidification of rain with long range transport of sulphur compounds in the atmosphere over Europe (Swedish Ministries of Foreign Affairs and Agriculture, 1971) Research during the last 15 years has identified areas of freshwater acidification and the loss of fish populations and described many of the mechanisms of deposition, it has included studies of soil and freshwater chemistry

Many of the areas in which freshwater acidification is a problem in Britain and Norway are areas of high rainfall In Britain, affected areas are in the north and west, on slowly-weathering granitic catchments They include the mountains of the West Central Highlands, parts of Cumbria, and Galloway

Not enough is known about the wet deposition of pollutants on mountains, a matter of special importance in those areas which are geologically susceptible to acidification and where rainfall is greatest High altitude regions are often inaccessible and present greater sampling problems than flat terrain, so that in practice most measurements of rainfall chemistry have been made on low ground, or on the lower ground in hilly areas Estimates of the inputs of major ions in precipitation on hills or mountains have been made by

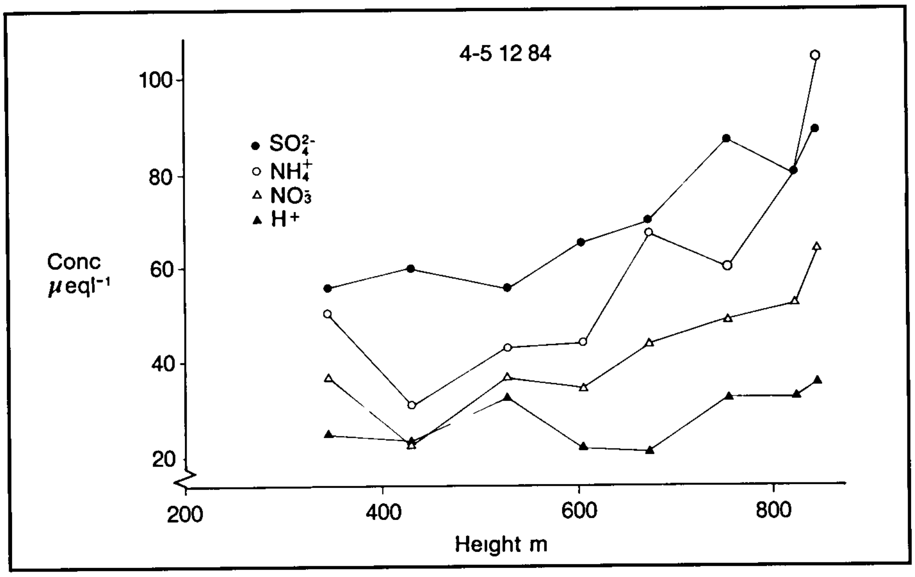


Figure 10
Concentrations of ions in rainfall collected at sites on Great Dun Fell

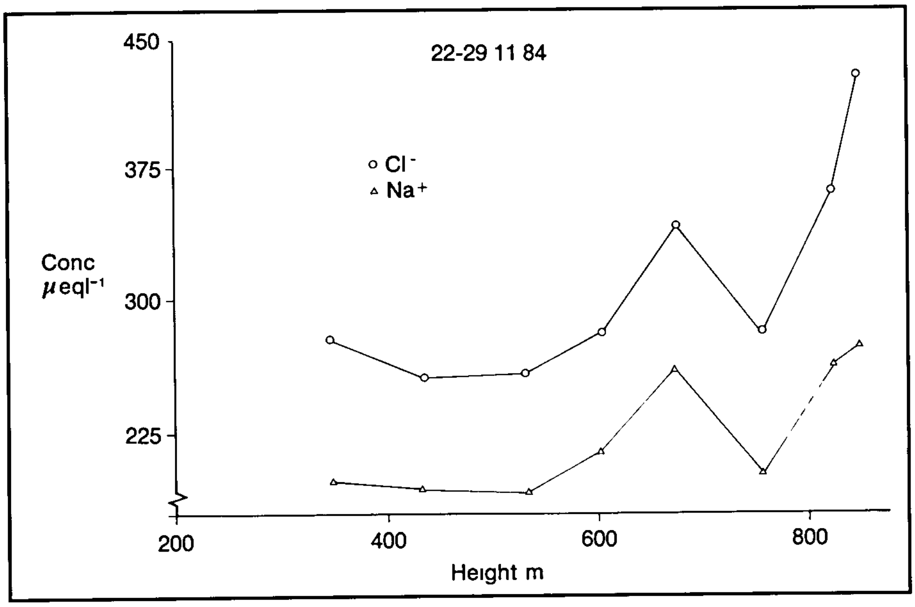


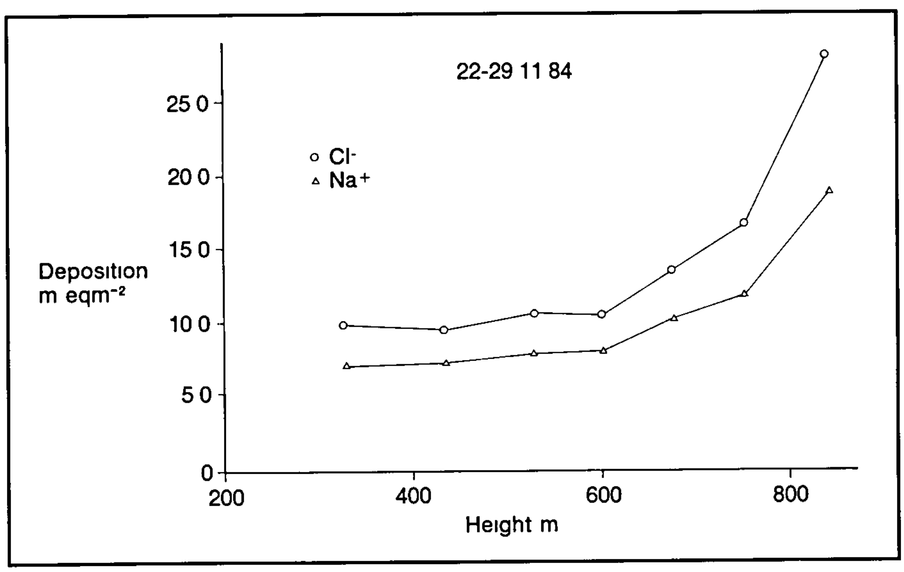
Figure 11
Concentrations of ions in rainfall collected at sites on Great Dun Fell

assuming that the composition of rain remains constant with altitude It has thus been customary to assume that wet deposition increases with altitude at the same rate as rainfall amount

This assumption has been examined in a large collaborative study in Cumbria by ITE, AERE Harwell, the University of Manchester Institute of Science & Technology (UMIST) and the University of East Anglia The joint study comprises a series of experiments on chemical processes in the atmosphere below and within cloud and on the deposition of rain and cloud water at different altitudes

To study the influence of altitude on the composition of precipitation, collectors were placed at eight altitudes between 150m ASL and the summit of Great Dun Fell (847m) As the hill summit is frequently in cloud, and the presence of this orographic cloud may influence the composition of falling raindrops, samplers for cloud water were installed alongside four of the higher level rain collectors on the hillside The distribution of sampling equipment is shown in Figure 9

Figure 12
Deposition of ions at sites on Great Dun Fell



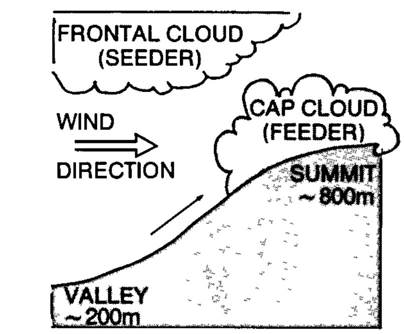
Measurements of rain and cloudwater composition were made for individual rainfall events to avoid the confounding effects of different meteorological conditions contributing to 'bulked' samples

Examples of the results obtained for an episode during the autumn of 1984 are shown in Figures 10 and 11 The concentrations of all major ions increase with altitude, the increase being typically a factor of two between the lowest sampling point and the hill summit The rainfall amount also increased by almost a factor of two over this height range, the wet deposition therefore increased by a factor of four (Figure 12)

For conditions with a south-west wind and a capping orographic cloud on the hill summit, the rainfall amounts and concentrations of major ions both increase with altitude The average increases in concentration, for 30 rainfall events, between the lowest collector and the summit, are shown for SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, H^+, with the rainfall amount, in Table 1 The increases are substantial, being typically by a factor of two for concentrations and of four for deposition At this site, therefore, the rainfall composition cannot be assumed to remain constant with altitude To extrapolate to other sites or more extensive areas, it is necessary to understand the underlying mechanism causing the change in composition with altitude

Cloud water composition measurements show that concentrations of major ions in the 'cap cloud' are generally much larger

Figure 13
Feeder seeder mechanism for enhanced rainfall concentrations of major ions in rain



TYPICAL CONCENTRATIONS
(ueql – ¹)

	Cap cloud	Rain 200m	Rain 800m
SO_4^{2-}	100-2000	42	60
NO_3^-	30-2000	45	65
H^+	10-1000	25	40

than in rain at the same site (Table 2), the increase being by a factor of between two and three The mechanism proposed to explain the changes in rainwater composition with altitude is that falling rain scavenges the polluted 'cap-cloud' droplets in the manner shown in Figure 13, where the rain from a higher level 'seeder' cloud falls through the low level 'feeder' cloud, scavenging the cloud drops and their chemical content (Fowler *et al*, 1988, Choularton *et al*, 1988)

The mechanism is clearly important at this location, elsewhere along the ridge of the Pennine hills, and on other west-facing hills in the UK For the more extensive upland areas, much more needs to be known about the composition of cloud water on successive hills during rain, this is being investigated in current field campaigns The interpretation of results so far has been assisted by the development at UMIST of numerical models of the meteorology and chemistry of air which flows over Great Dun Fell The model has been able to reproduce quantitatively the observed patterns of wet deposition on the windward slopes of the hill It predicts that the areas receiving the greatest enhancement in deposition are a few kilometres down the leeward side of the hill, at which point the rain falling from the seeder cloud has the greatest trajectory through the low-level feeder cloud Measurements during the next field campaign will test this prediction

D Fowler

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Fowler, D; Cape, J N; Leith, I D; Choularton, T W; Jones, A & Gay, M J. 1988 Wet deposition and altitude, the role of the orographic cloud *Atmos Environ* (In press)

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Table 1 Ratio of concentration of summit/valley for major ions and rain amount

	H^+	NH_4	Cl	NO_3^-	SO_4^{2-}	RAIN
x	2 9	3 1	2 9	2 3	2 2	2 0

Mean of 20 precipitation events at Great Dun Fell with measurements at 8 levels (244-847m) showing increase in concentration between valley and summit, 1984-85

Table 2 Ratio of concentration in cloud/rain (μeq 1 ¹)

H^+	NH_4^+	Cl	NO_3	SO_4^2
3 9	2 4	2 6	2 8	2 0

Mean of 11 precipitation and cloud events at summit (847m) during Spring 1985

The Status of Fish in Scottish Lochs Vulnerable to Acidification

(This work was supported by the Commission of the European Communities and the Department of the Environment)

In recent years concern has grown about the effect on freshwater fish populations of the acidification of inland waters by atmospheric pollutants Research on the problem has been intensifying, particularly in Scandinavia, North America and the UK The project described here was initiated to investigate whether fish in the lochs of Scotland were being affected by acidification

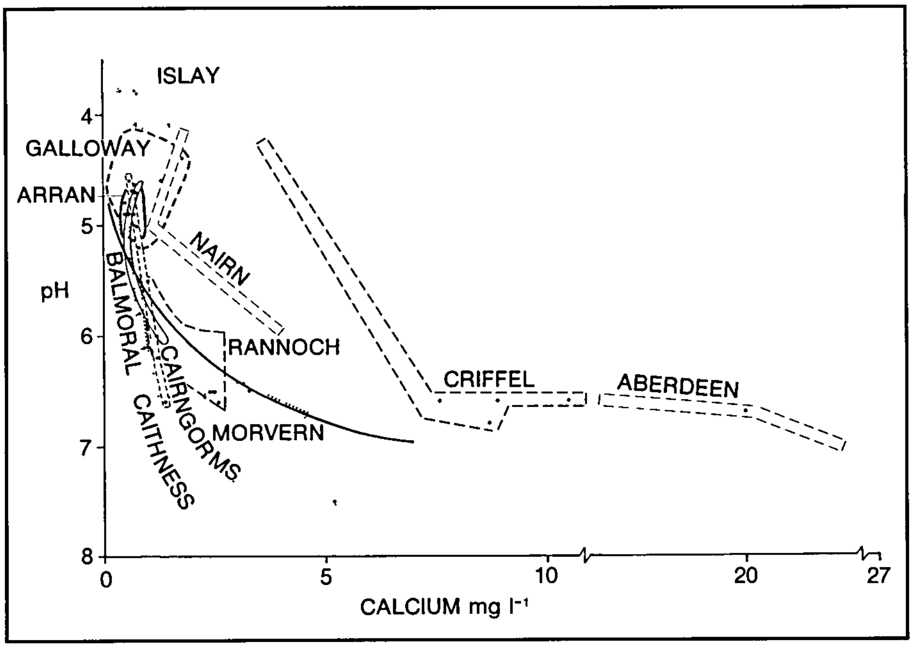
Although there are over 30,000 lochs in Scotland (Smith and Lyle, 1979), only a minority lie on hard, slow weathering rock where they are most vulnerable to acidification It was from such areas that the sites to be examined were selected The task was simplified by considering only lochs lying entirely on granite, of which there are many discrete blocks widely distributed throughout Scotland (Anderson, 1939)

The first phase involved a map study at the 1 50,000 scale, which showed that there were 279 suitable lochs, over 1ha in area, with basin and catchment entirely on granite bedrock (later some larger lochs, 75% of whose catchments were on granite, were included) Field sites were selected by taking into consideration their geographical location, the number of such lochs in the locality, associated streams, ease of access, etc Fifty-four lochs on granite were selected and 11 'control' lochs lying near to, but not on, the granite A further 18 sites of interest were included as the survey progressed, giving an overall total of 83 sites (32 of which were sampled in 1984 and 51 in 1985) All sites were visited at least twice

The majority of the lochs concerned are in mountainous areas, often at some distance from the nearest vehicle access This forced the use of light and portable equipment Normally, a team of four people was required and site visits involved walks of up to 20km each day

Although the main focus of investigation was on the fish populations, physical and chemical

Figure 15
Geographic relationships of pH and calcium plots of all lochs on granite sampled during the project Also shown is the Henriksen (1979) acidification curve though it should be noted that not all the sites shown are applicable to this curve because of their high organic content



measurements were also made at each site Bathymetric information, an important contribution to any study of loch ecology, was obtained, together with hydrological data, for a total of 64 sites, 49 of which were surveyed by echo sounding during the field programme The information was used to examine the relationship between water retention time and acidification status as defined by Henriksen (1979) The results indicated that lochs with retention times of a few months are those most likely to suffer from long term acidification In view of the importance of episodic events to acidification (Bjarnborg, 1983) their relationship with retention time is summarised in Figure 14

Two sets of water samples for chemical analysis were routinely taken, usually on consecutive days, from the major inflow and outflow of each loch Chemical measurements included pH and calcium, since one of the most interesting aspects of water chemistry and acidification is the relationship of these two values and the 'acidification curve' proposed by Henriksen (1979) Data from the survey (shown in Figure 15) indicate a number of sites which could be classified as acidified according to this criterion There is also often a close similarity between the values of pH and calcium at sites in the same geographic area, but there are widely differing values from different areas

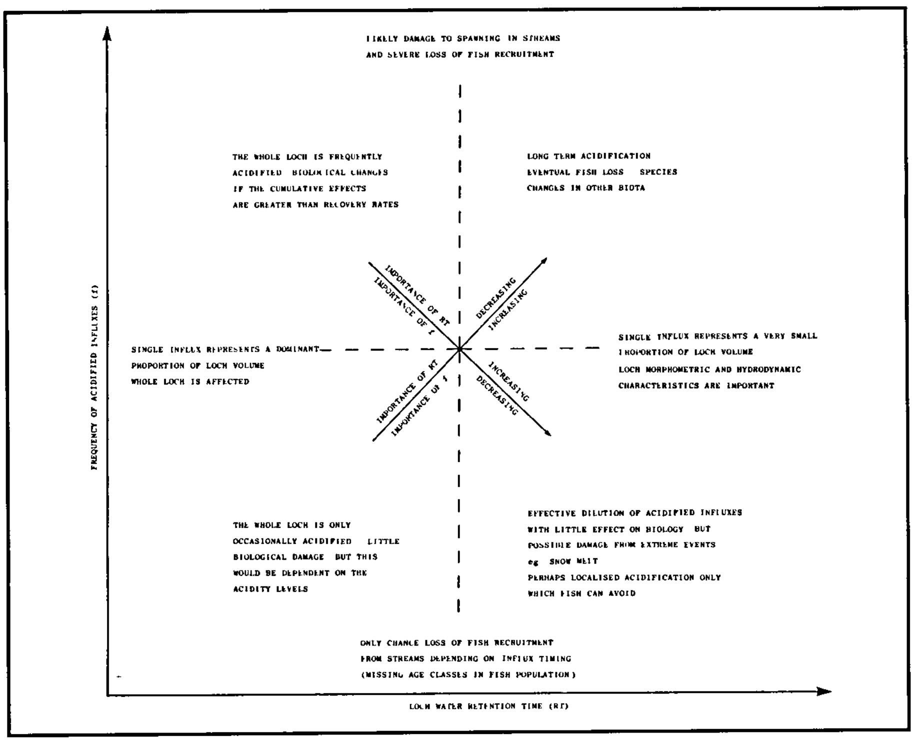


Figure 14
A diagrammatic summary of the relationship between loch retention time the frequency of acidic inputs and the biological effects in lochs vulnerable to acidification

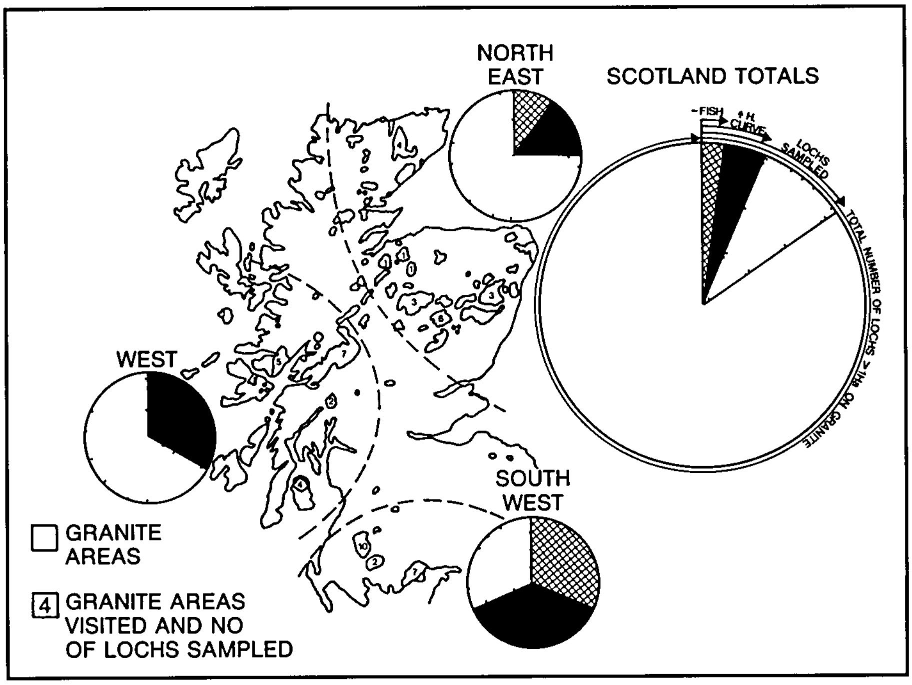
Henriksen's criterion is not relevant to highly organically stained waters, such as the (non-granite) lochs in Islay

The loss or decline of fish populations, particularly salmonids (salmon, trout and charr) because of their commercial and sporting importance, is perhaps the most conspicuous indication of the acidification process in fresh waters The main effect of acidification on loch salmonid populations results from damage to juvenile populations in the associated spawning streams As a first step, historical evidence was collected from landowners, estate factors, anglers, etc In the field, loch fish were sampled from the littoral and open water areas by setting gill nets out overnight In streams, fish were sampled using standard electro-fishing methods, they were identified and measured on site and returned alive In both situations, the predominant species of interest was brown trout, although a further nine species were also recorded

Of the lochs sampled, five, all in one small area of south-west Scotland, have lost their fish populations altogether Historical records are limited, but indicate that fish stocks in these lochs have been declining throughout this century, and that extinction has occurred as recently as the last decade Trout populations in another six lochs in that area, show population characteristics (reduced numbers, increased individual size and condition, faster growth and possibly earlier maturity) consistent with reduced recruitment and with a consequent increase in individual resources A further six lochs in other parts of Scotland show the same traits However, 16 lochs, apparently also vulnerable to acidification, did not show these features Table 3 summarises the fish data obtained during the survey and differentiates between acidified and non-acidified sites

Of the 39 streams found to be fishless, 87% can be classified as acidified Only in three cases were fish (eels) found in streams (outflows) associated with fishless lochs

Figure 16
National and regional summary of chemical and fish data from the lochs on granite surveyed during this study The coding for the regional charts is the same as for the Scotland totals where H CURVE represents the proportions of lochs acidified as defined by Henriksen (1979), and — FISH is the proportion acidified and also fishless



The impression gained of the state of trout populations in acidified lochs in Scotland is that the process of acidification has been mild and gradual There does not seem to have been a sharp cut-off in recruitment, leaving a population to age and die out, but rather a reduction of numbers of all ages It may be that in Scotland the spring snow-melt is so much less than in Scandinavia and North America that the effects of accumulated winter acidity on spawning streams is much less dramatic

The main conclusion to be drawn from these results appears to be quite simple — a number of lochs on granite in Scotland has been acidified and become fishless over recent years, but this is a small percentage of the Scottish total The effect is localised and occurs predominantly in south-west Scotland (see Figure 16) In addition, some other lochs are acidifying and are likely to lose their fish over the next decade or two Again, the number involved appears to be small

This study is described more fully in an ITE publication (Maitland *et al*, 1987), A similar study of fresh waters in Wales has been initiated and funded by the Department of the Environment, and will be carried out jointly by ITE and the Welsh Water Authority

A A Lyle

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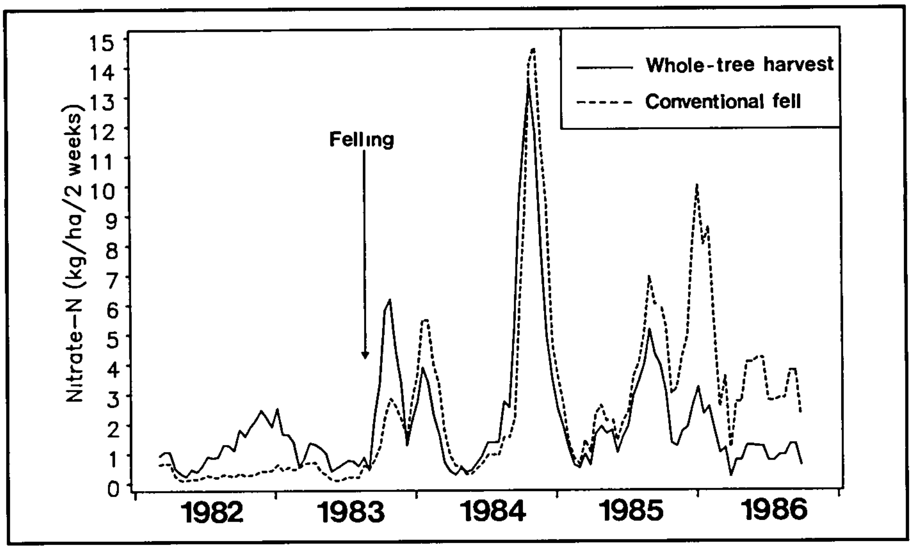
Table 3 A summary of the netting results showing the differences between brown trout populations in acidified and non-acidified lochs, as defined by Henriksen (1979)

PARAMETER	GROUP AVERAGES	
	ACIDIFIED	NON-ACIDIFIED
Population size (fish/net/night including zero catches)	4 71	15 03
Population size (fish/net/night excluding zero catches)	6 39	15 03
Individual size (fork length mm)	225	181
Condition (K factor)	1 29	1 19

Figure 18
Fortnightly nitrate-N fluxes (kg ha^{-1} a^{-1}) in the C horizon of whole tree harvested and conventionally felled plots at Beddgelert forest Points plotted are running means of four consecutive values



TREES, SOILS AND NUTRIENTS

The Effects of Clearfelling on Soil Solution and Drainage Water Chemistry

(This work was partially supported by the Department of the Environment)

Since 1980, scientists from ITE and the Forestry Commission have studied the environmental effects of clearfelling plantation forests (Hill *et al*, 1984) ITE staff have been particularly concerned with the effects on soil solution and stream water chemistry, and have investigated these aspects in Beddgelert Forest, North Wales, and Kershope Forest, Cumbria, a third site, Hafren Forest, in mid-Wales, is currently being felled

The main aims of the study are

(i) to discover if the nutrient elements lost are polluting streams or are liable to result in site nutrient depletion in the short or long term,

(ii) to explain losses to streams in terms of changes in solute concentrations and fluxes in soil waters and to investigate the mechanisms responsible for these changes,

(iii) at Beddgelert, to examine the differences between the effects of conventional felling and whole-tree harvesting

Major nutrient fluxes in soil waters at Beddgelert

Dissolved nutrient fluxes were calculated for fortnightly periods from early 1982 to late 1986 in five horizons of the dominant soil, a stagnopodzol Felling took place in the summer of 1983

Both potassium and inorganic nitrogen (nitrate) are readily leached after felling Postfelling fluxes of potassium are substantially higher than prefelling fluxes, in conventionally-felled plots (Figure 17) Potassium released from fresh brash is leached during the year after felling, little is immobilised in the soil profile (Table 1) but a small amount is additionally released from forest floor litter

Conventional felling and whole tree harvesting produce similar post-felling fluxes of nitrate in the C horizon (Figure 18), fluxes of up to 100kg ha^{-1} have been measured (similar to leaching losses from intensive lowland agriculture) In the upper soil horizons, dissolved nitrogen is dominated by organic-N (Stevens and Wannop, 1987) but nitrification is active, despite the very acid nature of the soil (pH 4 5), and nitrate dominates in the B and C horizons The presence of heterotrophic nitrifiers has been suggested, to explain the nitrogen chemistry of acid soils under conifer forests in Scotland (Killham, 1987)

The large nitrate losses can be explained by cessation of tree root uptake, increased soil water fluxes, the lack of any re-established natural vegetation soon after felling, or enhanced rates of nitrification The similar patterns of leaching loss from both felling treatments suggest that the presence or absence of brash does not affect leaching rates Lysimeter experiments, however, show that the presence of grasses limits nitrate leaching from the surface horizons The whole-tree-harvested area had become completely revegetated with grasses by summer 1986, whereas the area of conventional felling was still dominated by heaps of brash This may explain the difference in nitrate flux between the two treatments in 1986

One-third of the phosphorus, as phosphate, is readily leached from felling debris and through the L (litter) horizon (Table 4, Figure 19) However, it is immobilised in the mineral soil and is not detected in water samples from the E, B and C horizons Soil column studies indicate that approximately 65% is immobilised by chemical adsorption, and 35% is

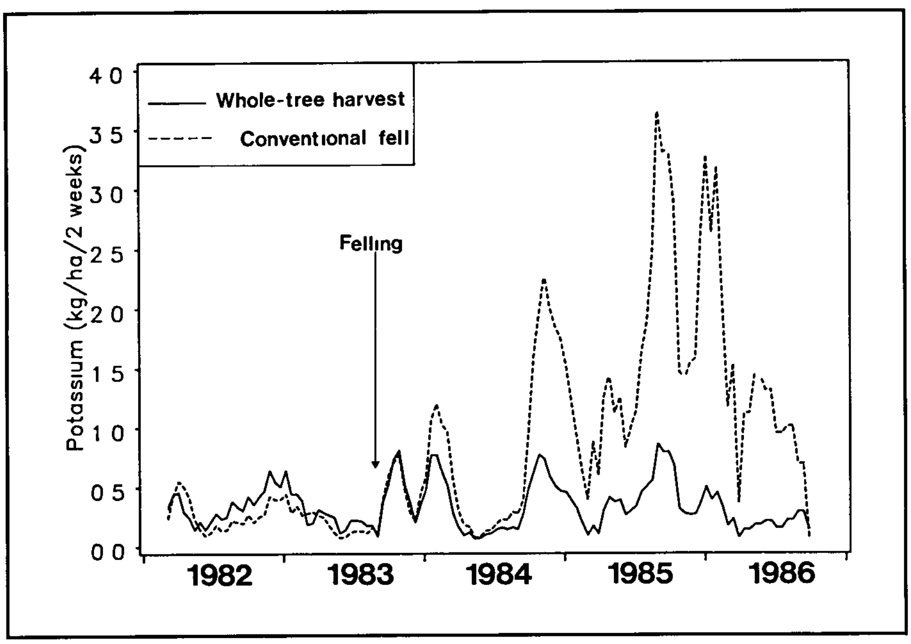


Figure 17
Fortnightly potassium fluxes (kg ha^{-1} a^{-1}) in the C horizon of whole-tree harvested and conventionally felled plots at Beddgelert forest Points plotted are running means of four consecutive values

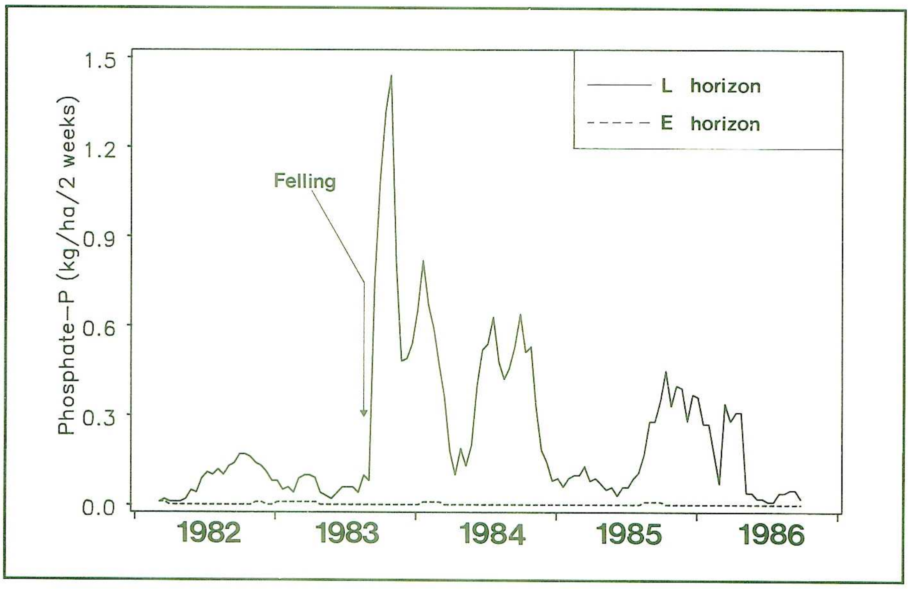


Figure 19.
Fortnightly phosphate-P fluxes (kg ha⁻¹ a⁻¹) in the litter (L) and E horizons of a conventionally felled plot at Beddgelert forest. Points plotted are running means of four consecutive values.

microbially assimilated. Pot experiments are planned, to determine whether immobilised phosphorus is available to re-established vegetation and the next spruce crop.

In addition to the fluxes of major nutrients, changes occur in concentrations of other solutes. A pulse of hydrogen accompanies the pulse of nitrate through the lower mineral soil, but its importance as a short-term source of further stream acidification is uncertain. Sulphate, chloride and sodium concentrations in the soil solution decline in the second year after felling. The trends are obscured by year to year variation in concentrations of these ions in rainfall and in the soil water of unfelled plots. However, the decline seems genuine and probably reflects the reduced inputs to the soil following removal of a tree canopy that would have intercepted considerable quantities of air-borne material.

Streams

In Beddgelert Forest, stream water concentrations of potassium and nitrate have doubled since partial felling of trees in each of the catchments. Detailed data on

Plot in Beddgelert Forest cleared by whole tree harvesting.

Table 4. Potassium and phosphorus content of tree crown material and leaching rates from brash and through soil at Beddgelert. (kg ha^{-1} a^{-1}).

		K	P
Nutrient in crown, tree chipping method, prefelling		106	31.2
Nutrient in crown, fresh brash sampling, postfelling		119	33.0
Nutrient released from brash into brash lysimeters	---year 1	106	10.6
	---year 2	9	1.0
	2 year total	115	11.6
Nutrient leaching through litter (L) horizon	---year 1	110	11.7
	---year 2	28	5.6
	2 year total	138	17.3
Nutrient leaching through B horizon	---year 1	42	0.0
	---year 2	68	0.1
	2 year total	110	0.1
Nutrient leaching through C horizon	---year 1	22	0.0
	---year 2	44	0.0
	2 year total	66	0.0

streamwater concentrations and fluxes before and after the felling of 2 ha blocks in Kershope Forest (Adamson *et al.,* in press), show that concentrations and fluxes of potassium, ammonium, nitrate and phosphate at least doubled after felling, although they were not sufficiently high to be of major concern for water quality. Phosphate reaches the drainage waters during heavy rain, when water moves laterally through the peaty surface horizon, preventing adsorption in the mineral soil. Concentrations of calcium, magnesium, sodium, sulphate and chloride all drop after felling, although fluxes of calcium and magnesium initially increase, in part due to increased water fluxes as a result of canopy removal. These results allow calculations of the total solute losses to streams to be made. In conjunction with measurements of nutrient removal in the crop at harvest, and measurements of inputs in bulk precipitation, a nutrient balance can be drawn up, and judgements can be made concerning possible long-term nutrient depletion of sites.

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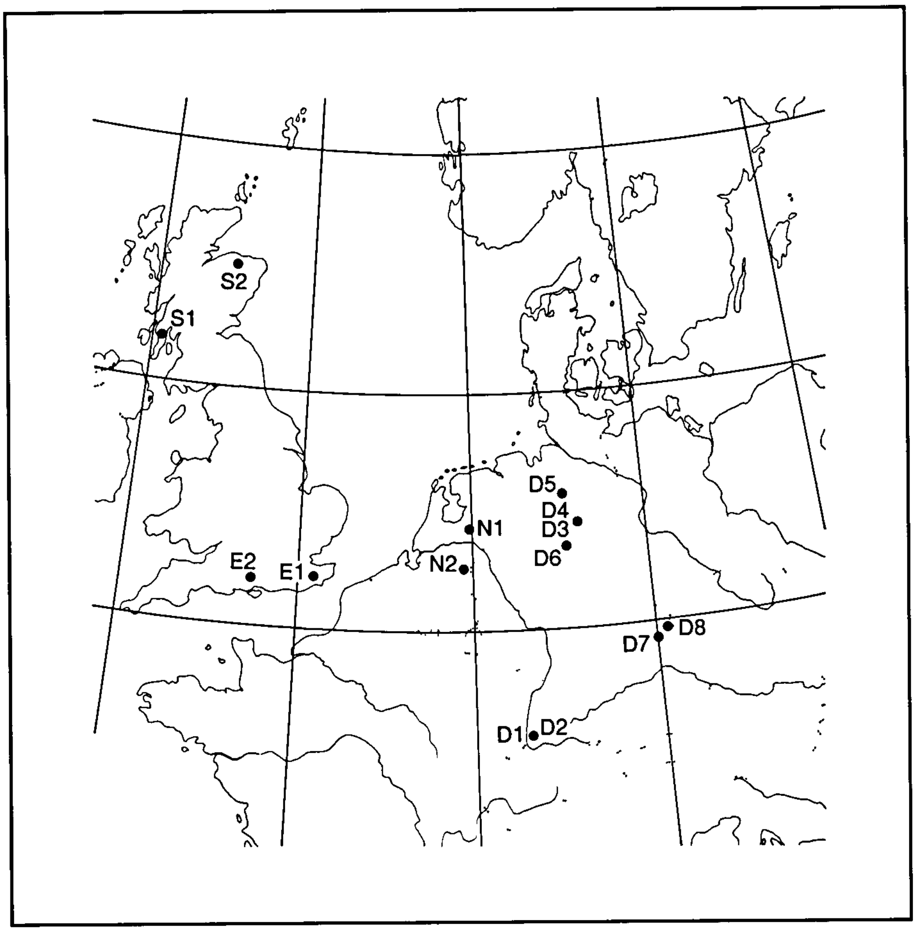

Figure 20
Map of W Europe showing locations of sampling sites

Rep Inst terr Ecol, 1983, 9-11
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Early Diagnosis of Forest Decline
(This work was supported by the Commission of the European Communities)

There has been growing concern recently at the state of health of forests over wide areas of Europe The visible symptoms of this 'new' type of forest decline are trees with thin crowns and discoloured foliage National surveys have shown several tree species to be affected However, it is difficult to assess accurately the extent of such damage from visual observations alone and it is even more difficult to assess the degree of potential damage in visibly unaffected areas

In order to address these problems, ITE, in collaboration with scientists from the University of Lancaster, the University of Ulster, Albert-Ludwigs University (Freiburg, W Germany) and the Ontario Ministry of the Environment, undertook a pilot survey during 1986 to evaluate a number of tests which might be useful for the early diagnosis of forest decline The ultimate objective was to define a test or tests which would allow predictions to be made of the state of health of forests in the absence of visible symptoms, and which would give an indication of possible causes

Because pollution has been implicated, either directly or indirectly, in this new type of forest decline, the design of the pilot survey took into account the different pollution climates which exist in Western Europe It was decided to sample along a broad transect from south-west Germany to north-east Scotland (Figure 20) This map shows the locations of the sampling sites, and Table 5 gives an indication of the pollution climates to be found in each region Sampling took place from July to September, using a modified minibus as a mobile laboratory Only three tree species were included Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*) At each site, up to 12 trees of each species, both with and without visible symptoms of damage, were sampled and described in detail In this pilot study the aim was to identify tests which showed consistent regional differences despite variations in soil type, in physical climate and genetic variation in trees The range of tests applied is shown in Table 6, with an indication of where the expertise exists In some cases measurements could be made in the field, but usually samples had to be prepared and stored before being transported to the laboratory for examination A brief summary of all the experimental results may be found in the survey report (Cape *et al*, 1988), but the more interesting results from the ITE-based tests are described here for Norway spruce Most of these tests were concerned with either the properties of the whole leaf (or needle), such as the dry weight:fresh weight ratio and nutrient content, or the properties of the leaf surface The results of the latter type of test showed consistent regional differences, and so fulfilled the initial aim of the pilot survey

The external surfaces of leaves are those most obviously exposed to such environmental factors as air pollution, or simply to the weather The cuticle of a leaf is covered by a layer of wax, which helps to waterproof the leaf and restricts uncontrolled diffusion of water vapour from inside the leaf to the atmosphere This layer of wax may also protect the leaf mechanically from abrasion and insect attack It can be seen to change with time, and with exposure to air pollution (Fowler and Crossley, 1986)
The amount of cuticular wax can be measured by shaking a fixed weight of spruce needles with a fixed volume of chloroform This method was used in the field, the extracted solution and the washed needles were returned to the

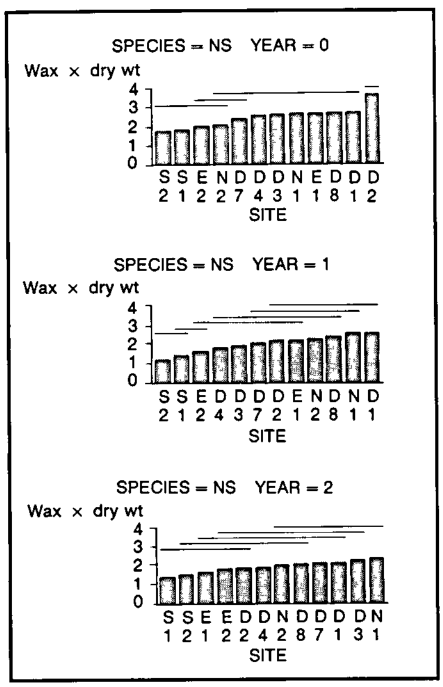

Figure 21
Amounts of surface wax extracted by 10s wash in chloroform expressed as % sample dry weight

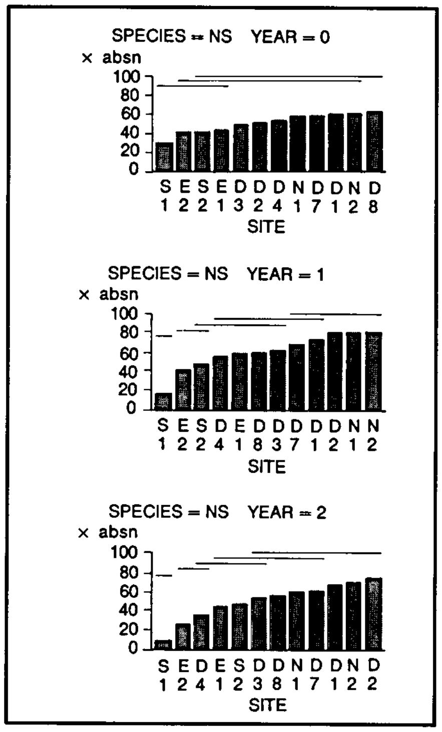

Figure 23.
Light absorption (%) of water extract of spruce needles

laboratory. After filtration to remove insoluble material, and removal of chloroform under vacuum, the wax was weighed The washed needles were oven-dried and weighed and the amount of wax calculated as a percentage of the dry weight The values for each site, calculated as the average over all trees at the site, are shown in Figure 21 for three year classes In general, trees from German and Dutch sites tended to have larger amounts of wax than trees from British sites

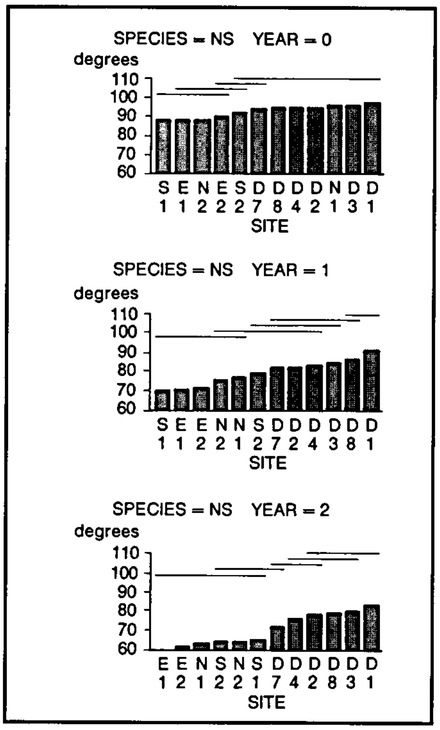

Figure 22
Contact angle of deionised water droplets on abaxial needle surfaces

The surface properties of the wax, related to both its chemical composition and physical structure, may be measured in terms of the contact angle of water droplets on the leaf surface An angle greater than 90° means that a water droplet retains its spherical shape and does not wet the surface, an angle less than 90° means that a water droplet has spread and wet the surface Droplets of distilled water (0 2μl) were placed on the leaf surface using a micro-syringe, and the contact angle measured using a binocular microscope with a protractor graticule At least 10 measurements were made for each year class for each tree, so that the values shown in Figure 22 are the averages of up to 120 measurements Although the differences between sites for newly-emerged (year 0) needles were small, a pattern developed markedly with time, with generally smaller values at British sites With two-year-old needles, there was a clear distinction between the British and Dutch sites and the German sites The rates of change were therefore also strongly regionally dependent, with much greater values at British sites These changes are not necessarily related directly to changes in the amounts of wax described earlier The contact angle is influenced by the physical structure of the wax layer, by its chemistry and by the accumulation of dust and other debris on the leaf surface This test fulfils the initial criterion of showing regional differences, but the direction of the changes is surprising, in that the greatest rate of change might have been expected in the more polluted areas, by analogy with results obtained with Scots pine (Cape, 1983) However, the chemical composition and morphology of the surface waxes on these two tree species are very different

The third test related to surface waxes was developed over 30 years ago (Hartel, 1953) and used as a measure of exposure to sulphur dioxide pollution Intact conifer needles are rapidly boiled in distilled water for 10 minutes The extract is decanted and allowed to cool, whereupon the liquid becomes cloudy as a wax emulsion forms The turbidity, measured in terms of light absorption, was found to increase with proximity to known sources of sulphur dioxide More recent studies with this test have shown that calcium ions in the extract are also important (Fuchshofer and Hartel, 1985) The results of this test for our survey samples are shown in Figure 23 There was again a consistent geographical distinction, with the Dutch sites showing the smallest values, and the British sites the greatest values These results suggest that the turbidity test is not applicable on a regional scale, despite its usefulness near point sources of sulphur dioxide

All these tests show good geographical distinctions, but the distinctions are not consistent The relative rankings of the Dutch and German sites, for example, are different in different tests The interpretation of the tests is even more complex and at this stage we cannot explain the results The observations may be related to visible damage symptoms, or to air pollution, but may equally be ascribed to differences in climate or soil type

In order to investigate the origins of the observed regional differences, we are now starting, together with researchers at the collaborating institutions, a programme of laboratory-based studies, which will allow the tests to be applied under controlled conditions where only one factor (e g air pollution, stress or genotype) is allowed to vary Only by such studies can a potential diagnostic test be validated for large-scale field use

Acknowledgements
ITE is indebted to colleagues in Germany, the Netherlands and Britain who helped to identify suitable sampling sites The Ontario Ministry of the Environment provided the invaluable assistance of Dr W D McIlveen during the sampling period The study could not have taken place without the full collaboration of the other institutions involved, and the results presented here, although more closely associated with ITE, must be seen as a part of the whole study
J N Cape and I S Paterson

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EARLY DIAGNOSIS OF FOREST DECLINE

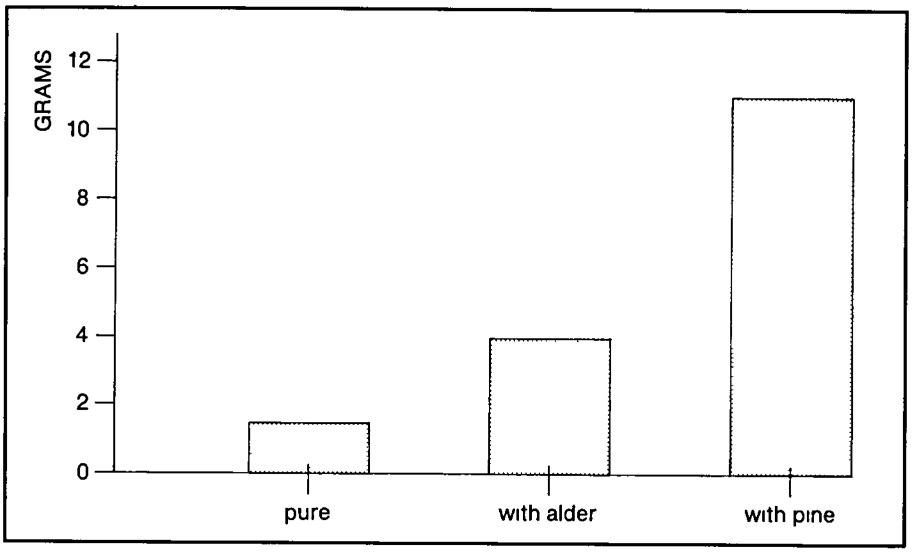
Table 5 Pollution climate of sampling regions

Region	**Average SO_2/NO_x** concentration	Frequency of O_3 episodes	Frequency of mist	Acidity of rainfall	Amount of wet deposited acidity
Black Forest (SW Germany)	+	+ + +	+ + +	+ +	+ +
Netherlands	+ + +	+ +	+	+ + +	+ +
Harz Mountains	+	+ +	+ + +	+ + +	+ + +
Fichtelgebirge (W Germany)	+ + +	+ + +	+ + +	+ + +	+ + +
S England	+ +	+ +	+	+ +	+
W Scotland	+	+	+ +	+	+ + +
NE Scotland	+	+	+	+ +	+

Table 6 Potential diagnostic tests used in pilot survey, on samples of foliage from 3 tree species

ITE	dry weight/fresh weight ratios nutrient analysis amounts of surface wax contact angle of water droplets Hartel turbidity test
University of Lancaster	buffer capacity of leaf tissue analysis of pigments emission of small organic molecules modulated fluorescence analysis for α-tocopherol
University of Ulster	water relations and photosynthesis
University of Freiburg	histology and histochemistry

Figure 25
Mean biomass (preserved 'fresh' weight) of earthworms per trap under Norway spruce canopies pure and mixed at Gisburn (two trapping periods in 1981, combined blocks 2 and 3 combined)



The Mechanisms of Tree Mixture Effects at Gisburn

The effects of growing trees in mixed stands, in the joint experiment being carried out at Gisburn by ITE and the Forestry Commission, were described in the ITE Annual Report for 1985 The reported findings, summarised in Table 7, were

(i) Scots pine increased the growth of Norway spruce, oak and alder at no cost to its own growth, the stand as a whole did better than the mean of the two components grown separately,

(ii) alder had a smaller beneficial effect on oak and spruce, but only at the expense of its own growth, the two effects cancelled out, to give an overall stand performance no different from what was expected,

(iii) oak and spruce tended to inhibit growth, not only of alder but also of each other, the oak/spruce mixture therefore grew less well than expected

In this report, results of further studies on the Norway spruce mixtures at Gisburn are presented

Field Studies

Foliar analysis of Norway spruce indicated that both phosphorus (P) and, more especially, nitrogen (N) appear to be involved in the improved growth of the mixed spruce stands, there is a significant positive relationship between height growth and foliar N and P concentrations (Figures 24a and 24b)

That both nitrogen and phosphorus are involved in this phenomenon points to an organic matter source, these two nutrient elements are known to be held tightly within organic materials whose rate of mineralisation can often limit tree growth on poor sites Breakdown of organic matter, and associated release of nitrogen and phosphorus, is largely mediated through microbiological activity, which in turn can be aided by mesofauna — especially earthworms Differences in microbial decomposition and in earthworm populations between the pure and mixed spruce stands at Gisburn were therefore estimated

The results (Figures 25 and 26) show that admixture of spruce with pine led to the greatest increase in both earthworm populations and the decomposer index relative to the pure stands, mixture with alder gave an intermediate resonse Subsequent investigation of spruce/oak mixture (Chapman, 1986) indicated there were no earthworms present In general, therefore, differences in biological activity parallel the growth responses, strengthening the view that enhanced turnover of organic matter is an important component of the mixture effect

To check whether increased biological activity was in fact accompanied by release of more N and P, lysimeters were placed within, and filled with material from, the forest floor (Chapman, 1986), leachates were collected fortnightly and analysed for N and P Results (Figure 27) indicate that the forest floor materials release most N and P under spruce canopies when pine is present, least under pure spruce and spruce-with-oak, and intermediate amounts under the spruce portion of the alder mixture There is good correspondence, therefore, between growth of spruce, N and P foliar levels, and mobilisation of these nutrients under spruce

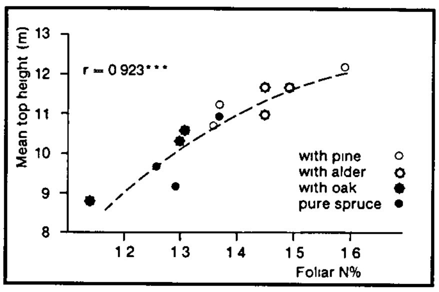
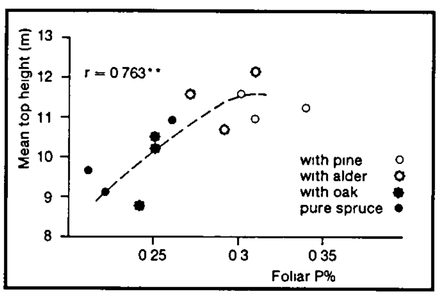


Figure 24a
The relationship between mean dominant heights (at 26 years) of Norway spruce pure and mixed and foliar N concentrations at Gisburn

Figure 24b
The relationship between mean dominant heights (at 26 years) of Norway spruce pure and mixed and foliar P concentrations at Gisburn



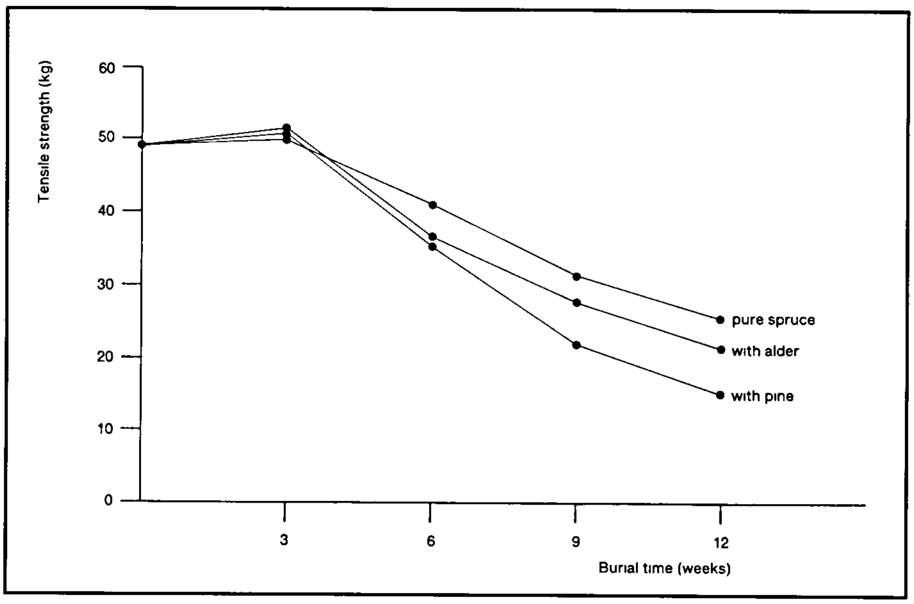


Figure 26
Mean loss in tensile strength with time of buried cotton cloth under Norway spruce canopies pure and mixed at Gisburn (all depths and three blocks combined, 1981)

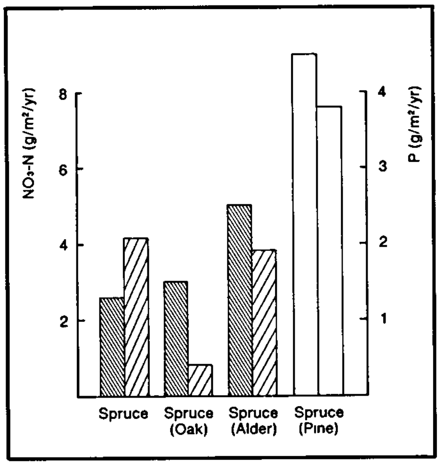


Figure 27
Mean gross fluxes of NO_3-N and P from forest floor lysimeters under Norway spruce canopies, pure and mixed, at Gisburn (block 2 only, 1983/1984)

Table 8 shows, however, that only the spruce/pine mixture gave a positive result for N mobilisation The spruce/alder mixture produced appreciably less nitrogen than the mean of the two components grown in monoculture, the presence of spruce seems to "switch off" the normally high nitrification associated with alder The low levels of nutrient release for the spruce/oak mixture were as expected Similar results were found for mobilisation of phosphorus Although there are several factors which might be involved, the mixing of the litters from the different species seems a likely source of the effect

Laboratory Studies
Laboratory studies of the effects of mixing forest floor materials enabled environmental variables such as moisture and temperature to be controlled while the interaction was being investigated

Chapman (1986) used decomposing forest floor materials which were leached at intervals to follow nutrient release, and from which CO_2 was monitored as a measure of concomitant respiration — assumed to be largely microbial activity He compared pure spruce, pure pine, and a 50 50 mixture of the two, using material from the fresh litter (L), the upper fermentation layer (F_1), the lower fermentation layer (F_2) and the humus (H) Results are shown in Figure 28

The release of N and P per unit of respired CO_2 was very slow at first, increasing with the age of the material, a result consistent with the view that nitrogen, initially, must be retained to reduce the C/N ratio Significant mixture interactions occurred, in which the observed values differed from the mean of the two separate components These effects were all positive, except for N and P release from L layer material, despite a positive interaction with respect to CO_2 evolution However, the negative effect of mixed L materials was considerably out-weighed by the positive interactions of the other horizons, with the F_2 layer in particular

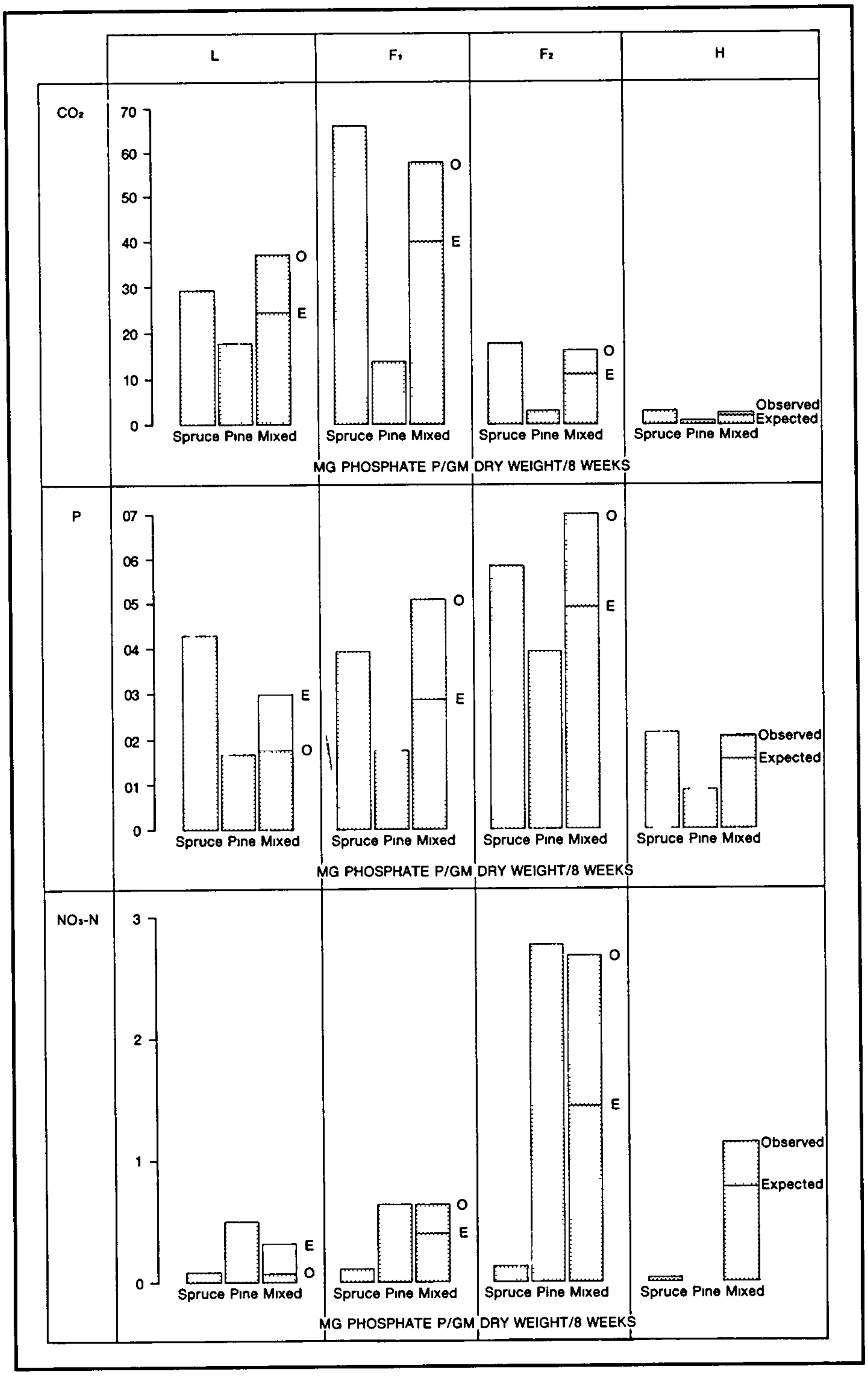


Figure 28
Mean fluxes of NO_3-N and P leached from Gisburn forest floor materials in laboratory microcosms over an 8-week period, and mean quantities of CO_2 evolved at fortnightly intervals Pure Norway spruce, pure Scots pine and mixed materials from litter layer (L) upper fermentation layer (F_1) lower fermentation layer (F_2) and humus (H)

dominating in the forest-floor interaction as a whole

Organic Matter Quality
As part of a PhD study, Ogden (1986) made some qualitative comparisons of the soil organic matter in unplanted grassland, pure spruce, pine, oak and alder stands, and the mixed spruce/pine stand at Gisburn These comparisons included (i) a determination of the ratio of low molecular weight to high molecular weight materials, to give an index of the degree of humification, (ii) the degree of enrichment with "bomb" ^{14}C, providing a measure of the incorporation into the surface soils of organic matter derived from the present vegetation

These indices of soil organic matter quality (presented in Figure 29) show the unplanted control — a heathy

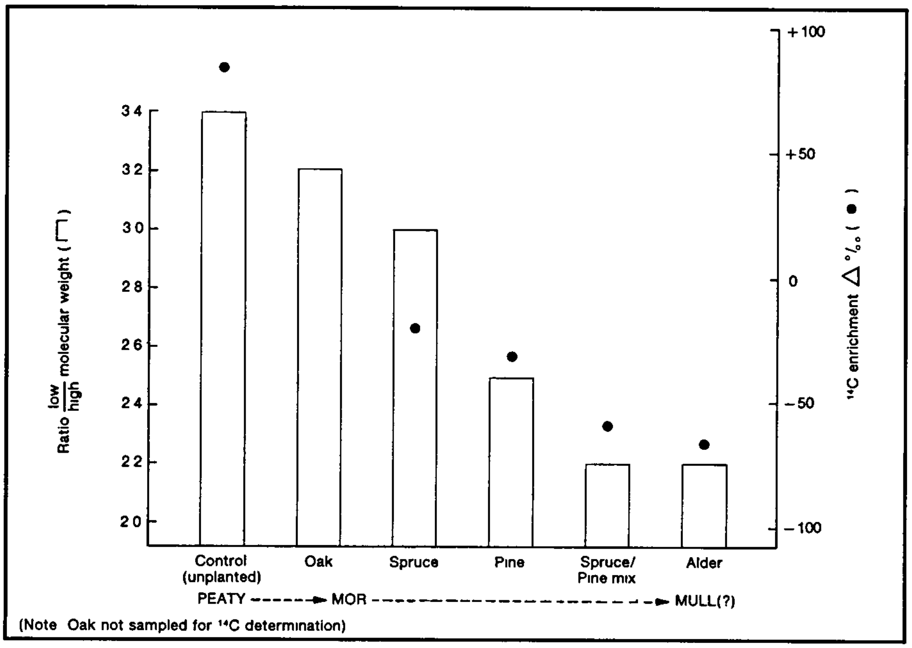


Figure 29
Qualitative analyses of borate soluble soil organic matter in some Gisburn stands, 1984

grassland with a tendency to peat formation — at one extreme and alder at the other Alder is known to have the most biologically active forest floor of the experimental stands and the most rapid turnover of litter All the tree stands can be regarded as site improving, in the sense of apparently increasing organic matter breakdown, on a site otherwise subject to peat formation Oak and spruce have least effect in these respects, alder most, with pine intermediate The mixed stand of spruce and pine is not intermediate between its two components, but very similar to alder, suggesting that it has greater site-improving qualities than either pure component

A H F Brown

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Table 7 Heights (m) of Norway spruce in pure and mixed stands at age 26 Gisburn, 3 blocks combined

	Ht of spruce	Mean ht of whole mixture	Mean ht of 2 components, pure
pure	8 8	–	–
Spruce/oak	8 8	7 2	7 7
Spruce/alder	9 8	8 7	8 5
Spruce/Scots pine	10 6	11 1	10 0

Table 8 Mean gross fluxes of NO_3-N and P from forest floor lysimeters for the stand as a whole in pure and mixed Norway spruce at Gisburn, 1983/84

	Observed		*Expected*
spruce	0 26		–
pine	1 14		–
alder	3 32		–
oak	0 09		–
spruce/pine	0 82	>	0 70
spruce/alder	0 48	<	1 79
spruce/oak	0 22	≃	0 18

Modelling Nitrogen Cycling in a Mixed Deciduous Woodland

Deciduous woodland is an important UK resource for hardwood timber, wildlife conservation and recreation It is also increasingly being seen as an alternative use for some of the land currently under agriculture, yet the management of mixed, uneven-aged deciduous woodland is often *ad hoc* or, at best, empirical There is clearly a need for a model system which accurately predicts changes in tree species composition and productivity with woodland development and simulates the responses of woodland growth to management practices Researchers in the USA (Aber and Melillo, 1983) have produced such a model, developed from a synthesis of extensive data from Hubbard Brook forest

In February 1986 we obtained the program for this model from the authors and applied it to data for Meathop Wood, a mixed deciduous woodland in Cumbria, which was a site for the International Biological Programme (IBP) and is probably the most intensively studied woodland in the UK

The FORTNITE model

The computer model called FORTNITE (an acronym for 'Forest Nitrogen'), is a comprehensive model for multi-species, uneven-aged forest ecosystems The program is written in FORTRAN 66, integrates data on tree growth, environmental factors and nitrogen cycling, and predicts changes in stand development with time, providing outputs on species composition, stem, root and leaf biomass, forest floor mass, and potentially available nitrogen in the soil

The data required to run the model are of four types (i) environmental factors, (ii) tree growth parameters, (iii) tree nitrogen response data and (iv) forest floor decomposition and nitrogen variables The environmental factors include, for example, the heat sum (degree days) for the global distribution of limits of each tree species, actual evapotranspiration at these limits, and the values of these variables for the study site Tree growth parameters are mainly regression constants and coefficients relating tree diameter at 1 3m to

Meathop Wood: oak-ash-birch mixed deciduous coppice-with-standards woodland.

b Decomposing litter layer

c Soil profile

d Surface root mat excavated by washing

a Woodland in 1970

height, weight, crown width, root growth, leaf weight and a variety of other growth aspects, for each of the species under study. The tree nitrogen response data are the constants and coefficients from regressions of tree responses on available soil nitrogen based on fertilizer trials. The rates of decomposition of different woody materials, leaf litter, twigs, woody and fine roots, are required for each of the species of tree in the woodland.

Meathop Wood

Meathop Wood is a mixed deciduous coppice-with-standards woodland, containing five major tree species, including oak (*Quercus petraea*), ash (*Fraxinus excelsior*), birch (*Betula pubescens* and *Betula pendula*), sycamore (*Acer pseudoplatanus*), with an understorey of hazel (*Corylus avellana*). The soil is an acid brown earth, averaging 13.5cm in depth and derived from Silurian slates and shales, overlying Carboniferous limestone. The site was last fully coppiced in 1939.

The central aim for the study of Meathop Wood as part of the IBP was to quantify rates of nutrient cycling in the wood. Figure 30 describes some of the main components studied. Most of the data required to run the FORTNITE model for Meathop Wood were determined during the IBP. However, it became apparent that information on several aspects of the woodland were missing, including, for example, fine root decomposition and the distribution of regenerating stumps after the coppicing of hazel. Some of the missing information has been obtained by fieldwork in the wood, other data are estimates based on the literature.

Running the model for Meathop Wood

The model as received from the USA required some modification before it could be applied to the Meathop Wood data. For example, a routine was implemented to accommodate coppicing in hazel, the form of equation relating tree height to diameter was altered, and graphical routines were added to increase ease of use and interpretation of results.

After modification, the model was run (using a VAX 8600 computer) for a 100-year simulation of Meathop Wood from the coppicing in 1939. A full description of the parameters used, and the assumptions made, is given in Harrison and Ineson (1987).

There was a close match between the predicted total biomass of the five tree species and the empirical biomass estimates made for the woodland between 1962 and 1972. The model showed that the total biomass may increase to about 280 tonnes dry matter per hectare, with oak and ash dominating (Figure 31) and predicted a significant decline in birch; the death of this species is now clearly seen in the wood. The model also predicted that sycamore, an invasive species, would not become a major component of the wood and that, apart from minor changes, the woodland would remain in a similar state to that presently seen.

Scenarios have been run on the model to examine the effects of selective

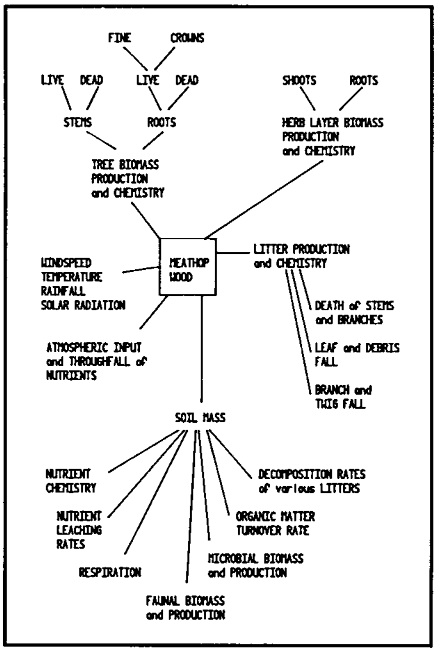

Figure 30
The data available for Meathop Wood as a consequence of the International Biological Programme study

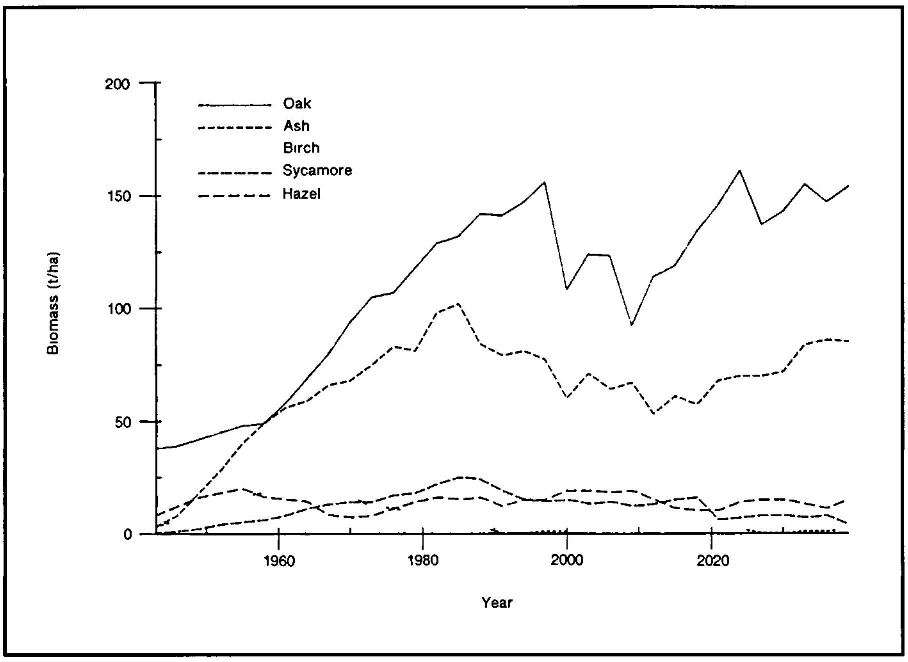

Figure 31
Trends in total biomass of each tree species in Meathop Wood, predicted using FORTNITE

felling of particular species on the productivity of other species One example suggests that the woodland would respond to removal of all the sycamore trees by significant increases in the growth of ash and oak, due to removal of competition for light and nitrogen However, with time, sycamore would become re-established (Harrison and Ineson, 1987)

Future developments
Some limitations in the model have been identified, for example it simulates the cycling only of nitrogen and not of other nutrients, which may well be limiting in UK woodlands, and does not simulate adequately the heterogeneity within the wood Ways of making good these deficiencies are currently being investigated

The model can be used to indicate where current knowledge is thin or non-existent One area is the response of broad-leaved species to fertilization Though some limited trials have been carried out (Evans, 1986), more fertilizer trials of the common broad-leaved tree species are needed, if we are to understand interrelationships between tree productivity and soil fertility

ITE is currently engaged in a co-operative programme with the Institute of Forestry and Soil Sciences, Shenyang, China, to synthesise data, collected over more than a decade, for the *Pinus koraiensis* broad-leaved forest type in north-east China It is hoped to use the model to predict the effects of management practices, such as selective felling, on long-term structure and productivity of this forest type

If the model is to be extended to UK woodlands other than the Meathop type, data for more tree species will need to be acquired Incorporation of data for a sufficient number of common species would enable simulation of woodlands of defined species composition and provide a more scientific basis for woodland management in the UK

A F Harrison and P Ineson

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The Effects of Ectomycorrhizal Inoculation on the Growth of Sitka Spruce Seedlings at a First-rotation Forest Site
Sitka spruce (*Picea sitchensis* (Bong) Carr) is the predominant tree in British commercial forestry Pot experiments with its seedlings suggest that it is responsive to inoculation with ectomycorrhizal fungi and that the species and isolate of fungus used, the soil type and fertilizer regime all influence the extent of the response (Shaw *et al*, 1982, Holden *et al*, 1983, Mason *et al*, 1983) Following a promising preliminary field trial (Last *et al*, 1984, 1984a) in which inoculated Sitka spruce seedlings performed significantly better than uninoculated controls in the first two years after outplanting, further trials have been initiated to evaluate the potential of mycorrhizal inoculation for forestry

In May 1985, a trial was planted on a first rotation forest site (Gleedlee) made available by Economic Forestry Group in Northumberland, north-east England The trial, which is described in detail in Wilson *et al* (1987), consisted of eight inoculation treatments and three control treatments (Table 9) which were planted in four 11 × 11 Latin squares on each of two soil types — a brown gley and a brown earth

Following inoculation, a random sample of plants was taken from each treatment at outplanting, for determination of root and shoot dry weights and the mycorrhizal characteristics of the root systems (Table 10) Root systems of inoculated

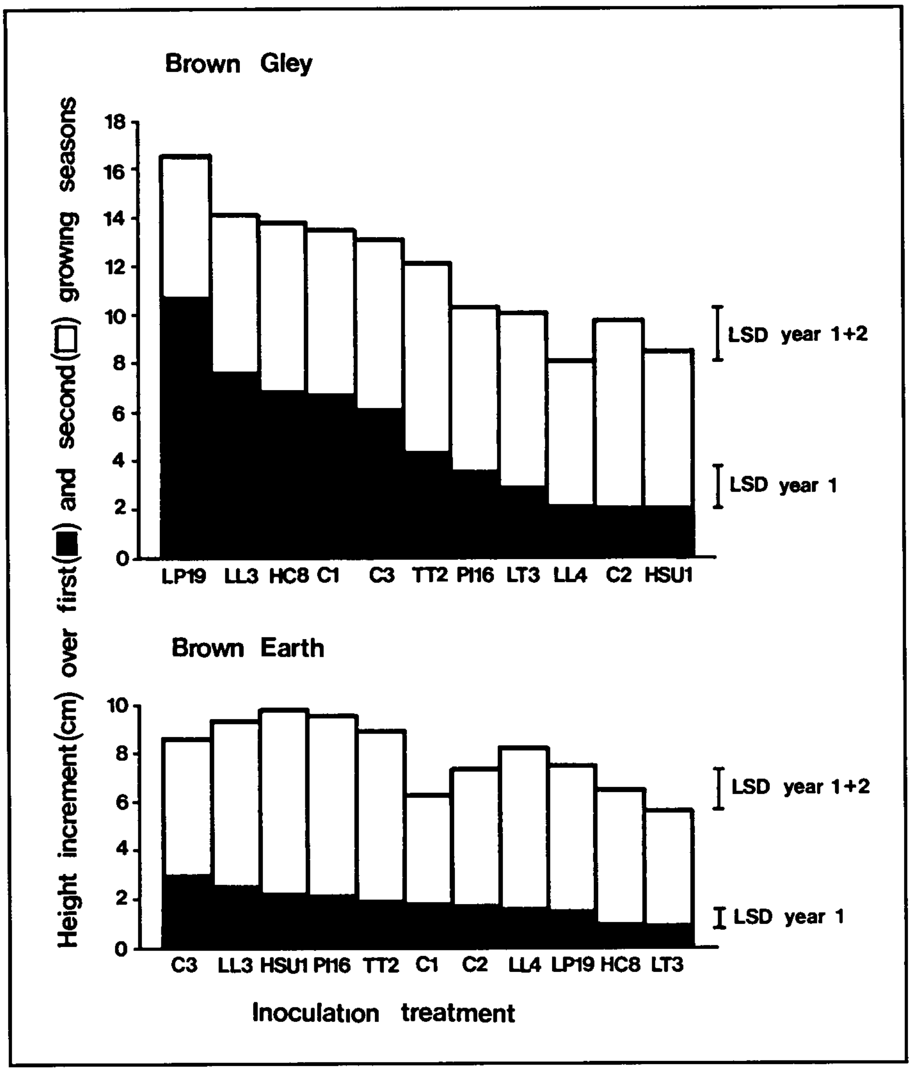

Figure 32
Height increment (cm) of inoculated Sitka spruce seedlings over the first 2 years after outplanting to brown gley and brown earth soils at Gleedlee Northumberland (for explanation of treatments see Table 9)

plants were 16-36% mycorrhizal, with inoculant fungi forming 0-66% of the mycorrhizas Control plant root systems were 10-21% mycorrhizal Differences in root and shoot dry weight between treatments indicate the amount of growth made by plants receiving the different treatments during the inoculation phase

Height growth has been monitored since planting Increments during the period from planting to the end of the first and second growing seasons are shown in Figure 32 There is a marked inconsistency in the results of treatments on the two soils On the brown gley, where the best results were achieved, plants inoculated with LP19 made most growth in the first year and plants inoculated with LL4, HSU1 and those receiving Control 2 treatment made least growth In the second year, the ranking of plants which was established in the first year was more or less maintained By contrast, on the brown earth soil, plants receiving the Control 3 treatment grew better than the other treatments in the first year and those inoculated with LP19, HC8 and LT3 grew least In the second year, plants initially inoculated with HSU1 made most growth and the ranking of the treatments changed Relationships between plant performance at the field site and parameters of plant growth determined at outplanting have been examined by use of correlation coefficients (Table 11) On the brown gley, in the first year, height increment and growth rate were positively correlated with the proportion of root tips that was mycorrhizal at the time of planting By contrast, on the brown earth, increment and growth rate were positively correlated with root/shoot ratio No correlations were found between increment or growth rate and any of the preplanting parameters when data for the first two years were combined The relationship between increment and mycorrhizal infection is shown in Figure 33 On the brown gley, points for all treatments except HSU1 conform to a linear relationship Examination of root systems from the field trial will be necessary to compare persistence of the various mycorrhizal types The poor performance of plants inoculated with *Hebeloma*

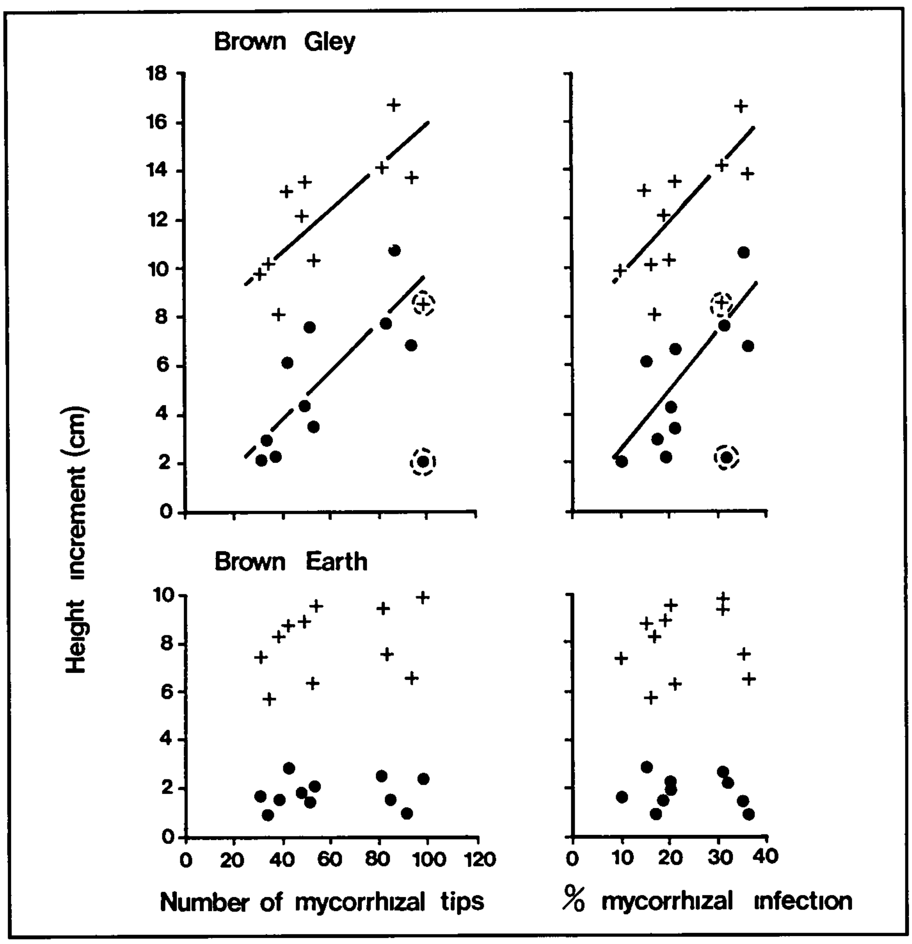

Figure 33
Relationship between height increment (cm) in the first (●) and first and second (+) years and the number of mycorrhizal root tips or % mycorrhizal infection determined prior to outplanting to brown gley and brown earth soils at Gleedlee (■) data points for HSU1 have been ignored in line fitting)

subsaponaceum (HSU1) on the brown gley may be due to the disappearance of the fungus after outplanting The mycorrhizal status of plants on the brown earth soil needs to be determined

Despite the low rates of mycorrhizal infection obtained, inoculation treatments did produce significant differences in height increment and growth rate in the first two years after outplanting In the trial reported here, a high infection rate was not a concomitant of greater plant size but an indication of *potential* for subsequent growth that was expressed in the brown gley soil but not in the brown earth Data of Cline and Reid (1982) and Holden *et al* (1983) show strong positive relationships between plant size and mycorrhizal infection when infection levels of >40-60% were achieved but not when infection levels were lower Our data show a strong linear relationship between *initial* infection and *subsequent* growth at much lower levels of infection (Figure 33), such that an increase in infection level of 10% resulted in an extra 2cm of height increment

Our results suggest that inoculation with ectomycorrhizal fungi may have a role to play in forestry in Britain and elsewhere The extent of initial mycorrhizal infection has a strong influence on early growth, at least on some sites This is important, as evidence from other trials (Wilson *et al*, 1987) suggests that invasion of tree root systems on first rotation forest sites by indigenous mycorrhizal fungi can be slow even in the proximity of established forests Although Sitka spruce does become mycorrhizal in British nurseries, it is not always with those fungi that are most suited to forest sites In other countries with different nursery practices, seedlings may remain non-mycorrhizal as a result of the use of regular fungicidal drenches to control pathogens (Trappe *et al*, 1984) and also through the use of containerised systems with semi-sterile substrates and high rates of nutrient addition In these circumstances mycorrhizal inoculation could be of considerable benefit However, further evaluation is needed of the effectiveness of a much wider range of mycorrhizal fungi on both first rotation and restock sites and on a wide range of soil types, to determine the sites and tree species which will most benefit from mycorrhizal inoculation

J Wilson, P A Mason and F T Last

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Table 9 Fungal isolates and control treatments used at Gleedlee

Treatment	Notes
HC8	*Hebeloma crustuliniforme* (Bull ex St Amans) Quelet 5 years old *P sitchensis*, Scotland
HSU1	*H subsaponaceum* Karst 6 years old *P sitchensis*, Scotland
LL4	*Laccaria laccata* (Scop ex Fr) Cooke 12 years old *P sitchensis*, Scotland
LL3*	*L proxima* (Boud) Pat provided by Dr R M Jackson, University of Surrey
LP19	*L proxima* 2 years old *P sitchensis*, Scotland
LT3	*L tortilis* (Bolt) S F Gray 5 years old *Betula* sp , Scotland
PI16	*Paxillus involutus* (Batsch) Fr 15-20 years old *Betula* sp , coal spoil, Scotland
TT2	*Thelephora terrestris* Ehrenb ex Fr provided by Dr R M Jackson, University of Surrey
Control 1(C1)	Root systems pruned, plants maintained in glasshouse in uninoculated peat
Control 2 (C2)	Root systems pruned, plants maintained in glasshouse in nursery soil
Control 3(C3)	Root systems not pruned, plants maintained outdoors in nursery soil

* initially thought to be *L laccata*, now identified as *L proxima*

Table 10 Mean dry weights and root system characteristics of inoculated Sitka spruce seedlings at outplanting

Measurement	**Treatment**[1]										
	HC8	**HSU1**	**LL4**	**LL3**	**LP19**	**LT3**	**PI16**	**TT2**	**Control 1**	**Control 2**	**Control 3**
Shoot dry weight (mg)	619*abc**	752*a*	614*abc*	670*ab*	61*ab*	580*bc*	522*c*	652*abc*	637*abc*	641*abc*	506*c*
Root dry weight (mg)	178*bcde*	224*ab*	145*de*	212*ab*	198*abc*	138*e*	144*de*	189*bcd*	157*cde*	240*a*	216*ab*
Root/shoot ratio	0 30*cde*	0 31*cd*	0 23*f*	0 32*c*	0 29*cdef*	0 24*ef*	0 28*cdef*	0 30*cde*	0 25*def*	0 38*b*	0 46*a*
No root tips	256*abc*	306*a*	211*bc*	266*abc*	239*abc*	202*c*	255*abc*	247*abc*	248*abc*	309*a*	279*abc*
% root tips mycorrhizal[2]	3*ba*	31*a*	17*bc*	31*a*	35*a*	16*bc*	20*b*	19*b*	21*b*	10*d*	15*cd*
% mycorrhizal tips attributable to inoculant	66	39	0	48	59	1	8	12	—	—	—

[1]15 replicates per treatment, counts of root tips made on *subsample* of root systems

[2]Arc sine transformations of percentages were used for statistical analysis Indication of significance is given against untransformed values

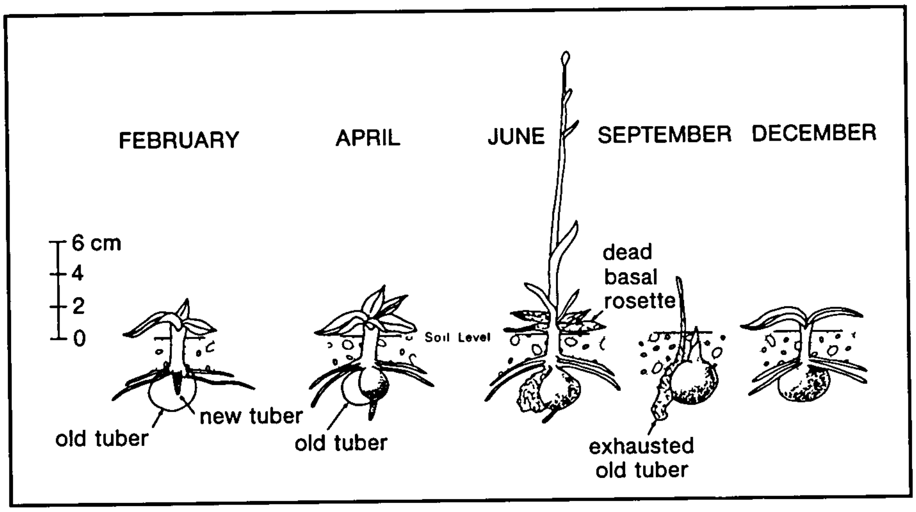
*Means followed by the same letter are not significantly different at p=0 05 as determined by ANOVA and Fisher's F-test

Table 11 Correlation coefficients between parameters determined at outplanting and plant growth in year 1 and year 1+2 after outplanting to brown gley and brown earth soils (n = 11)'

Variable	Brown Gley				Brown earth			
	Year 1		Year 1 + 2		Year 1		Year 1 + 2	
	1	2	1	2	1	2	1	2
1 Height increment	1 00		1 00		1 00		1 00	
2 Growth rate	0 99***	1 00	0 97***	1 00 7 0 99***		1 00	0 98***	1 00
3 Shoot dry weight	0 12	0 06	0 43	0 29	−0 12	−0 18	−0 35	−0 43
4 Root dry weight	0 11	0 14	0 42	0 43	0 49	0 45	0 06	0 03
5 Total dry weight	0 14	0 10	0 50	0 39	0 09	0 04	−0 25	−0 32
6 Root/shoot ratio	0 07	0 15	0 21	0 34	0 63*	0 63*	0 28	0 31
7 No of mycorrhizal root tips	0 46	0 44	0 39	0 33	0 04	−0 02	0 22	0 07
8 No of non-mycorrhizal root tips	−0 43	−0 40	−0 32	−0 29	0 48	0 48	0 28	0 32
9 Total No of root tips	−0 12	−0 10	−0 05	−0 06	0 54	0 49	0 46	0 40
10 % root tips mycorrhizal	0 60*	0 60*	0 51	0 45	−0 13	−0 18	0 05	−0 09

* and *** significant at p=0 05 and 0 001 respectively The first two variables were determined from field measurements and the remainder were determined on plants sampled at the time of planting

Figure 34
Generalised phenology of *Ophrys apifera*, illustrating tuber formation and annual production of leaves, roots and inflorescence



STUDYING ANIMAL AND PLANT POPULATIONS

Predicting the Probability of a Bee Orchid *(Ophrys Apifera)* Flowering

There is a growing awareness among plant ecologists that the size of an individual is more important in determining its behaviour than its chronological age Rabotnov (1950) was among the first to demonstrate that in any closed community there is likely to be a distribution of plants in different age classes He noted that there would be seedlings, juveniles, immature adult plants, reproductive plants, vegetative adult plants and senescent non-flowering plants, but he was unable to identify the factors which contributed to a plant switching from a vegetative to a reproductive state More recently, Werner (1975), Baskin and Baskin (1979) and Gross (1981) have shown that for a number of biennials a minimum size must be reached before flowering can be induced and, above a minimum size, the probability of an individual's flowering increases directly with rosette size

As little is known about the factors which influence flowering in terrestrial orchids, the relationship between leaf area and the propensity of an individual to flower or remain vegetative was studied over a six-year period in a population of bee orchids growing on a heavy clay soil at Monks Wood Individual plants in a permanent study area were identified using co-ordinates (Wells, 1967), The whole population was recorded on 22 occasions during the period 1975-85, the main census being made in July each year, when flowers were fully open Counts of the number of leaves in the basal rosette, and measurements of the length and breadth of the longest leaf, were made at intervals throughout each year

Leaves of *Ophrys apifera* usually emerge above ground from early September onwards, but in some years, e g 1985, appearance above ground may be delayed until November or early December Late emergence appears to be correlated with low rainfall in the period August to October Leaves remain green throughout the winter and spring and are unaffected by low temperatures or snow, although, in the absence of snow cover, fully expanded leaves may be blackened at the tips and edges by severe frosts Severe blackening, sometimes accompanied by death of individual leaves, occurs during periods of drying winds in late spring, and appears most severe in small plants, when all the leaves may be killed, although the subterranean parts of the plant survive

Tubers and roots are replaced annually New tubers arise in November as small white protuberances on the stem above the old tubers, eventually bursting through the leaf-sheath Growth is slow during the winter, but in mid-March the new tuber begins to increase in size rapidly, and by late May is as large as, or larger than, the old one White adventitious roots are visible above the new tuber in November, large plants having six to eleven roots by April, smaller plants have fewer roots, but tubers as small as 3mm in diameter usually have at least one root A generalised phenology, based on observations made on excavated plants, is shown in Figure 34

The number of leaves in the basal rosette increases steadily during the annual growth cycle, although there are large differences between individuals in the number of leaves in the rosette, probably reflecting differences in age During the six-year study, the mean number of leaves per plant for the whole population increased from 1 03 in late September to 1 98 by the end of November, reaching 3 23 in February, thereafter increasing to 4 05 in mid-April, and reaching a maximum of 4 7 in mid-May Average values mask considerable variation in the frequency distribution of leaf numbers between years (Figure 35), and between plants which flower and those which remain vegetative In general, plants with most leaves and the longest leaves, and hence the largest leaf area, were more likely to flower than plants with fewer and smaller leaves

The probability of flowering or remaining vegetative, as a function of leaf number in April or May, is given in Table 12 Plants with six leaves are certain to flower, plants with one leaf are certain not to flower In 1980, 1981 and 1985 all plants with five leaves flowered In four years out of six, all plants with two leaves remained vegetative Significant differences in the number of leaves and the length of the longest leaf between plants which were to flower and those that

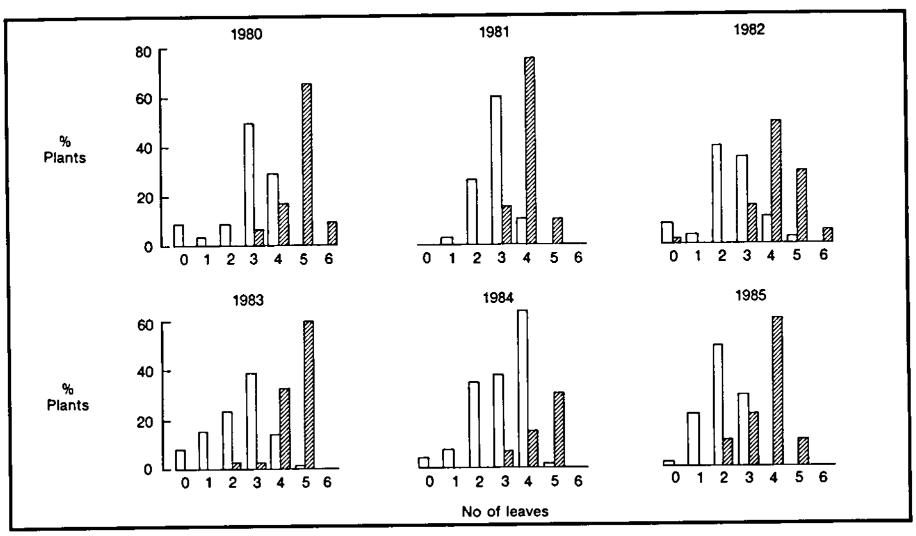


Figure 35
Frequency of leaf number, as a percentage of vegetative (open column) and flowering plants (hatched columns), in a population of *Ophrys apifera*, 1980-85 Counts were made when leaf numbers were at their highest

remained vegetative were found in all years and months, except for April 1981 (Table 13)

In order to look more closely at differences between plants which were going to flower and those which remained vegetative, an adjacent bee orchid population was destructively sampled on four occasions (16 November 1983, 7 March, 17 May and 28 June 1984) There were highly significant differences (p‹0 001) in leaf area, leaf number, number of roots, tuber volume and weight, and total plant dry weight at all sampling dates (except for new tuber weight in June) between plants which were going to flower and those which were to remain vegetative (Table 14) There was a progressive increase in all measured attributes with time, some growth taking place even during the winter months, when daily temperatures were considerably lower than the 6 °C threshold commonly taken to be the temperature below which growth ceases The mean daily temperature for the period 16 November 1983 to 7 March 1984 was 4 18 °C, yet in that period, mean total dry weight of plants which were to flower increased from 174 3mg in November to 228 0mg in March, and of non-flowering plants, from 12 2mg per plant to 36 7mg, indicating that some growth and accumulation of photosynthates had occurred Soluble carbohydrates in tubers were high in March and April (73% and 70% respectively) falling to 20% by 28 June, when plants were in full bloom

It was clear from the destructive sampling that plants with most leaves and the largest leaf area also had large tubers and high numbers of roots The critical size requirement for flowering may reflect that a certain level of carbohydrate reserves has to be reached before the plant is able to respond to the flowering stimulus; whether this is photoperiodic or temperature-related is at present unknown

We conclude that leaf area and numbers of leaves are reliable predictors of the potential of a plant of *Ophrys apifera* to flower However, other factors, of which water supply at certain critical times is probably most important, may prevent the plant from flowering, or restrict its performance by causing the abortion of some, or all of the flowers

T C E Wells and R Cox

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Table 12 The probability of *Ophrys apifera* flowering in July (F) or remaining vegetative (V) as a function of leaf number, measured in April or May in the period 1980-85

No of leaves	May 1980 F	May 1980 V	April 1981 F	April 1981 V	April 1982 F	April 1982 V	May 1983 F	May 1983 V	May 1984 F	May 1984 V	April 1985 F	April 1985 V	Total Number of observations
0	0	1 00	–	–	0 25	0 75	0	1 00	0	1 00	0	1 00	15
1	0	1 00	0	1 00	0	1 00	0	1 00	0	1 00	0	1 00	30
2	0	1 00	0	1 00	0	1 00	0 29	0 71	0	1 00	0 03	0 97	102
3	0 10	0 90	0 08	0 92	0 37	0 63	0 05	0 95	0 04	0 96	0 10	0 90	143
4	0 33	0 66	0 71	0 29	0 84	0 16	0 57	0 43	0 55	0 45	1 00	0	106
5	1 00	0	1 00	0	0 93	0 07	0 95	0 05	0 83	0 17	1 00	0	64
6	1 00	0	–	–	1 00	0	–	–	–	–	–	–	5

Table 13 Mean number of leaves and mean length of longest leaf in rosettes of *Ophrys apifera* among individuals which flowered or remained vegetative, on 14 occasions, 1980-85

Date	N= Flower	N= Vegetative	Mean number of leaves ± SE Flower	Mean number of leaves ± SE Vegetative	P‹	Mean length of longest leaf (cm) ± SE Flower	Mean length of longest leaf (cm) ± SE Vegetative	P‹
Feb 26 1980	94	83	3 23 ± 0 06	2 33 ± 0 07	0 001	ND	ND	
May 14 1980	95	83	4 52 ± 0 08	3 37 ± 0 07	0 5	6 43 ± 0 15	5 93 ± 0 17	0 001
Nov 28 1980	59	120	1 98 ± 0 10	1 29 ± 0 08	0 001	5 03 ± 0 27	3 28 ± 0 22	0 001
April 7 1981	78	135	4 05 ± 0 08	3 10 ± 0 05	0 001	5 55 ± 0 16	5 23 ± 0 10	NS
Sept 25 1981	146	74	1 49 ± 0 06	0 58 ± 0 07	0 001	2 74 ± 0 16	0 98 ± 0 15	0 001
April 19 1982	163	79	4 38 ± 0 06	2 91 ± 0 10	0 001	ND	ND	
Oct 26 1982	119	138	1 87 ± 0 05	1 05 ± 0 05	0 001	4 42 ± 0 17	2 86 ± 0 15	0 001
March 8 1983	124	148	2 99 ± 0 05	1 97 ± 0 06	0 001	5 32 ± 0 11	3 94 ± 0 12	0 001
May 23 1983	125	153	4 70 ± 0 08	2 84 ± 0 09	0 001	ND	ND	
Oct 1983	74	192	2 08 ± 0 03	1 38 ± 0 05	0 001	4 55 ± 0 17	3 19 ± 0 30	0 001
March 6 1984	74	196	3 04 ± 0 06	2 04 ± 0 06	0 001	5 33 ± 0 15	4 04 ± 0 24	0 001
May 1984	75	205	4 27 ± 0 04	2 81 ± 0 09	0 001	8 67 ± 0 31	6 29 ± 0 55	0 001
Nov 1984	46	218	2 02 ± 0 01	1 25 ± 0 03	0 001	5 16 ± 0 10	3 22 ± 0 17	0 001
April 1985	47	244	3 55 ± 0 09	2 23 ± 0 04	0 001	ND	ND	

Table 14 Leaf area, number of leaves and roots, volume of old tubers, weight of new tubers and total plant dry weight of *Ophrys apifera* at 4 sampling dates, separated into plants with inflorescences (F) and plants without inflorescences (V). (x = mean; s = standard deviation; n = number of plants in sample)

		16 November 1983			7 March 1984			17 May 1984			28 June 1984		
		V	F	P	V	F	P	V	F	P	V	F	P
Leaf area (cm^{-2})	x	1.92	17.69	<0.001	3.85	22.97	<0.001	6.62	28.64	<0.001	10.40	40.97	<0.001
	s	1.49	8.34	13									
Number of Roots	x	2.14	6.58	<0.001	2.77	6.80	<0.001	3.00	7.08	<0.001	4.31	7.23	<0.001
	s	0.95	1.44		1.48	1.23		1.55	1.75		1.74	1.30	
	n	7	23		9	20		11	23		16	13	
Volume of old tuber (ml)	x	0.014	0.182	<0.001	0.015	0.746	<0.001	0.136	0.538	<0.001	0.141	0.723	<0.001
	s	0.009	0.184		0.023	0.315		0.101	0.279		0.135	0.292	
	n	7	23		9	20		10	22		14	12	
Dry weight new tuber (mg)	x	–	0.739		–	0.450		13.5	101.4	<0.001	101	108	NS
	s	–	1.572		–	0.604		9.0	68.2		74	52	
	n	–	25		–	20		8	25		16	13	
Total plant dry weight (mg)	x	12.16	174.30	<0.001	36.66	228.00	<0.001	76.75	313.68	<0.001	160.0	642.0	<0.001
	n	6.33	100.43		17.51	85.44		66.14	169.52		122.0	251.0	
	s	6	23		6	20		8	25		16	13	

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The Ecology of the Midwife Toad

(This work was supported by the British Ecological Society)

Midwife toads, together with fire-bellied toads and painted frogs, are members of the Discoglossidae, a small, relatively primitive, family of anurans. In Europe this family is represented by seven species, of which three belong to the genus *Alytes.* Of these, the Balearic midwife toad, *Alytes muletensis,* is found only on Mallorca, and the Iberian midwife toad, *A. cisternasii,* is restricted to parts of central western Spain and Portugal. In contrast, the midwife toad, *A. obstetricans,* occurs throughout the Iberian peninsula and as far north as Belgium, where it is rare.

Midwife toads are unlike any other European amphibians in that they pair and spawn on land. As the female lays the eggs (in a long string), the male simultaneously fertilises them and wraps them around his hind legs. He then broods them on land for between three and four weeks until they are ready to hatch. When development of the tadpole within the egg is complete, the male kicks off the string of eggs into shallow water along the edges of a pond, where the tadpoles hatch and swim away within five minutes.

Male midwife toad carrying string of eggs

The breeding behaviour of *A. obstetricans* was studied in the field in Central Spain in 1986. Of particular interest was mate selection, since the choice of a male that is unable to brood eggs correctly may result in their failing to hatch.

The study sites were:

(i) the banks of a small lake near the mountain village of La Alberca, and
(ii) the banks of the Rio Frio near the village of Villiasrubias.

Midwife toads are nocturnal, hiding by day under rocks or in burrows excavated in earth banks. Adults found under rocks were sexed, weighed and their body length (snout to urostyle) measured. The size of eggs carried by males was measured using vernier calipers; the number of eggs carried was counted only in selected males, as this entailed the removal of the egg string from the animal.

The data given here relate to the lake population only. The mean body length of females (x=40.2mm ± S.D. 3.0; N=35; range =32-46mm) was significantly larger (p<0,001) than that of males (x=36.5mm ± S.D. 2.9; N=91; range =31-42mm). No significant difference (p>0.10) was found between the mean body lengths of males with (x=36.9mm ± S.D. 2.8; N=44; range = 31-42mm) and without eggs (x=36.1mm ± S.D. 3.0; N=47; range = 31-42mm).

The number of eggs laid per clutch by a female was investigated by:

(i) counting the number of eggs carried by individual males, and
(ii) counting the number of egg cases per egg string left behind once the tadpoles had hatched.

These results were most interesting and indicated that females lay a mean of 53.2 eggs per clutch (S.D.=9.6; N=44; range=33-76) and that 59% of the males were carrying one clutch of eggs, 35% 2 clutches, and 6% possibly 3 clutches (Figure 36). The total number of eggs produced by a female (x=155.4 ± S.D. 22.8; N=7) was determined by dissecting out the ovaries and counting the eggs of females caught before spawning had occurred. This was done using preserved specimens held in the Department of Zoology at the University of Salamanca.

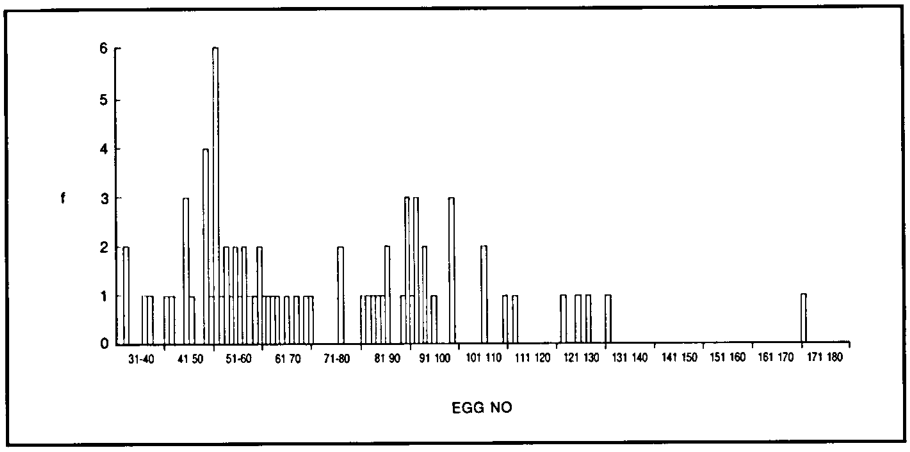

Figure 36
Number of eggs brooded by male *Alytes obstetricans*

Data from the egg cases retrieved after the tadpoles had hatched showed that a mean of 7 6% (± S D 14 7, N=49, range 0-100) of the eggs laid were infertile, and a further 2 5% of the total (± S D 3 5, N=49, range 0-18 1) failed to hatch although fertile, giving an overall mean egg success rate of 89 9% (± S D 15 0, N=49, range =0-100) More data will be collected to determine the relationship between egg failure rate and male body size

Males attract females by calling, starting at dusk from within their burrows and then slowly, as the night progresses, leaving their burrows to call from either cover or open ground Tape-recordings of males of different body lengths were taken for analysis on a sound spectrum analyser

Calls comprised three components call pitch, call duration and call rate Call pitch was inversely correlated with male body length (r= −0 8694, N=7, p ‹0 02) and tended to be constant for any individual once a calling bout was well under way Call pitch varied between 1424 and 1216 Hertz Call duration also varied, being between approximately 80 and 120 milliseconds, with no apparent correlation with male body length The time between each call of a calling bout (call rate) was inversely correlated with male body length and varied between 2 and 3 5 seconds

Using these three call parameters, artificial calls have been made using a synthesiser, in which each parameter has been varied independently of the others These calls will be played back to female midwife toads in 1987 to determine which part, or parts, of a male's call are important when choosing a mate
C J Reading

Development of Sexual Maturity in Juvenile Starlings
It has been known since the 1920s that increasing daylength during spring is the proximate factor by which birds time their breeding seasons Long days stimulate release of gonadotrophic hormones from the pituitary gland, these cause gonadal development and the synthesis of steroid hormones, which in turn are responsible for secondary sexual characters and sexual behaviour Since young birds hatch during spring and summer, when daylength is long, why do they show no gonadal development until the spring of the year after that in which they hatch?

Recent work on adult starlings has shown that long days have two distinct effects on the reproductive system One is the increased release of gonadotrophic hormones, due to increased release of gonadotrophin-releasing hormone (GnRH), from the hypothalamus of the brain The other effect of long days is to terminate synthesis of GnRH, leading to gonadal regression It is this second effect (photorefractoriness) which normally causes breeding seasons to end before short day lengths return during autumn Resumption of GnRH synthesis and the associated potential responsiveness to long days occurs during the short days of autumn (Dawson *et al*, 1986)

The annual reproductive cycle of starlings, and other birds, is therefore not innately cyclic Its periodic nature is imposed by cyclic changes in day length Under artificial conditions, if starlings are transferred from short to long days, the immediate response is gonadal growth, but after about six weeks, GnRH synthesis ceases and the gonads regress The gonads therefore only remain mature during the time it takes for long days to switch off GnRH synthesis If birds are kept on long days the gonads remain regressed indefinitely If they are transferred to short days, GnRH synthesis resumes between four and six weeks later, and the birds again become potentially responsive to long days

This system offers an explanation of why birds do not breed until they are almost one year old The reproductive system may develop in a similar, or identical, state to that of post-breeding photorefractory adults, and therefore young birds require exposure to short days before GnRH synthesis can begin and they become potentially responsive to long days Indeed, the reproductive system of free-living nestling and juvenile starlings does appear to be in a similar state to that of photorefractory adults (Williams *et al*, 1987a), and juveniles do become responsive to long days about four weeks after being transferred from long to short days (Williams *et al*, 1987b)

To test this hypothesis, four-day-old nestling starlings were collected from nest boxes and hand reared under different day lengths One group of nestlings was kept under long days continuously None of the birds in this group showed any gonadal development (Figure 37) Another group of birds was raised initially under short days and then transferred to long days when they were three weeks old One of these birds showed slight gonadal development two weeks after transfer to long days, but the rest of them showed no development (Figure 37) This would be expected if birds developed in 'photorefractory' state since it takes four weeks of short days to initiate GnRH synthesis A third group was initially raised under short days and transferred to long days at ten weeks of age All of these birds showed full gonadal growth, followed by gonadal regression some weeks later (Figure 37) These birds had seen enough short days to initiate GnRH synthesis before transfer to long days The last group was raised on short days continously They showed slow and continual gonadal maturation (Figure 37)

One striking feature of photorefractoriness in adult starlings is its dependence on thyroid hormones If photosensitive starlings have their thyroids removed and are then transferred to long days, they do not become photorefractory If photorefractory starlings on long days have their thyroids removed, photorefractoriness ends 4-6 weeks later If the reproductive system of nestling starlings is truly homologous with that of photorefractory adults, removal of thyroids should result in precocious gonadal maturation in young kept on long days When eight-day-old nestling starlings had their thyroids removed they did indeed show gonadal maturation a few weeks later (Dawson *et al*, 1987) However, not only did the gonads mature, but because thyroid hormones are also involved in somatic

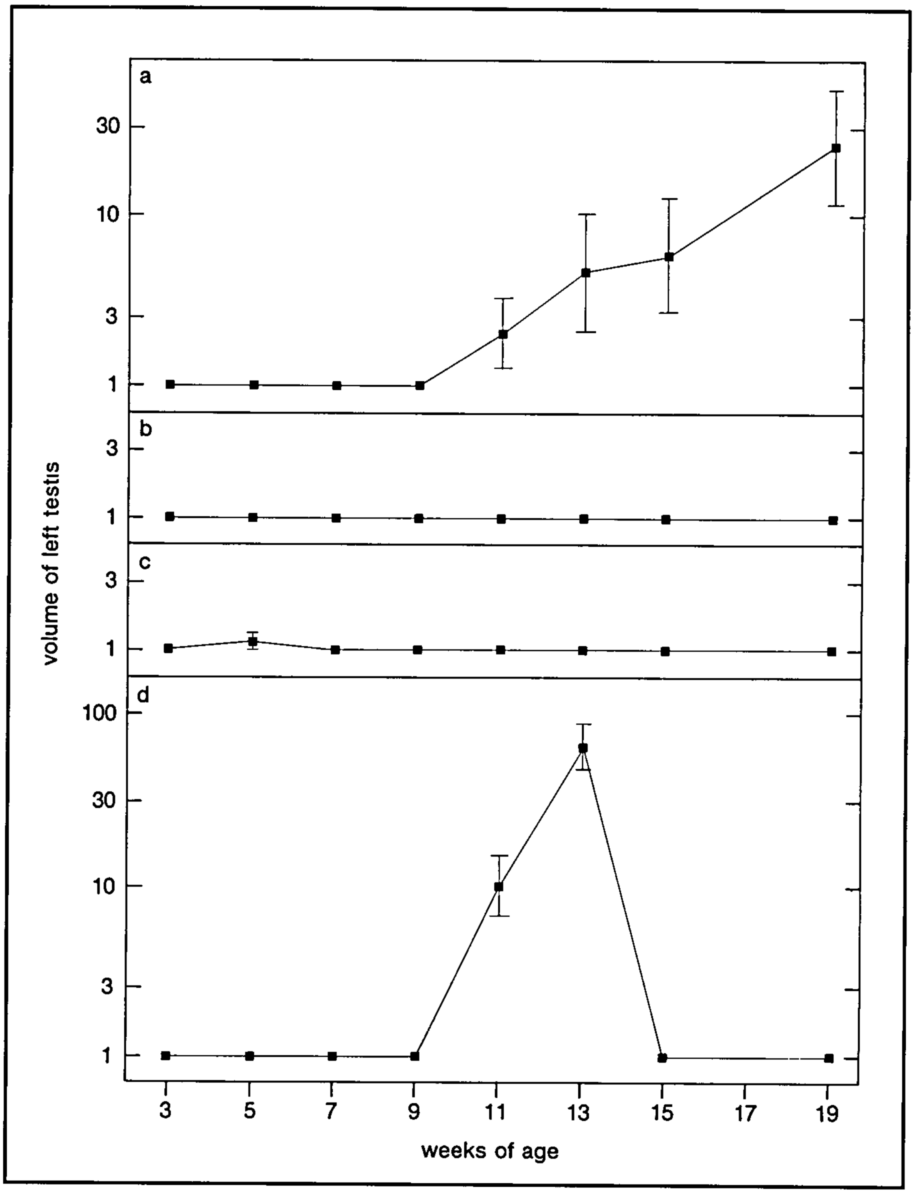

Figure 37
Changes in the volume of the left testis of starlings between 3 and 19 weeks of age Starlings were taken from nest boxes at 4 days old and then **a** reared on short days **b** reared on long days **c** reared on short days and transferred to long days at 3 weeks old, or **d** reared on short days and transferred to long days at 10 weeks old Each point represents mean ± SEM Volume is plotted on a log scale

development, these birds retained the physical characteristics of three-week-old birds indefinitely Sexual maturation while retaining juvenile features is called neoteny, and this condition is found naturally in the Ratites, such as ostriches and rheas Could thyroid dysfunction have been involved in the evolution of this group?

That thyroidectomy of nestling starlings results in precocious sexual maturation is further evidence that young birds are effectively photorefractory Short days are required to activate the reproductive system for the first time, and this is exactly the same process which occurs annually in adults The implication is that seasonal breeding is a repeated puberty (by definition the process of passage from sexual inactivity to activity) This may seem surprising since puberty has generally been regarded as a 'once in a lifetime' event However, this view has developed because of the extensive studies on continually breeding rodents and because of our anthropocentric viewpoint In reality, the majority of wild species in temperate latitudes reproduce annually only during a restricted period of the year, and a repeated puberty may be widespread

A S Dawson

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Kestrels in Farmland

The kestrel *(Falco tinnunculus)* Britain's most abundant and widespread bird of prey, occurs in a wide range of habitats, from remote hill-ground to city centres Kestrels feed mainly on small mammals, especially short-tailed voles *(Microtus agrestis)* but they will also take a wide variety of other prey and have adapted well to man-made environments Kestrels were not as seriously affected by organochlorine pesticides as were some other raptors, but nonetheless they declined in numbers in south-east England during the early 1960s, when dieldrin and DDT were used heavily Although numbers have now recovered, it was still felt necessary to investigate kestrels in arable farmland to gain a better understanding of their population dynamics The farming industry is undergoing rapid changes which are bound to affect our wildlife, kestrels included A knowledge of what factors limit kestrel numbers, and the extent of normal, year to year, variation in numbers, should enable us to make better predictions of the effects of any particular environmental change on kestrels and other raptors

Kestrel breeding and winter densities have been monitored in two contrasting farmland areas near Monks Wood since 1980 The mixed farmland area covers some 108km² in Rutland, where the main crops are wheat and barley, with some grass ley and permanent pasture in the valley bottoms Kestrels nest mainly in holes in deciduous trees, either in small woods or hedgerows The arable farmland area is 250km² of intensively cropped fenland near Ramsey in Cambridgeshire The main crops are wheat and roots, especially sugarbeet, potatoes and carrots There are fewer trees, and therefore fewer kestrel nest-sites, than in the mixed farmland area Small mammals live mainly in rough grass and exploit crops for only a few weeks before harvest In both areas, rough grass is limited to small patches or to strips along hedgerows, roads or ditches

Small mammal numbers in each area have been monitored by regular snap-trapping in the rough grass Species differ in their relative abundance between the areas in mixed farmland, voles are much more abundant than woodmice *(Apodemus sylvaticus)* but in arable farmland, woodmice sometimes outnumber voles in October or January (Table 15) The seasonal decline in numbers from autumn to spring is steeper for woodmice than for voles, so the latter are the most abundant small mammals in spring for both areas

Kestrel diet has been quantified by analysing pellets of undigested food remains collected at roosts or nests The main difference between the two areas is the greater frequency of woodmice in pellets from arable farmland, especially in autumn and winter, when woodmice are also most abundant in snap-traps (Table 15)

Kestrel winter numbers are estimated by making regular counts from a vehicle driven along a fixed 80km route In most years, kestrel densities have been roughly the same in both areas, and show the same seasonal decline from October to May (Table 16) This seasonal decline follows that of the main prey in each area, so that kestrel numbers are better correlated with vole than mouse numbers in mixed farmland, and the reverse is true in arable farmland (Figure 38) Food supply seems to be an important factor determining variations in numbers, both from year to year and during the course of a single winter The situation is not as simple as the correlations might suggest, more detailed experimental work has shown that kestrel numbers are not always closely adjusted to food supply in mid-winter After the end of October, when there are few kestrels migrating, birds experimentally removed from the population were not replaced by other birds moving into the vacated territories The population, therefore, fell below the food-supply level, a situation that could happen naturally if kestrels died for reasons other than food-shortage (such as poisoning, accidents or predation), or if they migrated out of an area in anticipation of a decline in the supply of food that did not then happen

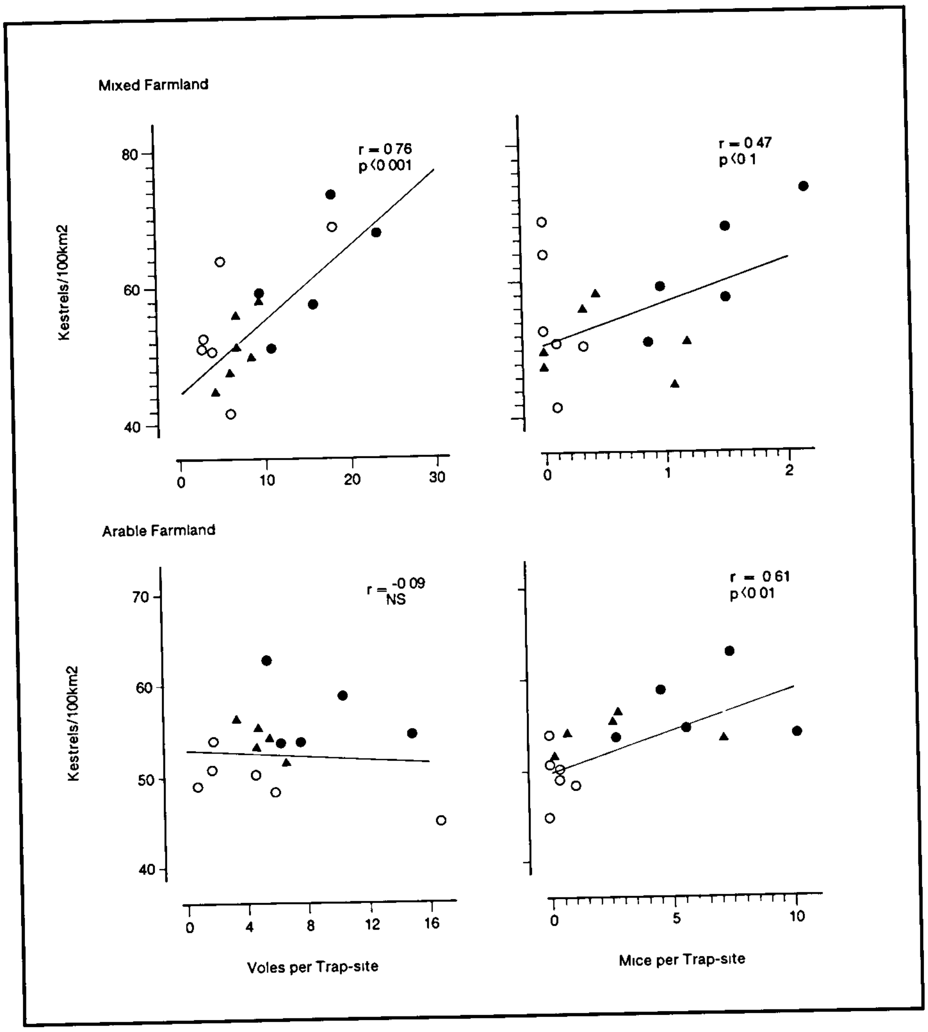

Figure 38
Relationships between kestrel densities and vole or woodmouse numbers in mixed and arable farmland The apparent trend between kestrel density and mice numbers in mixed farmland disappeared when the covariation of voles and mice was allowed for by partial correlation
= autumn = winter = spring

Kestrel breeding densities were recorded by thoroughly searching both areas each spring in order to locate all nesting pairs The density of pairs in these areas is lower than that previously found in more suitable vole habitat in Scotland (Village, 1985) In mixed farmland, density has ranged from 32 to 9 pairs $100km^{-2}$, with a steady decline from 1983 Numbers in arable farmland are more stable, 16-9 pairs $100km^{-2}$, but about half the peak densities of mixed farmland The difference between the two areas is not due to the scarcity of natural nest-sites in the arable area because neither population could be increased by providing extra nest-sites In 1985, nestboxes were erected in a 7 × 7km section of each study area This increased the density of nest-sites available to kestrels in these sections, but has yet to make any differences to the density of breeding pairs there (Table 17)

Experimental removal of nesting birds showed that females were more likely to be replaced by new birds than were males Males have to feed their mates in the pre-lay and incubation stages, and the lack of male replacements suggests that any non-breeding males in the population were having difficulty in catching enough food to feed a female Food supply was thus the most likely limit to breeding numbers, but over the last six years there has been only a poor correlation between kestrel breeding density and the spring vole trapping index This may be because other prey are also important, or because food availability is partly determined by other factors, such as rainfall or temperature These ideas will be tested when sufficient data have been collected to allow a more detailed examination of annual variations in breeding density

A Village, N J Westwood and D Myhill

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Table 15 Occurrence of woodmice in kestrel diets (% of pellets containing mouse remains) and traps (% of total vole and mouse captures) in mixed and arable farmland, 1980-85

		Arable				Mixed			
		% Pellets	n	% Traps	n	% Pellets	n	% Traps	n
1981	Winter	–	0	–	0	8	90	0	42
	Spring	21	28	0	94	2	60	0	107
	Autumn	19	37	27	115	8	89	4	68
1982	Winter	18	45	3	39	10	93	0	41
	Spring	13	52	8	24	3	78	0	22
	Autumn	35	46	57	72	12	50	8	72
1983	Winter	35	110	46	35	6	144	15	54
	Spring	33	49	33	6	5	55	7	30
	Autumn	51	65	30	43	20	60	9	137
1984	Winter	46	160	60	67	7	165	4	48
	Spring	12	65	0	10	2	65	0	34
	Autumn	48	62	31	85	18	85	8	119
1985	Winter	35	165	11	36	11	166	19	31
	Spring	10	125	0	11	4	111	5	19

Table 16 Mean (SE) kestrel winter densities (birds $100km^{-2}$) in each study area, 1980-85

	Mixed Farmland	Arable Farmland
October	60(3)	55 (2)
November	63 (6)	55 (1)
December	57 (5)	52 (2)
January	46 (4)	53 (1)
February	48 (6)	52 (1)
March	58 (5)	51 (1)
April	47 (5)	47 (1)
May	–	42 (1)

Table 17 Density ($100km^{-2}$) of usable nest-sites and breeding kestrel pairs in control and experimental areas 1984-86 Nest-sites were added to experimental areas just prior to the 1985 breeding season

		Mixed Farmland		Arable Farmland	
		Usable nest-sites	Kestrel pairs	Usable nest-sites	Kestrel pairs
1984	Control	48	24	15	12
	Expt	37	16	15	14
1985	Control	56	15	11	11
	Expt	65	18	52	12
1986	Control	56	11	15	11
	Expt	84	6	52	10

Estimating the Numbers of Red Deer in an Enclosed Area of Commercial Forest at Rannoch, Perthshire

Managers of commercial forests in the Scottish uplands have become increasingly concerned about the levels of crop damage brought about by the widespread penetration and settlement of plantations by red deer Although many of these forests are fenced against deer, the fences are costly, and they do not always remain effective Moreover, it is difficult to plan control measures, and to assess their effectiveness, without reliable information on deer abundance Research into the ecology of deer in such habitats also requires estimates of population densities Recognition of these common problems led to research aimed at testing what seemed the two most promising procedures for estimating the abundance of deer in concealing habitats (i) "drive-counting", using a line of people to beat through an area to flush and tally any deer present, and (ii) the "faecal accumulation" method, using known information on the defaecation rate of deer to interpret the rates of appearance of faecal deposits on sample areas of ground The first stages of this project, largely devoted to red deer (Mitchell and McCowan, 1980, 1981, 1982, 1983, 1984, Mitchell, McCowan and Campbell, 1983), with limited opportunistic work on roe deer (Mitchell *et al*, 1985), gave encouraging results However, much of this work was done in relatively small enclosures (up to 20ha) with known numbers of deer It still had to be shown that these methods could be applied successfully in larger, more typical, areas of commercial forest

The Camghouran Block (520ha) of Rannoch Forest was selected for study mainly because it had a resident population of red deer confined in thick woodland by a well-maintained deer fence Only about 25% of the area was completely open habitat (rides, unplanted parts and failed plantings), most of it being planted with Sitka spruce and lodgepole pine at 2500 trees/ha Trees were 1-4m tall, at the pre-thicket and thicket stages Except where the canopy had closed, the ground vegetation was partly old *Calluna* heath (dry sites) and deep *Molinia* grassland (wetter parts) As the area lay in a shallow basin, neighbouring high ground gave several vantage points from which deer in the open could be observed without disturbance Being able to view the area from outside was also potentially useful for casual observations on the deer, and controlling drive-counts (using radio communication) Vantage-point observations were made, when possible (by Forest Rangers at dawn and dusk, and by the authors at other times), for extra information on the minimum number of deer present The fence and gates were checked regularly for damage and signs of deer movement, damage to gates may have allowed a loss of some deer in late September 1982

Evaluating the two methods of population assessment clearly depended on there being other information on the actual number of red deer present, but a complete kill of the red deer at the end of the study period was impractical Instead, following a method first used in New Zealand (Riney, 1957, see also Caughley, 1977), the change in the faecal accumulation rate (FAR) associated with a known kill of red deer was assessed, the original population could then be estimated from the number killed and the proportionate drop in FAR

FAR measurements were begun in October 1981, suspended during the red deer cull (September 1983 to March 1984), and then continued until September 1984 Eighty permanent plots, each of 100m^2, randomly distributed over the whole area, were visited periodically to classify, count and clear away all pellet groups To minimise the effects of faecal decay, visits were more frequent in summer than in winter, marked samples of faeces were also observed to assess rates of decay

Table 18 shows the results in terms of deposits/day for the whole study area, calculated directly from what appeared on the sample plots in each period Despite discontinuities (due to a possible loss of deer in September 1982, and to the red deer cull in 1983-84), each year shows a distinct cycle, with a peak in winter and a trough in summer Comparing the five equivalent periods in 1983 (pre-cull) and 1984 (post-cull) indicates a reduction in FAR of 55-75%, an average drop of 67% Therefore, if a cull of 30 red deer reduced the FAR by 67%, the original population in late summer 1983 must have been 45 red deer, i e 30 × 100/67

Before the calving period in June 1983, the population must have been about 33 The post-cull population in early 1984 would have been about 15, rising to around 19 after calving Table 18 also includes estimates of individual faecal output, which show an annual cycle, ranging from about 10-13 deposits/deer/day in spring/summer to 21/deer/day in autumn/winter It seems unlikely that the annual cycles shown in these results reflect the true pattern of faecal output, although similar findings have been reported elsewhere (Staines and Welch, 1984) Earlier work on captive red deer in both rich and poor habitats, together with what is known about ruminant nutrition, strongly suggests higher rates of food intake and faecal output in summer than in winter The most likely explanation for the apparent summer minimum involves the combined effects of faecal decay and difficulties of finding faecal deposits, sample plots, particularly grassy ones, were much more difficult to search in summer

Drive-counting such a large area needed much planning and a large team of people The only time of year when 100 volunteers, together with 12-15 Forestry Commission staff (equipped with radio transceivers), could be assembled, was in early September On the first count, unforeseen problems arose, including sporadic failures in radio communication and some fragmentation in the line of beaters, so the results could not be interpreted with confidence, some deer may have remained undetected and others may have been tallied more than once In the following two years, counts had to be abandoned at the last minute due to heavy rainfall and flooding

Vantage-point observations, covering up to 40% of the total study area, seldom detected more than a few red deer at a time, often none The deer were much more active at dawn and dusk, so the Forest Rangers tended to see most Even so, in 69 observation periods between April 1982 and September 1983, the most the Rangers saw on one occasion was 23 red deer, i e about half the estimated population and less than the number subsequently shot These observations reflect the difficulties in detecting red deer resident in thick woodland

Results for the faecal accumulation method seem to confirm an earlier suspicion that this method is likely to give more reliable estimates of population density when applied over the colder months than at other times of year, i e when the vegetation is short and faecal decay slow This method is potentially useful, for both management and research purposes

Drive-counting, by contrast, is more limited in applicability Although it has been shown to work well with red deer in relatively small areas (up to 20ha), it is more likely to fail in larger areas, difficulties increase directly with the size of the area

ITE is grateful to the Forestry Commission for helping to finance the extra fencing, and for the use of the Camghouran Block, Rannoch Forest The Commission's Rangers gave much help and co-operation

B Mitchell and D McCowan

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Table 18 Faecal accumulation rates, deer numbers and apparent rates of faecal output of red deer in the Rannoch study area

Period	Total deposits/day Mean ± SE	Deer population	Deposits/ dear/day Mean ± SE
4 October 1981			
6 February 1982	936 ± 152	?	?
9 April	901 ± 147	?	?
10 June	315 ± 72	?	?
3 August	494 ± 119	?	?
7 October	1000 ± 148	?	?
Possible changes in deer population (see footnote)			
7 October 1982			
1 December	591 ± 114	33	18 ± 4
9 March 1983	763 ± 167	33	23 ± 5
Average (autumn/winter)	677 ± 100	33	21 ± 3
9 March 1983			
3 May	532 ± 103	33	16 ± 3
31 May	349 ± 106	33	11 ± 3
5 July	334 ± 88	33	10 ± 3
3 August	493 ± 136	33-45*	11-15 ± 3-4
1 September	743 ± 219	45	17 ± 5
Average (spring/summer)	490 ± 61	c 37	13 ± 2
Heavy cull of red deer (30 shot, September 1983 to February 1984)			
9 March 1984			
27 April	133 ± 44	15	9 ± 3
8 June	93 ± 37	15	6 ± 2
6 July	150 ± 60	15	10 ± 4
6 August	188 ± 67	15-19*	10-13 ± 4-5
8 September	236 ± 69	19	12 ± 4
Average (spring/summer)	160 ± 25	c 16	c 10 ± 2

Note – Problems with forest gates being left open could have allowed a loss of a few deer in late September 1982
*Increase due to birth of calves in June

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CHEMICALS IN THE ENVIRONMENT

The Effect of Gamma-HCH (Lindane) on the Behaviour and Survival of Pipistrelle Bats

Lindane, the gamma isomer of hexachlorocyclohexane (gamma-HCH or gamma-BHC), is one of few halogenated hydrocarbon insecticides still widely used for treating structural timbers in Britain Many species of bats in Britain regularly roost in close proximity to this type of timber and are therefore often exposed to insecticides which could be lethal The evidence that gamma-HCH is responsible for the deaths of bats is mainly circumstantial Specific incidents have occurred where deaths of bats have been preceded by treatment of their roost with lindane (Voute, 1981) and, on a wide scale, there is a correlation between the increased use of pesticides and declines in bats' populations (Stebbings and Griffith, 1986) Racey and Swift (1986) showed that gamma-HCH was lethal to bats under experimental conditions in captivity, but a question remains about how well these conditions replicated the type of exposure experienced by wild bats

In this study, two large outdoor enclosures (9m × 10m × 2m) were constructed which allowed the bats to fly freely and where there was a choice of roost site Eight adult pipistrelle bats (*Pipistrellus pipistrellus*), which had been taken from the wild and trained to feed on mealworms, were kept in each enclosure One of these groups was exposed to gamma-HCH applied to wood blocks which had been immersed in a hexane solution of gamma-HCH, while the other group was given blocks containing no gamma-HCH During the first 44 days, dosed blocks with an initial surface gamma-HCH concentration of 9 94 ± 1 15mg/m^2, estimated from surface scrapings, were used and for a further 44 days blocks with an initial surface gamma-HCH concentration of 866 ± 51mg/m^2 were used

Blocks were placed in the roost boxes to simulate the type of exposure experienced by wild bats Each group of bats was checked and fed daily Feeding activity was recorded automatically and used as a measure of bat behaviour, to detect any sublethal toxicity Bats exposed to gamma-HCH were also given a roost box with a wood block containing no gamma-HCH

Six of the eight bats in the group exposed to gamma-HCH died, while all the bats from the control group survived ($P < 0\,007$) However, only one of the eight bats exposed to gamma-HCH died during the first 44-day period, when a low dose was used There was no detectable effect prior to death, on the total activity, diurnal pattern of activity or roosting behaviour of bats exposed to gamma-HCH, although there was a significant weight loss Bats exposed to gamma-HCH did not show a preference for the roost box with no gamma-HCH present, which suggests

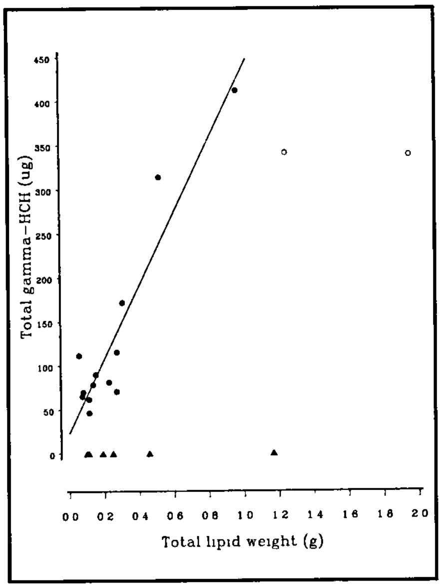

Figure 39
The total weight of gamma HCH in the carcasses of each bat in both experiments plotted with the total weight of lipid extracted from the carcasses Bats which died during the experiments are marked by dots, those which survived exposure to gamma-HCH are marked by circles and 6 of the bats in the control groups, which had no exposure to gamma HCH are marked by triangles Data from 3 bats in experiment 1 were excluded because when found the carcasses were incomplete due to scavenging by voles and shrews The solid line represents a linear least squares regression ($r^2 = 0\ 881$ $P < 0\ 001$) fitted to the data for bats which died during the experiments and the dashed lines mark the 95% confidence intervals for estimates of individual values based on the regression model (regression equation $Y = 413x + 23$)

that gamma-HCH did not actively repel bats from a roost site

In a second experiment, there were three groups of five adult bats kept in identical indoor cages under conditions similar to those used by Racey and Swift (1986) Two groups were exposed to identical wood blocks dosed with gamma-HCH, which gave an initial surface concentration of 21 1mg/m^2, while the other group received a wood block treated with solvent alone All bats in the groups exposed to gamma-HCH died within 17 days, while all bats in the control group survived ($P < 0\ 001$) Bats which died also lost weight before death

Tissues of bats were analysed for gamma-HCH by gas chromatography There was a critical concentration of 622 ± 102 μg gamma-HCH/g extractable lipid at which bats died The total weight of gamma-HCH in the carcasses of bats which died during the experiments was directly related to the weight of extractable lipid (Figure 39) The two bats which survived exposure to gamma-HCH in the first experiment probably did so because they had a large mass of subcutaneous fat, which buffered them against the toxic effects of gamma-HCH However, loss of this fat through metabolism would probably have led to the death of these individuals On average, bats died when the gamma-HCH concentration in the body reached 27 9 ± 4 8μg/g, but this value increased as body weight increased (Figure 40)

This work confirms the results of a previous study, that gamma-HCH is toxic to bats in conditions simulating exposure in the wild It has also shown that bats which have large amounts of fat are more tolerant to gamma-HCH than bats in poor condition Figure 41 shows the weights of wild pipistrelle bats at different times of the year and, if this is compared with Figure 42, it is clear that, at some times of year, these bats have very low levels of adipose fat The effect on survival of exposure to gamma-HCH will depend on the level of exposure, the rate of gamma-HCH detoxication, and the metabolic state of bats, which is related to time of year

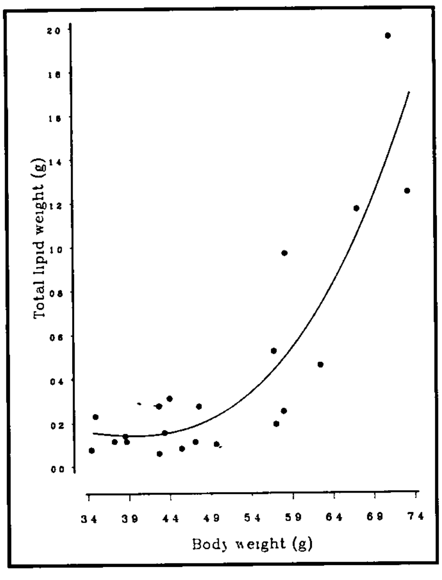

Figure 40
The total weight of lipid extracted from the carcass of each bat plotted with body weight The solid line represents a cubic least squares regression ($r^2 = 0\ 844$) fitted to the data The dashed lines mark the 95% confidence intervals for the regression line (regression equation $y = 8\ 14x - 1\ 94x^2 + 0\ 15x^3 - 11\ 16$)

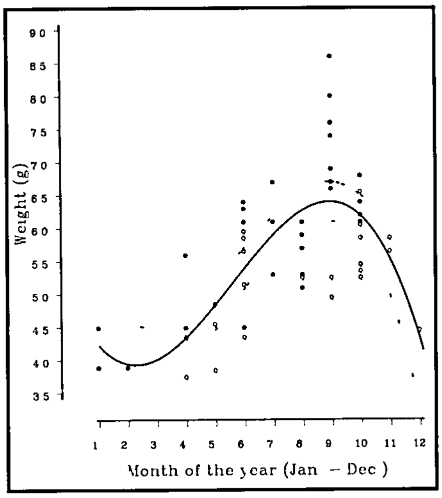

Figure 41
The weight of adult pipistrelle bats caught in the wild at different times of year (data supplied by R E Stebbings) Females are represented by dots while males are represented by open circles Pregnant females caught in June were excluded The curve is a cubic polynomial fitted to the data by least squares regression Dashed lines show the 95% confidence limits of this curve Hibernation normally occurs from October to March Body fat reserves approach zero at weights below 4 5g

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The Impact of Spray Drift on Native Flora and Fauna

The damage to susceptible crops and to hedgerow vegetation from herbicide drift has been recognised for over 30 years (Brooks, 1947) However, whereas economic losses are quickly noticed and quantified, the ecological significance of pesticides on non-target organisms outside sprayed areas is much less obvious Any deleterious effects have also been obscured by other changes, especially the complete removal of many hedges and ditches in areas of intensive agriculture There is still, therefore, considerable uncertainty about the effects of herbicide drift on native vegetation, and even more uncertainty about the impact of insecticide drift on the invertebrate fauna of habitats adjoining farmland The increase in usage and variety of pesticides in recent decades has magnified the complexity of the problem

The effects of pesticides on the environment are also receiving increased attention, part III of the Food and Environment Protection Act (1985) stresses the need to make information about pesticides available to the public Much of this responsibility falls to the Nature Conservancy Council who are likely to be increasingly consulted about the implications of spraying operations, especially in and near SSSIs The NCC therefore commissioned ITE to review the extent to which pesticide drift is known to occur, and the effects of herbicides and insecticides on plants and animals, in order to predict situations where drift might be damaging native flora and fauna

The main points from the ITE review are summarised here The physical aspects of spray drift, and the effects of herbicide drift on crop plants, have already been well reviewed by Elliott and Wilson (1983)

Drift is determined by the interaction of several factors, namely meteorological conditions, site size and topography, and the choice of equipment and mode of operation These interactions are described, and the results of many different experiments are brought together and compared, in order to draw general conclusions Drift deposit concentrations on targets indicate that 1% of emission rates can occur 10m downwind of areas sprayed with conventional ground sprayers in light winds, or 40m if winds are above $4ms^{-1}$ Bioassays with crop plants and herbicides, using recommended dose rates, show that such concentrations can cause significant reductions in growth The most sensitive crops are affected at <0 1% of application rates, and can therefore be damaged >100m away

Hydraulic sprayers account for about 90% of all spraying in Britain Operators can reduce drift by keeping the spray boom as low as possible, and by using nozzle pressures as low as practicable, to minimise the proportion of very fine droplets The operator can greatly reduce drift by choice of suitable nozzles, but weather conditions can severely limit the availability of "spray-occasions" between October and April Rotary atomisers, and other "controlled droplet" application techniques, produce a narrower range of droplet sizes than hydraulic nozzles, and a smaller proportion of drift-prone droplets Air-assisted spraying of bush and tree crops produces large volumes of small droplets which are very liable to drift Drift deposits may be 5-20 times greater than from conventional ground sprayers up to 50m downwind

In 1984, aerial crop spraying consisted of 60% fungicides and 36% insecticides (mainly organophosphorus compounds) The risk of drift is considerably greater than from ground spraying, *maximum* concentrations of drift, measured at 25m distance, can range from 6 5–58 times as much as from conventional ground spraying Plants and animals at tree height close to sprayed areas are at much higher risk from aerial spraying than from ground spraying

There have been few direct measurements of spray drift on native plants or animals All currently used herbicides are ranked according to a risk index for drift damage depending on the weighting of certain properties Features such as plant structure, life cycle and competition have been reviewed to determine the likely extent of drift damage to native species "Safe distances" which should be left between sprayed fields and sensitive plants may be in the order of 50-500m depending on application technique, but there are insufficient data on native plants, repeated sublethal effects could alter the competitive balance between species

Likewise, the hazards to terrestrial invertebrates are based largely on indirect evidence No general ranking of compounds is possible because of their high specificity in many cases, and the lack of information on "ecological susceptibilities" of most non-target organisms The hazard ratings of compounds to honeybees have been compared, and estimates made of the distances from sprayed areas at which drift concentrations might read LD_{50} levels Thus the most dangerous compound (fenitrothion) is calculated to have an "LD_{50} distance" of 63-80m in light winds, while many compounds do not reach LD_{50} concentrations for bees even at full field dose rates

A pilot field study and bioassay is described on the effects of short-range drift of demeton-S-methyl (used against cereal aphids) The results suggest that large (>50%) reductions in invertebrate populations are likely immediately adjacent to sprayed fields, even when wind conditions are ideal for spraying, longer-range effects, however, are unlikely Parasitic Hymenoptera were particularly severely affected and might therefore be suitable "indicator species" for such studies Recovery rates are dependent on the extent of the sprayed areas and reinvasion from unaffected populations

The relative toxicities of 64 insecticides to rainbow trout are calculated with respect to full application rates to crops The risk to fish from spray drift appears to be very small for the great majority of currently used compounds, because of dilution in the water and adsorption on sediments However, the latter poses a possible risk to bottom-living invertebrates which are generally much more sensitive than fish to insecticides

Groups of high usage/high-moderate risk herbicides are identified, and a list of 15 hedgerow and grassland herbs is suggested for future studies on drift deposition and its effects on plant performance Work on terrestrial invertebrates should concentrate on bioassays and population studies in field margins

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MANAGING HABITATS

Management of Lowland Heaths

(This work was largely supported by the Nature Conservancy Council)

The conservation of lowland heaths in southern England has been of much concern in recent years Initially this concern was over the large loss in heathland area, accompanied by an increase in fragmentation, caused by changing patterns of land use (Moore, 1962, Armstrong, 1975, Sheail, 1979, Webb and Haskins, 1980) More recently, however, attention has also focused on additional substantial losses of open heath communities through successional change (Marrs, Hicks and Fuller, 1986, Marrs and Lowday, 1987) This successional loss occurred because lowland heaths are generally man-made communities, created and maintained by man's intervention The management practices which previously maintained them have been discontinued or reduced in intensity, with a consequent invasion of bracken and/or shrub and tree species (Gimingham, 1972, Gimingham and De Smidt, 1983, Marrs *et al*, 1986, Marrs and Lowday 1987) This paper describes the results of two experiments designed to develop methods for restoring such heaths The experiments took place at Knettishall Heath Country Park in Suffolk (grid reference TL 985805), where the heathland vegetation was old and degenerate, and there had been substantial invasion by bracken, birch and Scots pine

In the first experiment all tree species were felled, and four treatments (× 4 replicates), designed to selectively suppress or eliminate the scrub and bracken, were applied These were (i) no treatment after cutting, (ii) 2,4,5-T stump treatment of scrub after cutting, (iii) spraying the selective herbicide, fosamine, on both regenerating tree stumps and bracken fronds, and (iv) treatments (ii) and (iii) combined

Where birch was cut and left untreated, a few plants were killed, but most resprouted and had re-established themselves as dominants by between three and six years after cutting Thus, if no herbicides are applied, cutting birch will achieve, at best, a breathing space of six years When 2,4,5-T or fosamine were applied alone, most plants died, but those few that survived reached bracken canopy height in six years, and further management action was needed The most successful treatment was the combined treatment with 2,4,5-T and fosamine, which killed all birches

The changes in the heathland ground vegetation during the study period were most disappointing, with a decrease in *Calluna* cover and an increase in bare ground, especially under dense bracken There was hardly any production of new *Calluna* individuals Moreover, where birch and bracken were controlled or suppressed, there was rapid invasion of new birch seedlings and of *Deschampsia flexuosa* Birch seedlings grew less well than birches regenerating from cut stumps, but even these new saplings had reached half the bracken canopy height after six years

In the second experiment, all scrub was cut and the cut stumps were treated with 2,4,5-T at the start of the experiment Four disturbance treatments (× 4 replicates) were then applied to the heath vegetation These were (i) no treatment, (ii) cutting and removal of vegetation, (iii) treatment (ii) plus burning, and (iv) treatment (ii) plus rotavating In addition, a bracken suppression treatment was applied to half of each treated plot The results from the untreated plots confirmed the results of the first experiment, namely no *Calluna* regeneration and increased abundance of *Deschampsia flexuosa,* especially where bracken was reduced

Disturbing the ground vegetation by cutting, however, either alone or in combination with burning or rotavating, increased the successful establishment of pioneer *Calluna* There were no significant differences between the three disturbance treatments and, consequently, no additional benefit in burning or rotavating All the new *Calluna* established from seed Poor regeneration of old rootstocks is to be expected, because the potential to regenerate declines with age (Gimingham, 1972)

From these and other studies it has been possible to draw up a management strategy for the restoration of degenerate heaths

Phase 1 Cut or pull birch, and treat cut stumps with an appropriate herbicide (Marrs, 1985a) Cut or pull Scots pine

Phase 2 Cut and remove mature and degenerate *Calluna* Burning and/or rotavating may also be used as supplementary treatments If unsuccessful, *Calluna* seed may need to be added (Lowday, 1984a), although it was not required in the present study

Phase 3 Monitor *Calluna* establishment, and once good establishment has occurred, treat the bracken with asulam, which is more effective than fosamine (Veerasekaran, Kirkwood and Fletcher 1978, Lowday, 1984b), but does not damage *Calluna* (Marrs, 1985b) An alternative control treatment would be to cut and remove the bracken on a regular basis (Lowday, 1984b), but this treatment may damage the establishing *Calluna*

Phase 4 Monitor tree establishment, spot-spray new birch seedlings and regeneration from cut stumps with fosamine (Marrs, 1984, 1985c) and pull Scots pine This should be done after bracken control, so that all individuals can be seen, less herbicide will be used, because interception by bracken will be reduced

It is essential that management to maintain open *Calluna* heath is implemented subsequently (Marrs and Lowday, 1987), or the problem will reappear in a fairly short time, at best within the life cycle of the new *Calluna* In this study there was no vegetative regeneration of *Calluna,* mainly because the *Calluna* population at the time of treatment was too old One way to encourage vegetative regeneration would be to manage the *Calluna* by cutting or burning, when the *Calluna* is in the building phase (Gimingham, 1972)

R H Marrs

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Roadside Management and its Effect on the Vegetation of Grass Verges

An experiment was started in 1965 at two sites in Cambridgeshire to examine the effects of a range of cutting and chemical treatments on the vegetation of roadside verges. The experiment continued until 1982, by which time a unique body of data had been collected on the long term effects of 17 different management treatments. Treatments included combinations of cutting date, cutting frequency (0, 1, 2 or 5 times a year), cutting machine (haymower, flail mower or rotary mower), leaving or removing cuttings, a herbicide (2,4-D) and a growth retardant (maleic hydrazide (MH)).

Different methods of roadside management had a large effect on the structure and species composition of verges. Maximum species richness was recorded in plots which were cut twice a year (Figure 42). More frequent cutting, five times a year, resulted in a short turf dominated by prostrate plants, of little value to fauna. Cutting only once, or not at all, encouraged the growth of coarse grasses, such as couch *(Elymus repens)*, and tall herbs, such as hogweed *(Heracleum sphondylium)* and cow parsley (*Anthriscus sylvestris*) (Figure 43). Plots left uncut also contained a higher proportion of species classified as serious agricultural weeds (Parr and Way, 1982). More surprisingly, plots treated with a broadleaf herbicide (2,4-D), also contained more serious weed species than cut plots.

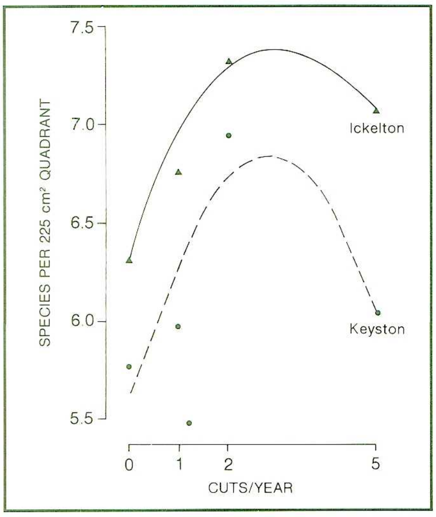

Figure 42.
Effect of cutting frequency on the species richness of 2 roadside sites in Cambridgeshire.

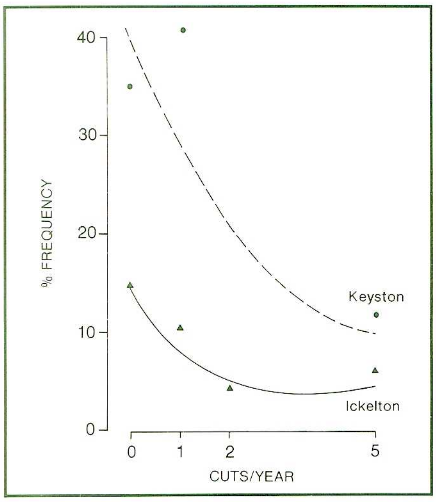

Figure 43.
Effect of cutting frequency on cow parsley *(Anthriscus sylvestris)*.

Removing cuttings led to an increase in plant species richness, mainly due to an increase in herbs. Over the 17-year period there was a corresponding decrease in soil potassium, but most soil nutrients were unaffected. It is possible that the main cause of the increase in plant richness was the disturbance and scarification accompanying the removal of cuttings by hand raking, which may have enhanced germination and seedling establishment.

Although cutting twice a year, in May and August, gave the maximum floristic diversity and good weed control, this treatment was not sufficient to maintain the vegetation below a safe height of 30cm. We found that the retardant maleic hydrazide was an effective, if somewhat unreliable, method of keeping the vegetation short. In plots treated with MH, vegetation height averaged only 28cm, 42% less than in the uncut verges. However, keeping the height below 30cm throughout the year was achieved only by combining the spray treatment in April with an additional cut in June.

When MH was first used on verges it was hoped that its effects would be beneficial to wildlife, because it would reduce the growth of grasses and tend to favour broadleaf plants. In the first four years of our experiment, the results supported this idea (Parr and Way, 1985). However, in the longer term there was a steady decline in many broadleaf species and, after 17 years, verges treated with MH contained significantly fewer species that the cut plots. Some species, such as ribwort plantain *(Plantago lanceolata)*, did increase in the MH treatment, and the effect of using MH was not as severe as using an indiscriminate broadleaf herbicide such as 2,4-D.

Growth retardants, such as MH, may have a part to play in the cost-effective management of roadside verges. Used carefully, preferably without additional herbicides, on safety strips and visibility splays, their impact on the verge as a whole should be small. Furthermore, the new generation of retardants (including mefluidide and paclobutrazol) which is now reaching the market, should be more effective (Parr *et al.*, 1987). Although the long term effect of these new retardants on vegetation is yet to be established, Damage attributable to walkers on the summit of Whernside.

there is some hope, particularly for mefluidide, that they will be less harmful than maleic hydrazide.

Roadside verge management in the UK

In 1975, about half of the 212 000ha of roadside habitat in the UK was managed grassland (Way, 1977). The responsibility for managing these grassland areas falls to the appropriate highway authority, either the Department of Transport (motorways and trunk roads) or a local authority. Highway authorities manage verges to maintain road safety and comply with their legal obligation to control the spread of injurious weeds. They are also becoming increasingly aware of the importance of verges as habitats for wildlife. However, they have frequently been forced to reduce the cost of their roadside management programmes. In the mid-1970s, following instructions from the Department of the Environment to save money, the mowing of verges on trunk roads and motorways was reduced to the minimum consistent with road safety. Local authorities responsible for rural verges have in many cases followed this lead and its overall effect has been that large areas of roadside verge have been uncut for over a decade. The consequences of this policy of neglect have been consistent with the results from our experiments. Most notably, there has been a widespread increase in coarser and more aggressive species and an increase in the proportion of serious agricultural weeds. Bramble and scrub have also increased. These changes have not only led to the loss of herb-rich grasslands, but also created vegetation which is beginning to pose longer term management problems. Scrub encroachment is obstructing the sight lines of motorists; tall herbs, such as cow parsley and hogweed, fall onto the road and reduce the effective road width, and the increase of agricultural weeds, such as the creeping thistle *(Cirsium arvense)*, is frowned upon by farmer and conservationist alike.

In conclusion, in the last decade there have been four developments which should affect the way in which verges are managed in the future. First, progressively fewer and fewer resources have been allocated to verge management; secondly, the practical consequences of leaving verges unmanaged have become apparent; thirdly, increased public concern for the environment and changing patterns of land use have increased the value of roadside verges as habitats for wildlife. Finally, using information from long-term experiments on roadside management, past changes are more readily explained and the effects of alternative management can be predicted. In view of these developments, the time is right for highway authorities to review management policies for roadside verges; reviews which should consider cost, safety, weed control and the environment. Based on past research in these fields, ITE is in a unique position to contribute to this work.

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Reinstatement and Management of the Three Peaks Footpath Network

(This work was supported by the Yorkshire Dales National Park)

The Yorkshire Dales National Park includes some of the most varied and interesting countryside in upland Britain and is particularly popular with walkers. In recent years, footpaths linking The Three Peaks (Ingleborough, Pen-y-ghent and Whernside) have become seriously eroded because of heavy use. More than 120 000 visitors reach the summit of Ingleborough each year (Smith, 1987).

In 1985, The National Park Committee initiated a programme of remedial work. ITE was commissioned to (a) survey the extent of damage to paths, (b) undertake reinstatement trials and (c) draw up a monitoring scheme which would identify changes in the pattern of damage, trigger management responses, and assess the effectiveness of reinstatement work. The remedial programme is expected to last for five years initially and involves collaboration between the National Park, Countryside Commission, Nature Conservancy Council and Manpower Services Commission.

The Footpath Survey

The aims were to assess the condition of each path and identify relationships between path condition and site factors, such as wetness, soil type, vegetation and slope. The results were to provide a baseline analysis for future monitoring and help the selection of sites for reinstatement trials.

A rapid survey technique (Bayfield, Lloyd and Shortridge, 1973) was used. Path widths (the total width of obviously trampled ground) and bare widths (the width of ground with no surviving vegetation) were measured at sample points stratified at approximately 50m intervals (Bayfield and McGowan, 1986). At each sample point, surface soil type, slope, wetness, adjacent vegetation, and various detracting features (features that reduced path quality) were also recorded (Figure 44). For each path, a listing of widths and other data was drawn up to permit the rapid identification of damaged sections with corresponding soil, vegetation and other site attributes.

The total length of paths surveyed was about 55km. The average trampled width (all paths) was 11.4m, and the bare width 2.7m. Some sections were, of course, much more worn than others, but the data indicated that about 23km of path were 10m or more wide, and about 10km had 5m or more of bare ground.

The Three Peaks footpaths are in very poor condition compared with upland

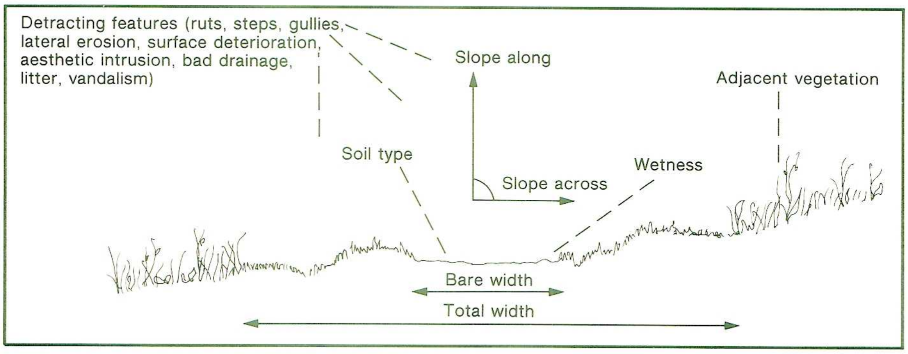

Figure 44.
Path characteristics recorded at each sample point.

footpaths elsewhere (the Pennine Way, for example, although badly worn in places, had an averaged trampled width of only 3.5m in 1983; Bayfield, 1985). Peat is the most frequent path surface (63% of path samples, Figure 45) and the survey indicated that about 77% of badly worn surface occurred on predominantly peaty soils. The vegetation of the area is a mixture of heathery heaths and grassland, with the latter predominant. Twelve vegetation categories based on predominant species were identified during the survey. The most frequent was bent-fescue *(Agrostis* spp. — *Festuca ovina)* grassland, the

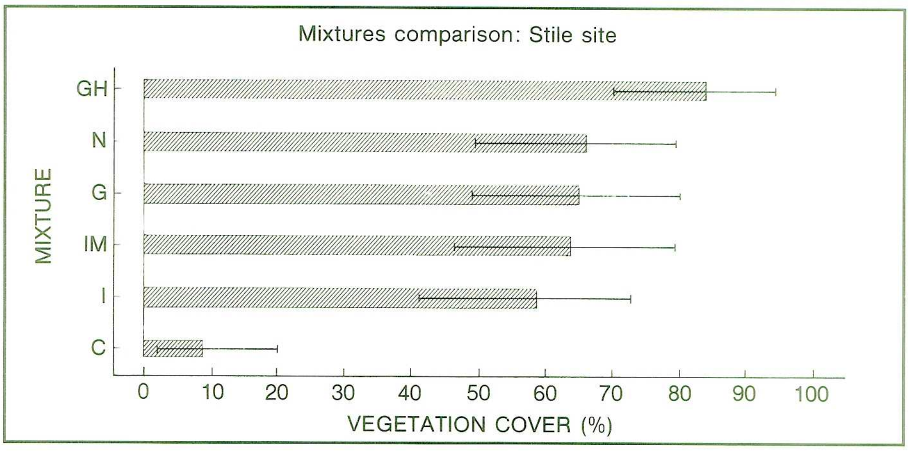

Figure 46.
Comparison of vegetation cover after 2½ months, produced by five seed mixtures and unsown (control) plots. GH, agricultural mixture with Yorkshire fog; N, mat grass-bent mixture; G, agricultural mixture; IM, sheep's fescue-bent-wavy hair grass mixture with moss fragments; I, sheep's fescue-bent-wavy hair grass mixture; C, unsown. A full listing of the composition of the mixtures is given in Bayfield and Miller, 1986. Data are totals of visual estimates for individual species (back-transformed from angular transformations). Horizontal bars indicate 95% confidence limits.

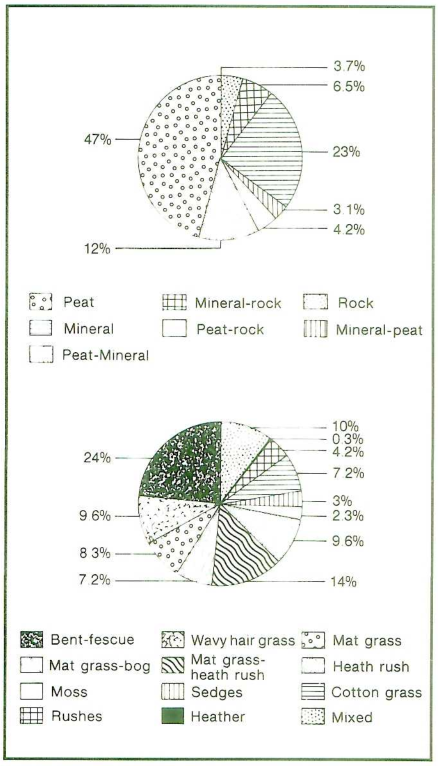

Figure 45.
The frequencies (%) of **a** soil surface categories and **b** vegetation categories along paths in The Three Peaks area (n = 1157).

characteristic vegetation of mineral soils overlying limestone. On organic soils, the vegetation comprised principally grasses, soft rush *(Juncus effusus)*, sedges (*Carex* spp.) and mosses.

Reinstatement Trials

Only a limited range of comparisons could be attempted in the first season, so those chosen were deliberately contrasting. There were three main types of trial: comparisons of seeds mixtures, of transplants, and of the use of fertilizers to improve the resistance of the vegetation to disturbance (Bayfield and Miller, 1986).

The seeding and transplanting trials were laid out at two gently sloping sites, about 500m ASL, where there was extensive exposure of bare peat. To prevent disturbance of the plots by walkers, a new gravel path was constructed at one site and a board walk at the other. Some of the trials were fenced, but the majority had no protection from sheep.

Part of a trial on Simon Fell Breast, Ingleborough, with a constructed gravel path, and fenced and unfenced plots of various seed mixtures.

The seed mixtures were based mainly on predominant local species. However, some agricultural species, used in seeding damaged ground at ski centres in Scotland (Bayfield, 1980), were included for comparison. Some mixtures were supplemented with chopped moss fragments or plant litter. At the end of the first season, satisfactory cover had been achieved by all the mixtures (Figure 46), with no pronounced difference in performance between the agricultural and native species. The addition of moss fragments or litter had no significant effect on cover but increased the diversity of moss species.

Transplanting trials (Figure 47) involved soft rush, heath rush, mat grass, sheep's heath rush, sheep's fescue, common sedge *(Carex nigra)* and cotton grass *Eriophorum angustifolium)*. Plants were transplanted as "turves" 10cm in diameter, "stretched turves" (turves pulled apart to about double their original area) or as "divots" made by splitting a turf into nine rooted fragments. Divots had a slightly higher mortality than turves but in most cases

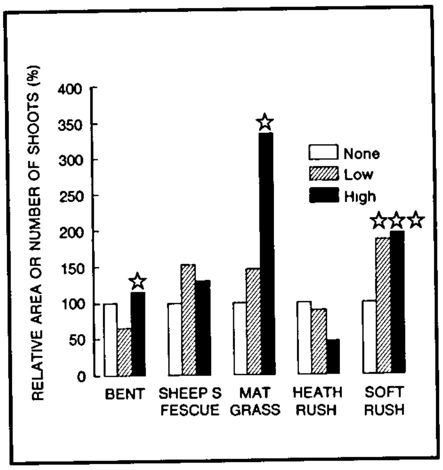

Figure 47
Effects of fertilizer on the areas of surviving divots 2½ months after transplanting The areas on fertilized plots are expressed as a proportion of those of unfertilized plots Variance, *, p<0 05, ***, p<0 001

made greater growth Some species (mat grass, soft rush) showed improved growth with fertilizer applications, others failed to show much response (sheep's fescue, bent) or showed a growth check (heath rush) Overall, transplants appeared to have potential as a means of creating pattern, texture and cover
At one site, many buried seeds germinated, and contributed up to 25% cover Tests showed that there was a reservoir of about 20 000 buried seeds m^{-2}. In future work it is intended to survey seed reservoirs, and to devise techniques for encouraging germination and establishment

Fertilizer was applied at light and heavy rates (35 and $105g^{-2}$ Enmag, 4 5 20 10 NPK) to sections of path in use, to see if the resistance of the vegetation to trampling could be enhanced After only 2½ months, the fertilizer had increased plant cover by up to 28%

Conclusions
After a single season, seeding, transplanting and fertilizing damaged ground all show promise but long-term performance will indicate which are satisfactory techniques Since the agricultural species have shown no special advantages, future mixtures will be based entirely on native species Further transplanting trials will investigate a wider range of species, and combinations of seeding and transplanting will be examined as a means of creating rapid cover and pattern Further work on the use of fertilizer will examine how little fertilizer is needed to achieve worthwhile improvements

The Three Peaks Project is an example of an integrated management scheme which has brought together the skills of planners, engineers, landscape architects and ecologists It has the backing of local and national statutory bodies, and at every stage there is consultation through a working group representing recreational, farming, conservation and voluntary interests

N G Bayfield and G R Miller

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The Response of Breeding Golden Plover to Experimentally Created Grassy Patches
In recent years there has been much concern about big declines in the numbers of golden plover *(Pluvialis apricaria)* breeding in Britain, following conversion of moorland to coniferous plantations and farmland It is therefore important to have a better understanding of factors which limit golden plover numbers naturally, as a step towards better management and conservation of the British population

Golden plover in Britain breed mainly on barren uplands or heather (*Calluna vulgaris* [L] Hull) moors with infertile blanket bog and podsolic soils They typically nest in short vegetation, a strategy which Ratcliffe (1976) suggested gives the sitting bird good all-round visibility and which may have evolved as a defence against predators Short vegetation is also important after hatching, as it enables adults and chicks to move and feed more freely On ground above 600m, vegetation is short as a result of exposure However, on moors below 600m, short vegetation can occur only if there is rotational burning of heather, one of the main forms of management for red grouse *Lagopus lagopus scoticus* (Watson and Miller, 1976), or grazing by red deer *(Cervus elaphus)*, sheep and cattle

Kerloch in Kincardineshire is a typical low-altitude grouse moor on a north-facing hillside The dominant vegetation is heather, which has been rotationally burned in the past to produce a 'patch-work' of varying age and height In a study of golden plover there (Parr, 1980), all 56 nests found between 1973 and 1978 were in heather less than 15cm tall However, short vegetation fulfils only one of the requirements for breeding At Kerloch, many areas with short heather held no golden plover, whereas others were used by two, or sometimes three, pairs of golden plover in the same breeding season, occupying the same piece of ground in sequence (Parr, 1979) This suggested that breeding sites were in short supply

The apparent shortage of breeding sites may have been related to the type of habitat Heather moorland supports lower numbers of soil invertebrates than base-rich grassland on the moors (Coulson, 1959 and 1962, Coulson and Whittaker, 1976) Golden plover feed mainly on invertebrates, and although adults can overcome food shortages on the moor by flying to improved pasture nearby (Ratcliffe, 1976, Parr, 1980), the chicks must find food near the nest until they fledge at 4-5 weeks Thus a second important requirement is a good source of food for chicks, quite near the nest

At Kerloch, all nests found had small patches of short *Agrosto-Festucetum* grassland within 100m After the eggs hatched, the adults led the chicks to one of these grassy patches, where they usually remained until fledging Statistical analysis showed that golden plover broods strongly favoured these grassy areas, even though they cover <1% of the moorland Breeding pairs at Kerloch were not found in short heather without grass, suggesting that a shortage of grassy patches was limiting the number of available sites

To test this hypothesis, small grassy plots were created on moorland which had short heather, but where there had been no golden plover territories for at least 20 years Six pairs of areas, each about $64m^2$, were marked out and one of each pair was chosen at random to be reseeded, the other acting as a control In September 1982, each experimental patch was rotavated, treated with 32kg of lime, 8kg of basic slag, 4kg of compound fertilizer (N P K 1·1 1), and 1kg of grass seed (*Festuca rubra* and *Agrostis tenuis*)

Visual estimates of the percentage of the ground covered by grass were as follows in spring 1983, 5% of grass with mainly bare earth and lime showing, in spring 1984, 50% grass cover, in spring 1985, 80% grass, cropped very short by grazing sheep, hares and rabbits Since spring 1986 grass has covered more than 90% of each plot but has remained short as a result of grazing

The response of golden plover to the reseeded plots varied None was occupied by golden plover in 1983, although three of the six had nesting oystercatchers *(Haematopus ostralegus)* (Previously, no oystercatchers had nested on moorland at Kerloch, and although all three nests were robbed by predators, oystercatchers have continued to nest there since 1983) In spring 1984, three of the reseeded plots were included in new golden plover territories Two of the new territories were held by colour-ringed birds which had moved from territories nearby, at distances of 500m and 300m These pairs had both held their previous territories for three years, but both members of the third pair were unringed and new to the area Although the behaviour of all three pairs strongly suggested that they had nests, no nests were found and no chicks were reared In 1985 and 1986, none of the reseeded plots was occupied and none of the ringed birds mentioned above was seen However, in spring 1987, new pairs of unringed golden plover were seen on two reseeded plots No golden plover were recorded on any of the control plots throughout the period from 1983 to 1987 This is encouraging preliminary evidence that it may be possible to increase the number of sites for golden plover by creating quite small grassy patches artificially

The results of the experiment are, however, partly inconclusive, as only some of the reseeded plots were occupied in only two out of five years, and no chicks have been reared to date Thus it has not been possible to see if the grassy patches are used by broods One possible reason for the poor response may have been that the population of golden plover at Kerloch was declining (Table 19) Nest predation also increased, from 52% in 1973-77 to 85% in 1981-86 Because of the drop in numbers, even territories that were occupied throughout the 1970s now lie vacant In view of this, it is perhaps not surprising that the reseeded areas have not been occupied continuously The real test of the experiment will come if and when the golden plover population at Kerloch increases It is hoped that this will occur as a result of a current experiment to improve breeding success by controlling the numbers of egg predators

R Parr

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Introductions to Conserve the Adonis Blue Butterfly

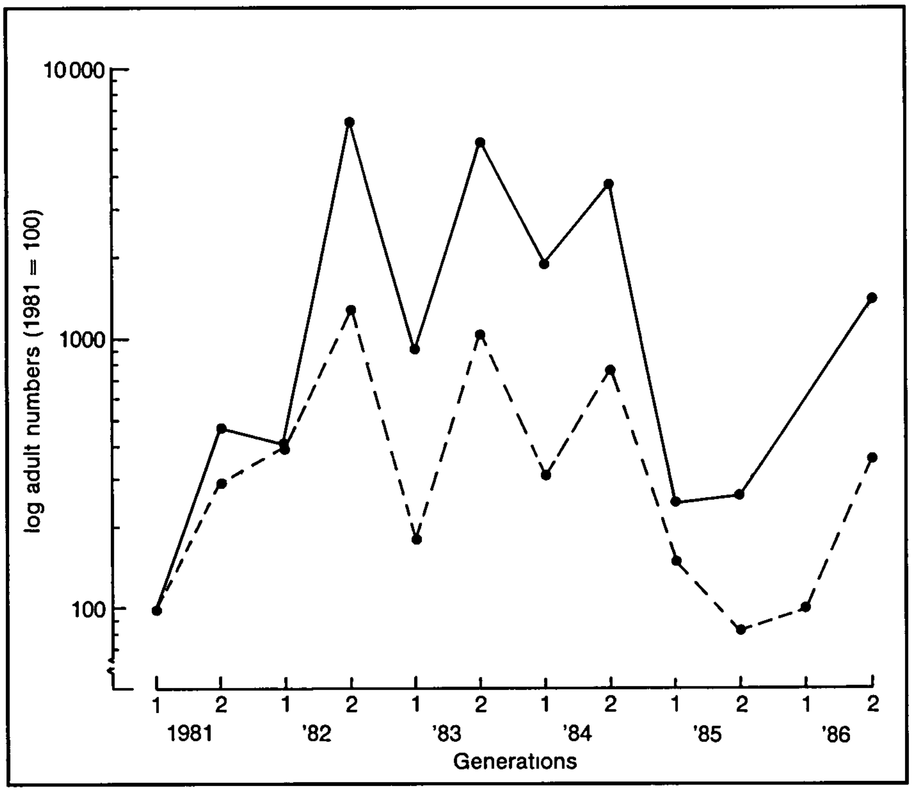
The Adonis blue *(Lysandra bellargus)* is a scarce butterfly of chalk and limestone grassland in southern Britain It has declined rapidly since the mid-1950s and has disappeared from about one quarter of the nature reserves that once supported it (Thomas, 1984) By the late 1970s, only 70-80 British populations survived, and most were small Our surveys revealed that about a third of the local extinctions occurred because ancient downland had been improved for

Table 19 Flock size, nest predation and breeding success of golden plover in different years

Year	Maximum flock size	Percentage of pairs robbed	Number of young reared per 10 old
1973	85	24	5
1974	52	59	4
1975	85	70	2
1976	89	56	3
1977	89	44	4
1978	50	*	*
1979	45	*	*
1980	43	*	*
1981	42	50	4
1982	36	93	0 5
1983	35	93	0 5
1984	35	88	1
1985	12	100	0
1986	12	100	0
1987	14	100	0

*In 1978-80 no data were collected as access to the moor was denied, but counts of flocks in the fields were possible

Figure 48
Changes in adult Adonis blue numbers on Old Winchester Hill (solid line) and in the mean on 3 sites in Dorset (broken line) Changes are plotted on a log scale with numbers in spring 1981 adjusted to 100 adults The first generation in 1986 was not estimated on Old Winchester Hill



agriculture, but that most former sites still supported the larval foodplant, horseshoe vetch *(Hippocrepis comosa)*, in considerable abundance

An earlier research project showed that most extinctions on unimproved downs could be explained by the fact that the sward had become taller and denser than formerly, due to the reduction of rabbits since myxomatosis and the abandonment of much unimproved pasture by farmers (Thomas, 1983) It transpired that the female Adonis blue restricts egglaying to *Hippocrepis* plants growing in very short patches of turf, probably because the young stages need a warm microclimate to survive in Britain Another discovery was that adults only leave their discrete breeding sites when numbers are unusually high, and then seldom fly far Local extinction usually occurred within two to three years of the end of grazing, but if suitable conditions returned, it was estimated that it might take tens or hundreds of years for the site to be recolonised unless another colony had survived on a neighbouring down It was suggested that most former sites in Britain would be able to support this butterfly again if grazing were intensified, but that many would be too isolated to be colonised naturally

An experiment to test some of these ideas was started on Old Winchester Hill NNR in 1981, in conjunction with the Nature Conservancy Council The whole site became overgrown and lost its population in the mid-1950s Sheep-grazing was re-established when the down was declared a nature reserve, but the nearest known population of Adonis blue was about 40km away, and the site was not reoccupied The main south slope, where the *Hippocrepis* grew, had been divided into 16 compartments, of which 13 were grazed and then left fallow in rotation, so that about one-quarter of the sward was short at any one time It was estimated that this was enough to support a small to medium-sized population of Adonis blue

An introduction of 65 adults was made on the south slope in spring 1981, numbers were monitored by transect counts of adults and counts of eggs on a known proportion of plants The population immediately increased and reached approximately 4200 adults in the second generation of 1982 These laid an estimated 235 467 eggs Adonis blue numbers were unusually high elsewhere in the second generations of 1982-4, probably due to three warm summers, but the increase at Old Winchester Hill initially outstripped that on other sites, as the vacant niche was occupied After 1982, numbers fluctuated in synchrony with the three donor populations, where the habitat remained constant (Figure 48) A better test of the re-establishment was provided in 1985-6, when there were two cool summers and numbers were low elsewhere The introduced population survived this period, falling to about 150 adults at its lowest emergence in spring 1985

The introduced population has survived for 14 generations so far, and after four generations colonised another small slope containing close-cropped *Hippocrepis*, 800m away on the reserve It was unnecessary for adults to cross barriers or improved grassland in order to reach this area This small population also increased disproportionately until it had fully occupied the habitat

As elsewhere, egglaying on Old Winchester Hill has been restricted to *Hippocrepis* growing in the shortest turf Under the present rotational management, many plants are rejected as being too overgrown (Figure 49), but a wide range of other species that prefer taller conditions flourish alongside Some compartments were always preferred to others for egglaying, due to their topography and other fixed features, but there have also been marked changes in their relative suitability, depending on whether they have recently been grazed or not To take an extreme example, the mean height of *Hippocrepis* in compartment L (Figure 50) was 9 1cm in 1982, and supported the lowest density of eggs per plant of all compartments that autumn, three years later, when it was the most closely-cropped section (1 3cm tall), the same *Hippocrepis*

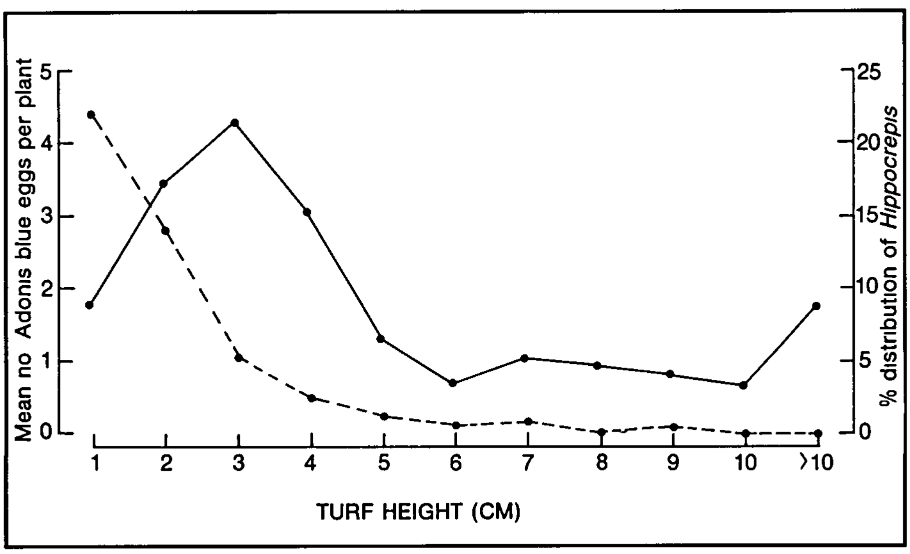


Figure 49
The distribution of *Hippocrepis* plants in turf of varying heights on Old Winchester Hill in 1984 (solid line), and the mean number of Adonis blue eggs per plant in each category (broken line)

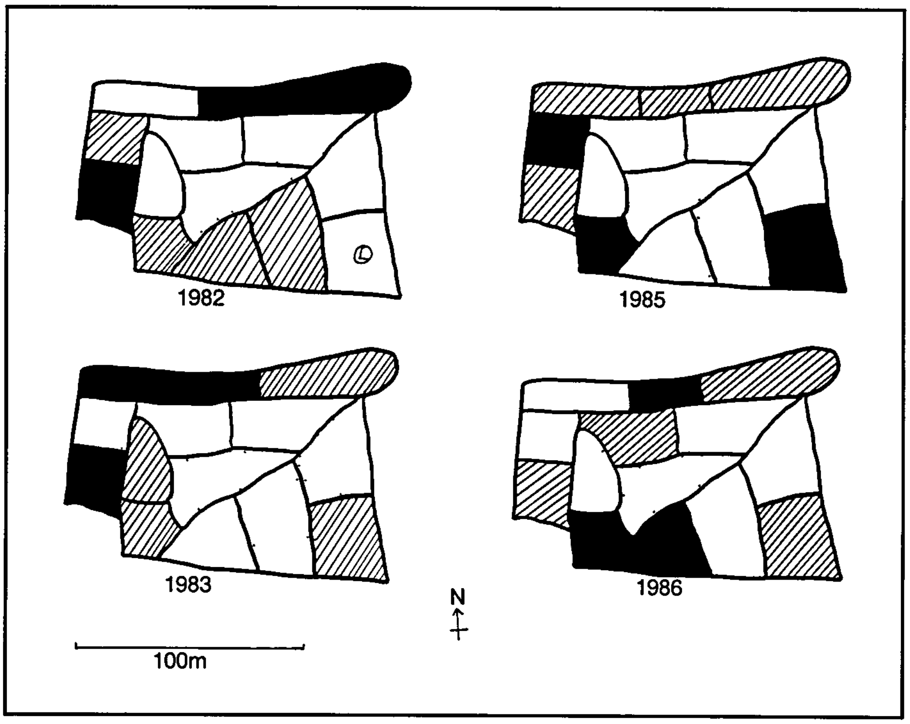


Figure 50
Changes in the density of Adonis blue eggs per *Hippocrepis* plant in 14 compartments of Old Winchester Hill Black – the 3 highest densities, hatched – the 4th-7th highest densities, stipple – the 8th-11th highest densities, white – the 3 lowest densities

plants supported much the highest density of eggs per plant, and indeed 45% of the whole population *Hippocrepis* has also increased on the down, since seedlings establish when the turf is short and there is some bare ground, but this has occurred at a very much slower rate than that at which established plants have alternated between being suitable or unsuitable for egglaying

This experiment suggests that the Adonis blue can be successfully conserved in Britain if sites are adequately grazed, but that deliberate introductions will be necessary in isolated areas There may, indeed, be many former sites that are suitable again, for rabbits have gradually returned as a significant grazing force during the 1980s, and EEC subsidies recently made it economic to farm some abandoned hillsides with domestic stock a repeat survey of Dorset downs in 1985 showed that the mean sward height was half what it had been in 1978, and that several Adonis blue populations had spread naturally to occupy adjoining downland This respite may soon disappear, especially if food production is reduced in Europe If so, it will become increasingly important to ensure that nature reserves are adequately managed to support populations of Adonis blue (and other insects) in the long-term, as appears to have been achieved at Old Winchester Hill It would be sensible to ensure that all suitable reserves are occupied, if necessary by introductions

J A Thomas

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CHANGES IN THE BRITISH LANDSCAPE

Some Examples of Landscape Changes During the Last Ten Years

The collection of standardised land use and landscape feature data during 1977 and 1978, from sample points throughout Britain, gave ITE a baseline against which assessments of landscape change could be made A resurvey, supplemented with additional sites, was carried out in 1984 This exercise formed part of a wider programme of research which attempted to compare the relative advantages of field survey with those of aerial photographic interpretation (Ball *et al*, 1987) and satellite imagery

The methods of field survey used in 1978 and 1984 are more fully described elsewhere (Bunce and Heal, 1984, Barr *et al*, 1985) but a brief description follows here In order to ensure coverage of the full range of environmental conditions in Britain, the survey was based on a land classification system A grid of 1200 sample units (1 × 1km squares) was established, covering Britain at 15km intervals For each site, existing mapped environmental data (such as climate, geology and altitude) were recorded Multivariate analysis of the data produced 32 different groups, known as land classes, representing the range of landscape types in Britain (Bunce *et al*, 1981)

Within each land class, eight 1 × 1km squares were taken at random, giving a total of 256 sites throughout Britain The sites were visited by ITE staff in 1977 and 1978 and, although the primary purpose of the survey was to collect ecological information, such as vegetation and soil data, land use and landscape features were also recorded

In 1984, the 256 sites were revisited and an additional 128 sites were surveyed

The data have been analysed to produce national and regional estimates For each feature under consideration, the squares in each land class contribute to a mean value for that class, thus, the mean area of barley in land class 4 in 1984 was 5 6ha per km² Since the number of 1 × 1km squares in each land class has been estimated, it is possible to compute the total area of barley by land class (for land class 4, it is 66 550ha) and make estimates for the whole of Britain Similarly, where land class totals are known for a region, estimates may be made for that region

In the same way, changes in land use may be calculated as national or regional statistics Table 20 shows estimates of some of the changes that have taken place between 1978 and 1984

Some of the data can be compared with those from independent sources, such as the Ministry of Agriculture, Fisheries and Food and the Forestry Commission Estimates for other features (e g lost hedgerows or new young trees) are unique for the period under consideration These and other estimates of change are more fully described in Barr *et al* (1986) Although some of these statistics are freely available elsewhere, their assessment over a six-year period provides some surprises, such as the 66% increase in the area under wheat; regional data showed that wheat was increasing in the south-west and central areas of Britain The surveys also showed the growth in popularity of oilseed rape, whose area had increased ten-fold in six years About 3% of rough grazing had been improved by ploughing, reseeding, fertilizing or drainage, much of this activity took place in areas of central and southern Britain where management of predominantly

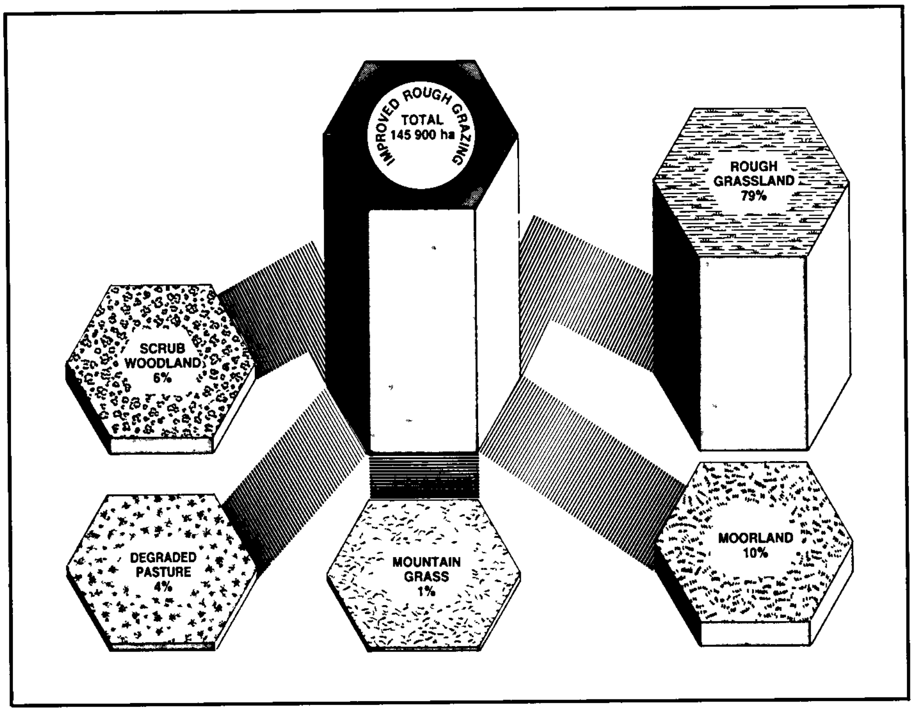

Figure 51
Proportions of rough grazing categories that were improved between 1978 and 1984

agricultural landscapes was still being intensified (Figure 51)

Somewhat surprisingly, there was evidence that great numbers of broadleaved trees were being planted (Barr and Whittaker, 1987) The area of newly planted broadleaved woodland exceeded that which had been removed and, although the ecological value of the new woodland is low at present compared with that which has been lost, it is encouraging to note this trend As well as increasing ecological diversity, trees are an important structural component of many landscapes The greatest density of individual young trees and lines of young trees was found in East Anglia, a region more usually renowned for landscape destruction Most of the new coniferous plantings took place in Scotland, about one-quarter were second-rotation plantings on clear felled sites

Boundaries, such as hedges, walls and fences, are also major elements in the appearance of the countryside There was evidence that hedges are still being removed, especially in central and southern Britain (Figure 52a) Reflecting the geographical diversification in cereal production, more hedges were lost by area in the south-west than in East Anglia, while the regions immediately adjacent to East Anglia showed the greatest rates of removal Some new hedges were being planted but most new boundaries were wire fences A surprising length of wooden fencing had been erected in East Anglia and the south-east, presumably due to the increase in the number of horses being kept for recreational purposes (Figure 52b)

Other recorded features, notably those associated with the built environment and with recreation, provided interesting results For instance, it was calculated that more than a million farm buildings had been erected in the six-year period between survey dates, representing, on average, a new building on every second farm, however, about 35% of these buildings were associated with cereal farms, while only 1% were in the uplands Although it was not possible to assess the generally recognised increase in the number of horses, the estimated number of horses in fields in the summer of 1984 was 558 000, and horses may be using up to 15% of the lowland grass area in Britain

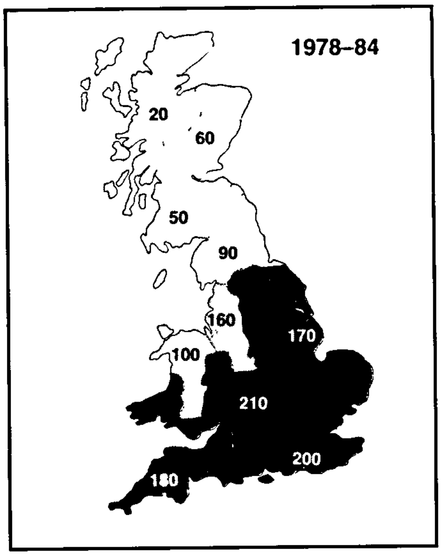

Figure 52a
Lengths of hedgerow removed between 1978 and 1984 shown in metres per kilometre square in each of 12 regions

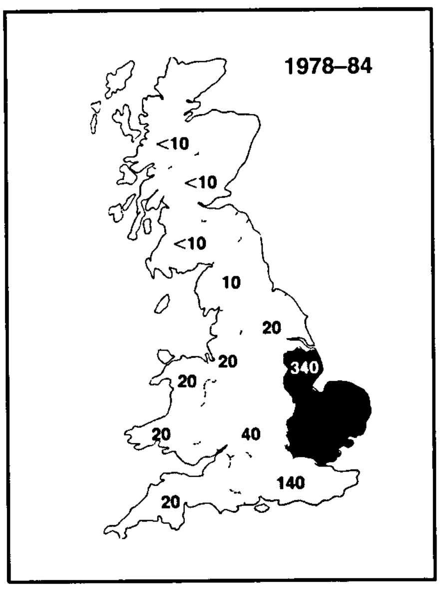

Figure 52b
Lengths of wooden fence erected between 1978 and 1984 shown in metres per kilometre square in each of 12 regions

Looking ahead, ITE's policy is to continue monitoring the sample sites at regular intervals The data from surveys already undertaken will be analysed in different ways and used in a variety of research projects For example, detailed vegetation data from the 1978 survey, and land use change statistics derived from the 1984 resurvey, are to be used in a new project examining the ecological consequences of land use change (contracted by the Department of the Environment) The data are also being integrated with information on social and economic factors (Bell *et al*, 1987), to gain a clearer insight into why changes are taking place and what their longer term consequences may be

C J Barr

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Table 20 Examples of some landscape changes between 1978 and 1984

Agriculture:	Area of wheat Area of barley Area of oilseed rape	+ 695 000ha (+66%) – 267 000ha (– 13%) + 164 800ha (+900%)
	Area of improved rough grazing	146 000ha
Forestry/trees:	Area of removed broadleaf woodland and scrub	24 700ha
	Area of new and restocked conifer plantation	177 000ha
	Number of new isolated trees ‹6 years old	220 000ha
Boundaries:	Length of removed hedgerow Length of new hedgerow Length of new wire fence Length of new wooden fence	28 000km 3 500km 48 400km 13 700
Buildings/ communications:	Area of new housing estates Number of new agricultural buildings Length of new tracks	39 000ha 105 450ha 5 000km
Recreation:	Area of golf courses Area of caravan sites	+ 14 000ha (+ 15%) + 3 800ha (+ 17%)

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Historical Changes in Lowland Grasslands

(This work was supported by the Nature Conservancy Council)

The agricultural improvement of grass swards involves the establishment and maintenance of productive, so-called 'preferred' species, especially ryegrass (*Lolium perenne* L), at the expense of indigenous species such as bents (*Agrostis* spp), red fescue (*Festuca rubra* L) and broadleaved 'weeds' Swards containing more than 20% ryegrass, or more than 25 to 30% preferred species, have generally been improved, either through ploughing and reseeding, or by heavy use of fertilizers and intensive grazing, usually with some weed control

Improvement of lowland grasslands has caused the largest of all Britain's habitat losses in the last half century (Nature Conservancy Council (NCC), 1984). NCC estimated, on the basis of a relatively few, local, and perhaps unrepresentative, surveys, that 95% of neutral grasslands lacked significant wildlife interest In order to substantiate and refine this estimate, NCC commissioned ITE to research and analyse historical information on grassland changes in lowland England and Wales (Fuller *et al*, 1986, Fuller, 1987)

The Animal and Grassland Research Institute (AGRI) holds copies of unpublished grassland surveys, which, with their published results, give data for 1934-6 (Wales), 1938-40, 1947 (England only), 1958-9 (England only), 1970-72 and 1974-76 These surveys recorded plant species' dominance in the field using stratified sampling schemes The data allow us to calculate the part of the total agricultural area of lowland England and Wales which was occupied by grasslands, and the relative proportions which were dominated either by indigenous or preferred species As England makes up 90% of the lowlands in England and Wales, extrapolation was used, in the absence of Welsh data, to estimate the likely cover of the swards throughout England and Wales Rough grasslands were not recorded by the surveys, but their cover was estimated by extrapolation from Ministry of Agriculture, Fisheries and Food (MAFF) agricultural statistics for lowland counties

ITE surveys of Britain in 1978 and 1984 provided more recent estimates of the cover of swards dominated by preferred and indigenous species The sampling system was used to stratify historical data from the survey of England and Wales undertaken by Stamp (1962) in the 1930s and also to structure a survey of grassland extent (not quality) based on air photographs from the 1940s

The various surveys were synthesised into as near a common format as possible, with error always on the side of caution (i e minimising change), where there were any doubts

Results (Figure 53) show that the total area of lowland agricultural grasslands (permanent pasture, rough grazing and leys) has declined by 39% from 7 8M ha in 1932 to 4 8M ha in 1984 Much more striking is the loss of some 92% of the 7M ha of unimproved swards, down to just 0 6M ha in 1984 About half the grassland has gone to arable farming, the other half remains as grassland but has been agriculturally improved Rough grasslands have fared better than other unimproved swards, with 0 5M ha now remaining (36% of the 1932 total) However, unimproved permanent pasture, the typical meadows of the 1930s, which once

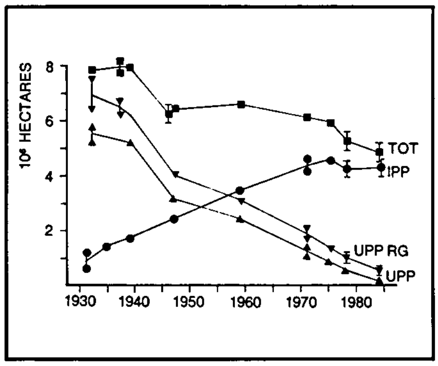

Figure 53.
Changing areas, millions of hectares, 1932-84, of total grassland (TOT), improved permanent pasture (IPP), unimproved permanent pasture/rough grazings (UPP/RG), and unimproved permanent pasture alone (UPP) Note that two linking points at one date represent a likely range (i e maximum and minimum values), a single point with error bars shows standard errors of estimates of cover, single points alone signify that no calculation of likely error has been possible

covered 5 8M ha of lowlands, now only totals 0 2M ha Thus 97% of the pre-war total has been destroyed, and only 4% of today's pastures are dominated by indigenous species Furthermore, many swards dominated by indigenous species have seen some improvements, so that they no longer contain all the species they once had

Various publications, from the 1930s to the present, give corroborative evidence for these findings When Stapledon had completed his pre-war survey he described grass farms as showing 'some of the worst examples of slovenly, negligent and deplorable husbandry' He recommended 'periodic breaking' of all grass swards (Stapledon 1939) and, in fact, with the ploughing subsidy introduced in 1939, such breaking became a regular practice, taking in 0 5M ha per year through the war years (Stapledon, 1943) Stapledon (1946) was still critical of the ' general weediness' of some swards post war, especially ' fields perpetually cut for hay [where] weeds dominate the vegetation' He estimated that these species-rich hay meadows might have exceeded 1 0M ha in area In 1960, Baker reported there still was a ' hard core of poor grassland on which ploughing grants [had] failed to have effect' But the 1971 survey (Green, 1982) showed that intensive management could achieve grassland improvement without the need to plough Even then, 'old hay meadows [were] still fairly common ' with 'more than 1M ha of old grass with less than 20% preferred species' By 1979 Hopkins reported 'it is now an exception to find swards where ryegrass is completely absent' He also reported the low incidence of swards dominated by indigenous grasses The situation is well known species-rich swards are very rare, as was confirmed by the ITE surveys

A survey of fertilizer usage, based on MAFF data, helps explain the trends of recent years (Figure 54) Fertilizer use on grassland has increased steadily

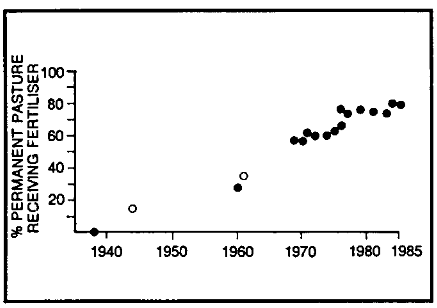

Figure 54
The percentage of permanent pasture fields (●) receiving fertilizer, in the year plotted, in the period 1938 to 1984, two additional points show percentage of permanent pastures with leys (○) receiving fertilizer

from about 1940 onwards so that, in the year 1985, nitrogen application affected 99% of all swards for silage, 93% of all mown grass, 85% of all grazings, and 79% of all permanent grasslands (upland included) As fertilizer is usually applied on the more easily worked areas it might be concluded that nearly all lowland agricultural grasslands now receive regular fertilizer applications

The results of the surveys confirm the NCC's conclusions that 95% of present day swards lack conservation interest, only 7% of the grasslands, or just 4% of permanent pastures, are essentially unimproved NCC estimated that 3% of swards were undamaged by agricultural intensification The NCC conclusion may actually be rather optimistic Yet to quibble about the exact percentage is pointless, the important fact is that objective analysis of historical data, originally collected in the field by a variety of organisations over a period of a half century, shows that unimproved permanent pastures, which once covered 40-45% of all lowlands in England and Wales, now cover, at the most, 1 4% of these lowlands

R Fuller

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Vegetation Change at Coom Rigg Moss NNR

(This work was supported by the Nature Conservancy Council)

Coom Rigg Mos is a peatland site within Kielder Forest in Northumberland Until afforestation in the mid-1950s, it was one of many peatland sites that were component parts of the hill farms, and sheep grazings, within the border region of England and Scotland Planting, and subsequent development of the Forest, has resulted in many of the peatland sites being blanketed by trees, whilst others remain as islands in a sea of forest As Kielder Forest has developed, so has concern over changes that are taking place within the remaining areas of peatland vegetation Some of these peatland sites were considered to be good examples of blanket, and raised, bogs Coom Rigg was such a site and was included in the Irthinghead series of peatlands in the *Nature Conservation Review* (Ratcliffe, 1977)

Between 1956 and 1959 Coom Rigg Moss was the subject of a series of ecological and hydrological studies (Chapman, 1961, 1964a, 1964b, 1965) Data collected at that time included descriptions of the vegetation based on samples from quadrats placed about the intersection points of a 100-metre grid The grid was resampled in August 1986 Examples of changes in individual plant species are shown in Figure 55 The outline on the maps denotes the boundary of the unforested area of peatland at Coom Rigg in 1986 The upper diagrams show the percentage frequency of species in 1958, the centre diagrams show the percentage frequencies of the same species in August 1986, and the lower diagrams show changes between 1958 and 1986

Drosera rotundifolia has undergone the greatest change, with an overall decrease in percentage frequency of 51% Five other species, *Sphagnum magellanicum, S papillosum, S capillifolium, Odontoschisma sphagni* and *Narthecium ossifragum* show a

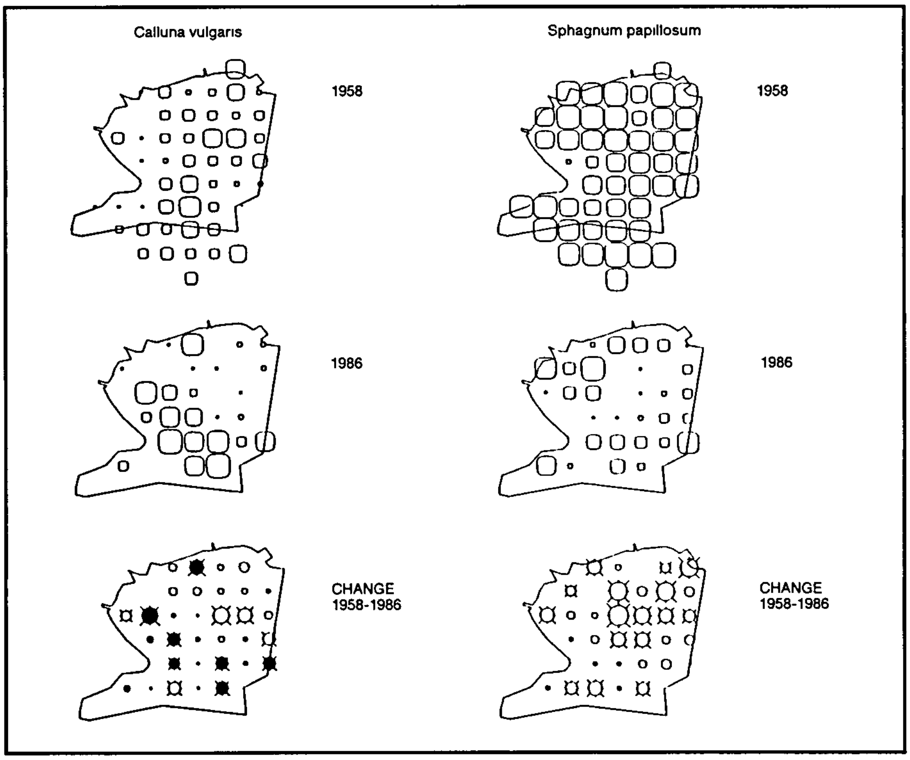

Figure 55
Changes in percentage frequency of *Calluna vulgaris* and *Sphagnum papillosum* at Coom Rigg Moss between 1958 and 1986 Outline denotes unplanted area of peatland in 1986 Size of symbols proportional to percentage frequency Solid circles denote increase open circles denote decrease Starred circles indicate change significant at 95% probability level

decrease of at least 40% The greatest increase in any species is 9 43%, in *Mylia anomala* At the time of the original survey, the vegetation showed only small variations over the bog surface This apparent uniformity no longer exists The surface of the bog now shows a series of distinct vegetation types, dominated by *Deschampsia flexuosa, Calluna* and *Eriophorum Deschampsia*-dominated vegetation occurs upon areas of shallow peat (‹3m) over a range of slopes *Calluna*-dominated vegetation is restricted to level areas of bog where the depth of peat is between 0 3 and 1 5m *Eriophorum*-dominated areas are found over a range of slopes, but where the peat is generally deeper than 3m

It is unlikely that the changes seen at Coom Rigg would have taken place if the surrounding area had not been afforested Evidence from adjacent sites, such as Butterburn Flow, suggests that changes during this period would have been very small Changes may be the direct result of afforestation, as tree-planting may have reduced rainfall, but the site does not appear very much drier than in the 1950s Analyses made in 1958 and 1986 show no great differences in water chemistry

The most probable reason for the changes at Coom Rigg is alteration in the land use of the bog itself Before afforestation, the site was part of two farm holdings Both were subjected to low levels of grazing throughout the year and to light burning, especially after frosty weather in the autumn The fires were fast-moving, and did little more than remove the dead grass and sedge vegetation from the general bog surface The low but continuous level of grazing must have been an important factor in maintaining the conditions found at Coom Rigg in the 1950s, and which still exist at nearby Butterburn Flow Although peatland accumulation depends upon production of organic matter, species such as *Calluna vulgaris, Eriophorum angustifolium, Molinia caerulea* and *Deschampsia flexuosa* produce physical conditions different from those of *Sphagnum*-dominated vegetation Lack of grazing has allowed the accumulation of standing dead material which blankets, and thus reduces, previously more abundant plant species In the absence of grazing and burning for a period of almost 30 years, slope and peat depth have become significant factors in determining the vegetation

The extensive development of *Calluna*, and the reduction in *Sphagnum* over the drier areas of Coom Rigg, are of particular interest and suggest mechanisms by which peat erosion in other areas might have originated

Coom Rigg now offers great potential for the establishment of a series of management trials upon the three main types of vegetation that exist on the bog The site provides valuable information about the changes that might be expected to take place on other sites if they became isolated from their surrounding moorland, and for the development of management treatments for use elsewhere

S B Chapman and R J Rose

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THE ENVIRONMENTAL PROBLEMS OF AFRICA

Desertification in Commonwealth Africa

Introduction

In the report of the Commonwealth Action Group on the Economic Crisis in Africa, the Commonwealth Secretary General was invited to undertake a study on the scope for action on soil erosion, desertification and related drought problems, taking into account previous studies and work now in progress, the constraints on follow-up action and the experience of countries which have achieved considerable success in combatting these problems ITE, in conjunction with the Centre for Arid Zone Studies at University College of North Wales, Bangor, completed this review in 1986

It is clear that any review of the problem of desertification in the Commonwealth countries of Africa will come up with generally similar and depressing conclusions However, land deterioration in Africa is not a recent phenomenon In 1931 Dr I B Pole Evans, Director of the Botanical Survey of South Africa, wrote of Eastern Botswana (then the Bechuanaland Protectorate)

"Much of the country is being spoilt by overstocking and overgrazing and this should at all costs be avoided"

There is, therefore, a long-standing failure of governments to recognise the importance of ecological principles in land management Desertification is the inevitable result

Stony desert in North Kenya.

Grazing.

if such principles are not observed; drought *per se* may be of lesser importance.

General Background

Despite the fact that drought is not the most important cause of desertification, it remains true that there have been downward trends in mean rainfall over wide areas of sub-Saharan Africa, since the 1950s, when rainfall was above average. All the Commonwealth countries have suffered to a greater or lesser degree, and countries such as Nigeria, Botswana and Kenya, fringing the great deserts, have suffered more than most. The trend in rainfall pattern throughout Africa over the last four decades has been consistent; there are many local variations but the overall pattern is clear. Some scientists, using computer models, believe that there is a distinct possibility that the drought will continue; others believe that the low rainfall we are experiencing is simply part of Africa's arid heritage and that it will right itself in time; still others believe that man's activities, by altering vegetation cover, soil moisture, atmospheric dust and carbon dioxide content, are exacerbating and prolonging the drought.

Most commonly, desertification occurs when inappropriate land management practices result in the destruction or reduction of vegetation cover, by overgrazing, inappropriate cultivation, unmanaged woodcutting, burning, and improper management of irrigation.

All the Commonwealth Countries have an overgrazing problem to some extent, although it is particularly acute in African countries with large populations of cattle, sheep and (in the case of Nigeria and Kenya) camels, and where the pastoral way of life is traditional. It is not confined to the semi-arid or arid countries. The pastoral use of savannahs brings secondary problems, as trees are felled for fuel, shelter, animal control and fodder; all these practices increase the probability of desertification.

Soil erosion of gullies in Lesotho.

Native vegetation is destroyed by cultivation and by burning, exposing the soil surface to wind and water erosion. Crops protect the soil surface but this protection is lost after harvesting or when crop residues are grazed. Tractors or heavy tillage implements increase subsoil compaction and soil surface crusting, reduce water penetration and increase surface run off. Erosion problems appear very quickly in arid or semi-arid areas, or where cultivation has been carried out on unsuitable soils, on steep slopes or using inappropriate practices. Irrigation is not widespread in Commonwealth Africa, but it can cause severe problems of waterlogging and salinisation if drainage is inadequate or water quality poor.

In conclusion, it should be emphasised that the deterioration of Africa's natural resources is widespread. Declining fertility, soil erosion and the loss of plant cover are common over large areas of the continent. No Commonwealth country is exempt from its effect and, without positive action, desertification will accelerate, affecting the capability of nations to feed their people.

International Initiatives

The possibility, obvious in the 1970s, that desertification was an increasing problem, stimulated the international community to unprecedented aid and activity in the Sudano-Sahelian zone. The United Nations Conference on Desertification (UNCOD) organised by The United Nations Environment Programme (UNEP), and meeting in 1977, initiated a Plan of Action against Desertification (PACD). The plan was reviewed in 1984, when the depressing conclusion was reached that its goal (control of desertification by the end of the century) was impossible to achieve. Seventy-five per cent of the productive area of the world's drylands and 40% of the world's total productive area is now desertified, costing some $20 billion in lost agricultural production. The rate of desertification has hardly slowed over much of Africa.

There are many agencies and non-governmental organisations

Table 21 The Present Status of Erosion and Soil Degradation in Commonwealth Africa

	Gully erosion	Sheet erosion	Wind erosion	Desert encroachment	Declining soil fertility	Soil crusting	Degraded vegetation	Modal value
The Gambia	1	1	–	–	2	1	1	1
Nigeria	2	2	1	1	2	1	2	2
Ghana	1	2	–	–	2	1	2	2
Sierra Leone	–	1	–	–	1	–	2	1
Uganda	1	2	–	–	1	–	1	1
Kenya	1	2	1	2	2	1	2	2
Tanzania	1	1	–	–	2	1	1	2
Malawi	1	2	–	–	2	2	2	2
Zambia	1	2	–	1	2	1	1	1
Zimbabwe	1	2	–	1	2	1	1	1
Botswana	1	2	2	2	2	1	2	2
Lesotho	2	2	–	–	2	–	1	2
Swaziland	2	2	–	–	2	1	1	2
Modal value for Commonwealth countries	1	2	1	1	2	1	1	2

1 = slight 2 = moderate 3 = severe – = not applicable

Source FAO African Agriculture — the next 25 years — Annex 2

deeply involved in the problem, including, of course, the old agencies in the developed Commonwealth countries The Southern Africa Development Co-ordination Conference (SADCC) countries have a unit of soil conservation in Lesotho, but there is no co-ordinating agency for most Commonwealth or Southern African countries The Commonwealth Secretariat could usefully stimulate such an initiative

The Problem in Commonwealth Africa

Table 21, taken from FAO sources, shows the present status of desertification in its various forms in Commonwealth Africa Declining soil fertility is a universal problem, as is erosion and the degradation of vegetation

The potential for desertification is still worse (Table 22) The Southern African countries have around 50% of their land area at risk and Kenya has even more, indeed, all the Commonwealth countries in semi-arid zones have appreciable areas at risk Even a moderate rating means virtually complete loss of productive capability in the area affected, with its consequent harvest of human misery

All the Commonwealth countries recognise and have responded to the problem in some measure, although this response varies considerably The Gambia, for example, perhaps because of its membership of the Comité Permanent Interetats de Lutte Contre la Secheresse, (CILSS) has an explicit plan of action Very few other Commonwealth countries have such a plan, although agricultural and forest programmes frequently reflect a

Table 22 Degree of Desertification in Commonwealth Countries Desertification Hazard Rating

	Percentage of area			
	None/slight	Moderate	Severe	Very Severe
The Gambia	44 4	56 0	0	0
Nigeria	62 8	31 4	5 8	0
Ghana	95 6	4 4	0	0
Sierra Leone	100	0	0	0
Uganda	80 2	19 2	0 6	0
Kenya	13 0	64 3	21 0	1 7
Tanzania	65 4	33 4	1 2	0
Malawi	94 5	5 5	0	0
Zambia	97 1	2 9	0	0
Zimbabwe	39 2	55 0	5 8	0
Botswana	39 3	60 7	0	0
Lesotho	26 9	57 2	0	15 9
Swaziland	69 6	30 4	0	0
Mean for Commonwealth countries	63 7	32 4	2 6	1 3

From map of desertification hazards, explanatory notes prepared for UNEP by FAO and Environmental Systems Research Institute — May 1984

concern with land degradation Explicit anti-desertification policies are necessary in all African countries and international agencies (including the Commonwealth) should use their good offices to expedite this process Without recognition of the problem, and policies to improve land management, the prospects for self sufficiency are bleak indeed

C Milner

ITE's Role in Hardwood Forestry in Africa

Since 1974, research in Edinburgh on techniques of vegetative propagation and clonal selection in *Triplochiton schleroxylon* and other West African hardwoods has been orientated towards the establishment of an alternative man-made and highly productive resource, to reduce the pressures on natural forest Centred on Nigeria for the first six years, this effort has in recent years spread also to Sierra Leone, Liberia, Ivory Coast, Ghana, Congo and particularly Cameroon In essence, this development has arisen from efforts to create a "Regional Programme for the Improvement of Tropical Hardwoods" involving the forestry research organisations of these seven African

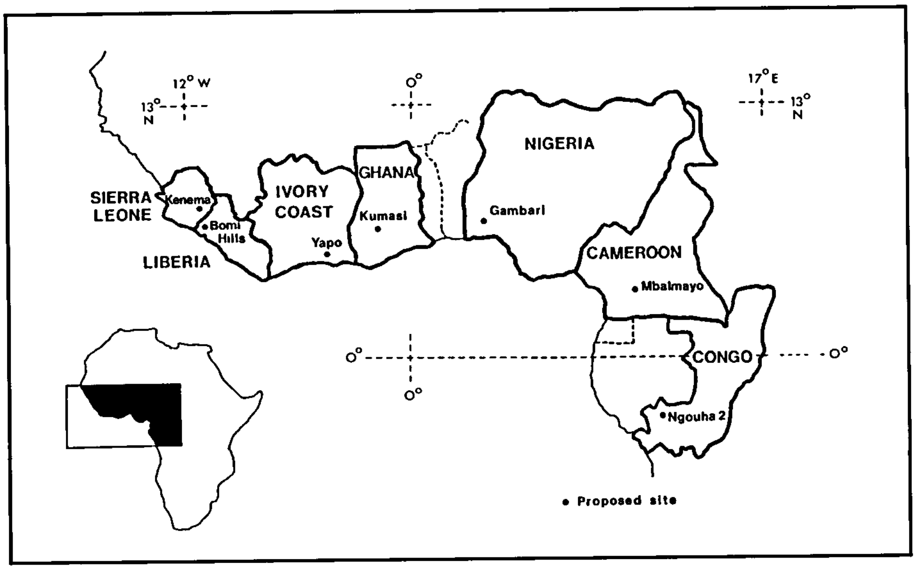
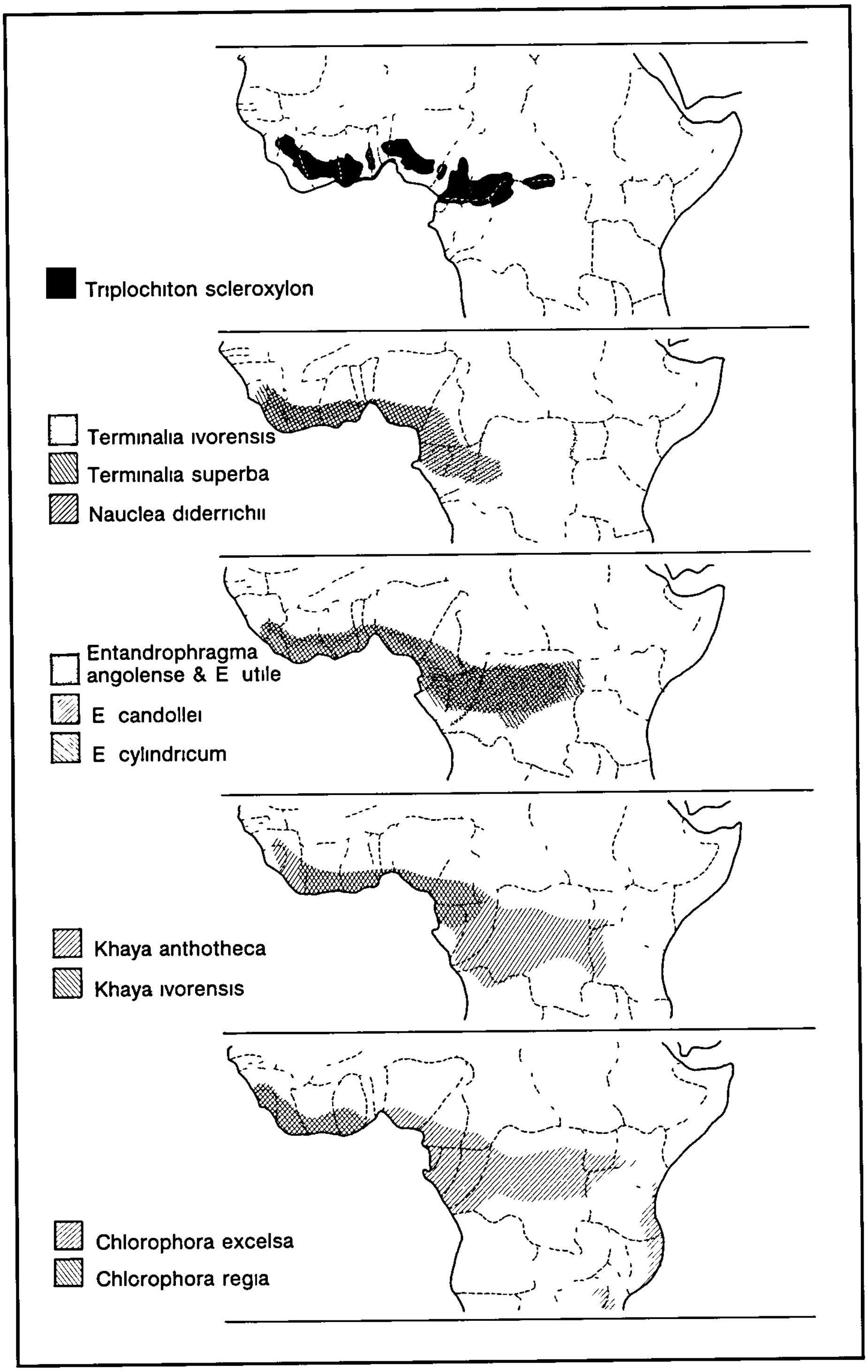


Figure 56
Countries wishing to participate in the hardwood improvement programme for West and Central Africa

Figure 57
Natural distribution of some commercially important hardwood species of West and Central Africa



countries and also the Centre Technique Forestier Tropical (CTFT) at Nogent-sur-Marne near Paris

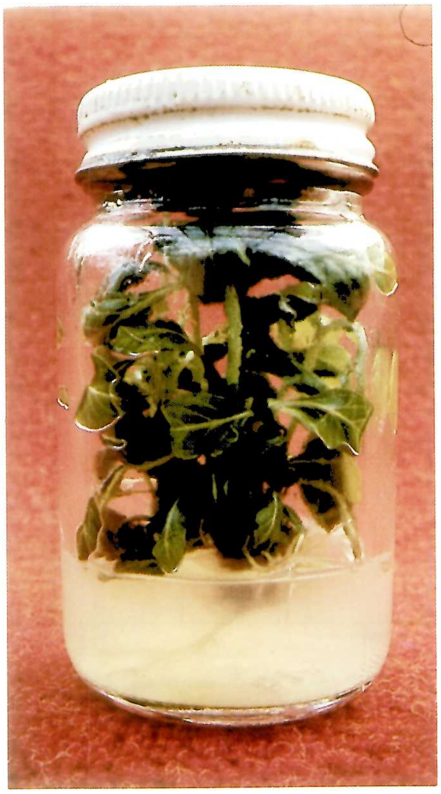
Starting in July 1981, discussions with foresters throughout the coastal countries of West Africa led to the preparation of proposals by each country for research projects to encourage hardwood afforestation, and a workshop meeting, funded by UNEP and UNESCO, held in Abidjan in October 1983 At this meeting, principles were discussed regarding the development of proposals for a regional research project, aimed at the development of new approaches to hardwood forestry, based on the concepts of tree improvement through vegetative propagation and clonal selection (Leakey, Last and Cossalter, 1983) As a consequence of this workshop, the European Development Fund financed a fact-finding mission in 1985 to make proposals for a Regional Hardwood Improvement Programme for West and Central Africa

The rationale for a Regional Programme is based on the common commercial interests of the seven participating countries (Figure 56) in 18 hardwood species (Table 23) and on the desirability of incorporating within an improvement programme the genetic variation likely to be inherent in such widely distributed species (Figure 57) It also takes into account the size of the task and the need to apportion the research on different species to different countries, as well as encouraging the interchange of ideas, skills, results, material and manpower through an integrated network of research

Five main themes of research were proposed (Leakey and Grison, 1985)

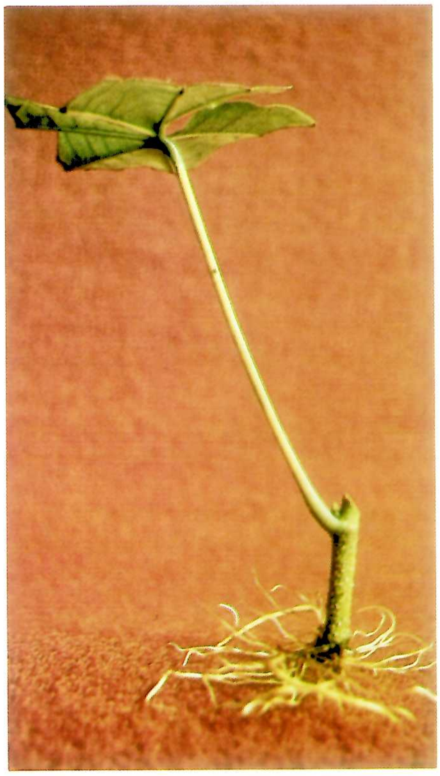
(i) The exploitation and utilisation of genetic variability by seed collection throughout the natural ranges of the species, the

i) Rooting a cutting of *Nauclea diderrichii*



ii) Adventitious buds produced in vitro

iii) A rooted cutting of *Triplochiton scleroxylon*



establishment of *ex situ* conservation plots and provenance, progeny and clonal trials.

(ii) The physiology of tropical trees as it affects: (a) root initiation in stem cuttings, particularly the identification of those factors affecting the maintenance of easy rooting in frequently cropped stockplants; (b) the identification of growth strategies, particularly branching processes and the allocation of dry matter within trees of different clones; (c) reproductive processes, especially floral initiation.

(iii) The identification of selection criteria for superior clones, provenances, or progenies and the identification of 'plus' trees in natural forest or plantations. Much of this work will involve understanding the genetic variation in the allocation of dry matter between stem and branches in tree species with different branching processes. In addition, attempts will be made to identify and predict tolerance to insect pests.

(iv) The silviculture of clonal forestry, particularly the effects of plantation management on productivity of single and multi-clone plots and on mixed species plantations.

(v) Aspects of the ecology of insect pests and the identification of genetic tolerance.

An integrated and multi-faceted programme such as this, spread over seven countries speaking two different languages (English and French), will obviously involve very considerable administrative and co-ordination difficulties. To try and minimise them, the organisation of the overall programme is planned at two levels: national and regional. Nationally the small research team (3-4 graduates) in each country will be situated in, and part of, the national organisation for forestry research, or where this does not exist, in the organisation for forest management. The team, which will be more or less autonomous financially, will be responsible for the implementation of its own research programme; a programme which will have been proposed locally, discussed by the Regional Co-ordination Committee and then agreed locally. The regional identity and character of the programme will result from the use of a special Regional Fund to co-ordinate the activities of the different teams through the Regional Co-ordination Committee and the Regional Office — the permanent secretariat of the programme. The Regional Fund will finance the training of staff within the region and in Europe, the movement of research staff and technicians between teams, the organisation of meetings, research workshops and seminars, the preparation of a range of publications and the administrative activities of the Regional Office, including the periodic travel of two research co-ordinators (one from ITE and one from CTFT).

Independently of the Regional Programme, ITE has also provided consultancy services to the Commonwealth Development Corporation's Forestry Project in SODEFOR of the Ivory Coast and to the World Bank Forestry Project in Cameroon. The latter, which spans four years, has particular regard to the establishment of a Tree Improvement and Seed Production Unit in the forest management organisation ONAREF (Office National de Regénération des Forets) of Cameroon. This Unit was created in 1987, with ITE providing an expert for two years as its director and training officer.

Much of ONAREF's activities will be with *Eucalyptus* and *Pinus* species, but, particularly in the moist deciduous forest areas, native hardwoods will be grown on a commercial scale (500ha/annum) based on clones selected for their form and yield. Consequently, recommendations have been made for the creation of a vegetative propagation facility for 500 000 plants per annum, based at Mbalmayo (Leakey, 1985). Forty stockplants of 250 clones, selected from different sources, will be established in a 2ha plot close to the propagation unit and nursery. Following propagation, selected clones will be established in trial plots of about 50m × 50m, where they can

Table 23 Priority species in the research programmes of the participating countries (P = priority, O = Other species to be studied)

Botanical Name	Official Trade Name (ATIBT)	Sierra Leone	Liberia	Ivory Coast	Ghana	Nigeria	Cameroon	Congo
Triplochiton scleroxylon	Obeche	P	O	O	P	P	P	–
Terminalia ivorensis	Framiré	P	O	P	P	O	P	–
Terminalia superba	Limba	–	O	P	O	O	P	P
Khaya spp	Acajou	O	P	–	O	P	–	–
Entandrophragma spp	Sipo/Kosipo Tiama/ Sapelli	O	P	–	O	P	–	–
Chlorophora spp	Iroko	O	–	–	O	P	–	–
Nauclea diderrichii	Bilinga	P	O	P	P	O	–	–
Lovoa trichilioides	Dibétou	O	P	–	–	–	P	–
Tarreitia utilis	Niangon	–	P	P	–	–	P	–
Tieghemella heckelii	Makoré	–	P	–	–	–	–	–
Aucoumea klaineane	Okoumé	–	O	–	–	–	–	P
Pericopsis elata	Afrormosia	–	–	–	O	–	–	–
Mansonia altissima	Mansonia	–	–	–	–	O	–	–

be managed and assessed for the full duration of the rotation It is hoped that in due course this planting scheme will be able to benefit from the research activities of the Cameroons team in the Regional Programme, which will also be based Mbalmayo

In conjunction with the consultancy to ONAREF, ITE and Edinburgh University Department of Forestry and Natural Resources are collaborating in a CEC- and ODA-funded post-graduate training programme for three Cameroonians The projects include (i) studies of vegetative propagation and clonal selection of indigenous hardwoods, (ii) an assessment of the mycorrhizal flora of native hardwoods and the potential for increasing productivity by inoculation techniques in the nursery, and (iii) a comparative study of nutrient cycling in natural forest and man-made plantations established on sites that have either been clear-felled and completely stripped of natural vegetation or partially felled and planted into the ground flora

An overall review of the forestry sector of Cameroon was made in 1987 by an Inter-agency Mission co-ordinated by FAO ITE provided the consultant for "forest genetics, seed supply and genetic resources conservation"

Currently ITE's own research in Edinburgh with West African hardwoods is concentrating on further understanding the factors that create within-clone variation in rooting ability of cuttings from managed stockplants This is seen as being important for the long-term retention of easy rooting in stockplants and the avoidance of the problems that are frequently attributed to 'phase-change' (the transition to sexual maturity) but which may in fact reflect a poor knowledge of stockplant physiology It is becoming increasingly apparent that the light environment, which interacts with (i) nutrient availability, (ii) competitive effects of different shoots on each others growth and (iii) the intrinsic variations in internode length arising from the position of origin of the cutting within the shoot and the shoot within the plant, is vitally important for successful and vigorous rooting Stockplant management regimes based on such knowledge should do much to ensure the prospects for cost-effective and large-scale propagation, but it is likely that in future it will also become important to further increase multiplication rates With this in mind, collaborative studies are in progress between the Department of Horticulture and Agriculture of the University of Nottingham at Sutton Bonington, to develop *in vitro* techniques for the micropropagation of tropical hardwoods, especially *Khaya ivorensis* (Acajou or African Mahogany) and *Nauclea diderrichii* (Bilinga)

Two further tropical tree improvement projects have been commissioned in 1987 The first by Shell for studies on the factors affecting the rooting ability of *Eucalyptus grandis*, particularly in difficult-to-root clones, and the second by ODA for agroforestry with semi-arid-zone species of Kenya This latter project involves both vegetative propagation of indigenous trees and the identification, culture and inoculation of their local endomycorrhizal flora

In conclusion, ITE is becoming increasingly involved not only with the physiological research that is fundamental to tree improvement programmes involving clonal approaches, but also in their implementation in afforestation programmes

R R B Leakey

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NEW METHODS

The Use of Digital Cartography in Ecology

The past year has seen the development of the ITE Digital Cartographic Service (DCS), based at Bangor Apart from the continuing development of the mapping system itself, DCS has had a vital role to play in a number of projects, ranging from

The interactive interrogation of digital map data at the "graphics workstation" at ITE (Bangor)

an ecological survey of a small forest to a national study of acid water.

The DCS's main mapping facility is built around a SysScan Mapping System, purchased by ITE in 1985. Hardware includes a digitising table, colour graphics screen, various computer terminals and printers and drum plotting equipment. The software systems available can be used to edit map data, to design output graphics, interrogate map-based statistical information and to link to other data sources. Data from original field documents can be captured in a digital form for further manipulation and interrogation by DCS staff, or by ITE scientists themselves. The data are displayed on a colour graphics screen and may be examined in many ways, such as overlaying and selectively displaying combinations of mapped data, or recording the boundary length and ground area of parcels of land. Data can also be 'imported' into the mapping system from other sources, eg magnetic computer tapes containing remote sensed images. The output is in many forms, including conventional maps in different designs. However, the more important elements of the service provided are the output of spatial information, in forms such as statistical tables, and the facility for interactive examination of mapped data.

DCS has put much effort into linking map data files with other computer files, such as species lists. Using the DEC/VAX information system 'Datatrieve', complex searches can be done on non-graphic files and the results fed back to the map data, perhaps to create a new map. Alternatively, the mapping system can be asked to feed map information, such as field sizes, to the data file for permanent storage.

The facility to move freely between map data and remotely sensed data has proved to be particularly useful for a number of ITE scientists. Data are stored on the mapping system in a vector (line) form, whereas remotely sensed data are stored in a raster ('grid squares') form. The Bangor facility allows for the free flow of data in either direction by using a series of 'transfer programs'. Mapped 'ground truthed' data can be superimposed on the remotely sensed image and used for geometric correction or for simple enhancement of the visual product. Mapped data have been used successfully to increase the accuracy of vegetation classification from image data. Classified remotely-sensed data have been transferred to the mapping system, where multi-colour maps and other output have been produced for further use.

Selected Mapping Projects

During the year, DCS has worked with people from many different NERC/ITE groups. Projects have been developed with ITE scientists based at Bangor, Monks Wood, Merlewood and Banchory, and also with the Freshwater Biological Association (FBA), the Institute of Hydrology (IH) and the NERC Unit for Thematic Information Systems (NUTIS).

A selection of these projects is described, to help to illustrate more clearly the type of work DCS has been doing.

Acid Waters in Wales

Soil scientists at Bangor have identified environmental features which give a reliable guide to susceptibility to acidification, and DCS has prepared a map data base of these. Figure 58 shows the results of overlaying various input data (soils, geology, land use) to produce a single map; two soil types, four geology types and two land use types have been used to date. The resultant digital maps have been compared with pH data from field soil samples to verify the methods. Presentation of the techniques to water authorities and soil scientists has resulted in a contract to continue the work with the aim of extending the idea to a national level.

Newborough Forest

The Forestry Commission (FC) requested ITE to carry out a survey of Newborough Forest, Anglesey, with a view to improving management strategies and enhancing the wider use of the forest by the public. The first objective was the preparation of a map of the forest depicting habitat types. DCS created a number of maps in differing formats, several of which were used as working documents during the ecological survey.

Small Scale Maps of Great Britain

DCS has an ongoing project to provide data for a 'digital atlas of the UK', two or more pages of which may be superimposed as required. The aim is

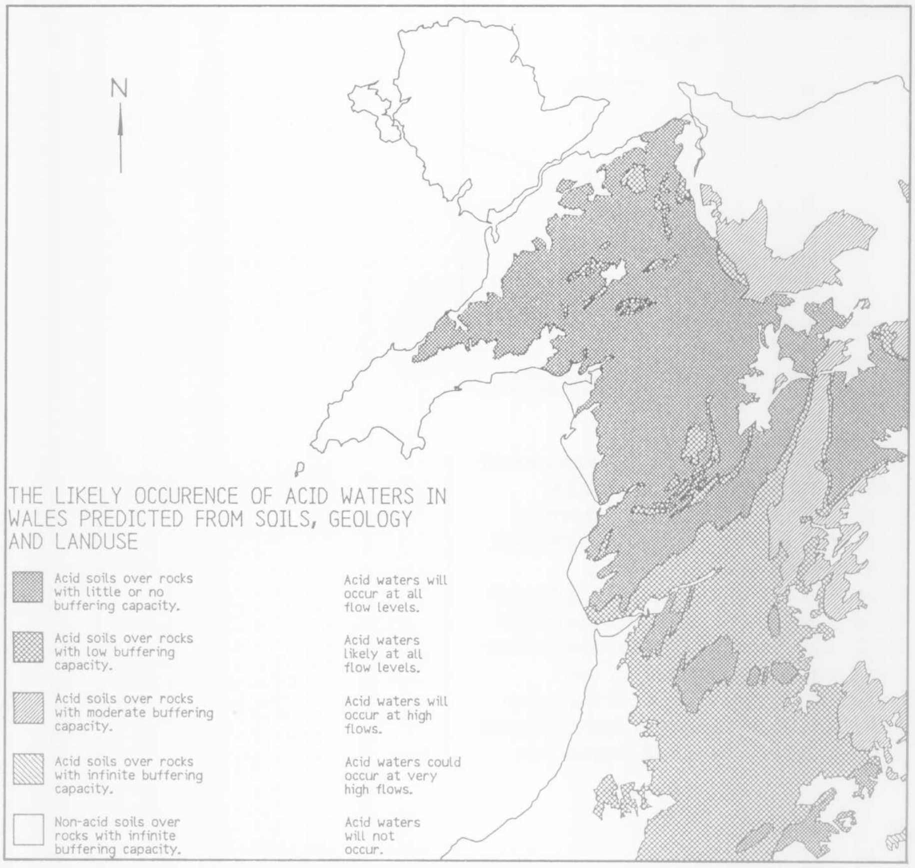

Figure 58.
One of a series of five maps, depicting single categories of susceptibility to acidification. Other maps showing such features as the nature of the original soils and geology, have also been produced.

to provide national information on specific environmental themes Many themes are already available, including soils, rainfall, height above sea level, county and national park boundaries DCS adds to the data set as specific requests are received For example, the FBA required a basic river network map showing sampling points for its River Communities Project DCS used its link to other computer files containing records of species distribution at over 350 locations In response to an enquiry about species distribution, a distribution map, at any scale, combined with other available data if desired, can be produced within a few hours

Glyderau vegetation
With the agreement of the Nature Conservancy Council (NCC), DCS has

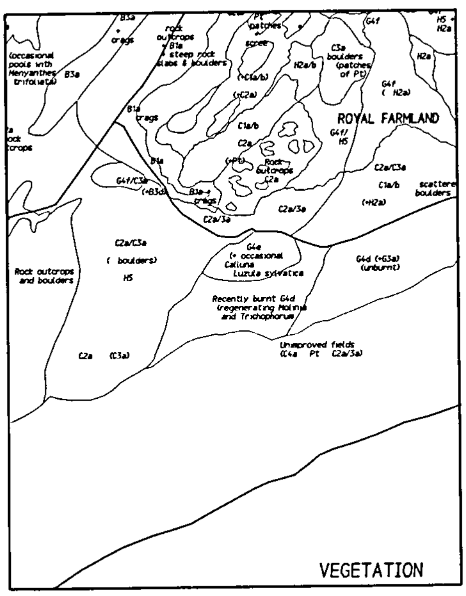

Figure 59
A computer 'test plot' of text content from the Glyderau project Vegetation and ownership boundaries can also be seen

completed a pilot mapping exercise of upland vegetation in Snowdonia National Park An NCC map derived from field survey has been converted, together with land ownership information, into digital form Both sets of map data have been transferred to the Image Analysis System where they can be used in conjunction with remotely sensed images of the same area This is an important development in the process of upland vegetation classification Such projects are also valuable for providing real data against which to test the capabilities of the mapping system In this project it was necessary to incorporate textual information on the digital map, an example can be seen in Figure 59

Future Developments
Development of a 'hands on' facility continues as the demand grows Some scientists have been trained to operate the map-editing functions so that they can edit their own source data, or generate statistical data at a site remote from the mapping system and link, via the NERC computer network, with a map data file at Bangor Such developments, together with the extension of DCS expertise into the Geographical Information System (GIS) field and the growing links with remote sensing, show the increasing potential for this ITE service

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BAND 8	Mr Robertson, A C	
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Grade 7	Dr Harris, M P	
Grade 7	Dr Kruuk, H	
Grade 7	Dr Miles, J	
Grade 7	Dr Miller, G R	
Grade 7	Dr Moss, R	
Grade 7	Dr Welch, D	
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SSO	Mr Cummins, R P	
SSO	Mr French, D D	
SSO	Dr Marquiss, M	
SSO	Mr Parr, R A	
SSO	Mr Paterson, I S	
SSO	Mr Picozzi, N	
HSO	Mr Catt, D C	
HSO	Mr Conroy, J W H	
HSO	Mr Young, W F	
SO	Mr Scott, D	
SO	Mr Trenholm, I B	
PTO	Mr Morris, J A	

Annex 2 Research projects at 31 December 1987

NOTES
Numbers in left-hand column relate to the terrestrial and freshwater sciences (TFS) Management Information System (* indicates that the project is wholly or partly supported by contract funding) Numbers in brackets indicate other programmes to which the project is relevant

Programme 1 FOREST AND WOODLAND ECOLOGY

T01001 Evaluation and selection of genotypes — **M G R Cannell**
- a Evaluation of conifer clones and progenies (8) M G R Cannell
- b Evaluation of red alder L J Sheppard
- c* Selection of conifer genotypes (8) A Crossley
- d* Genetic improvement of tea (8) M G R Cannell

T01002 Tree seedlings and their establishment — **J D Deans**
- c Effects of EFG's seedling storage and handling practices on outplanting survival and performance J D Deans
- d Influence of mycorrhizas on root growth potential P A Mason

T01005 Tree growth processes — **M G R Cannell**
- a Measurement and modelling of transpiration in plantation Sitka spruce R Milne
- b A model of tree growth R I Smith
- c Partitioning of assimilates between branchwood and foliage in forest trees M G R Cannell
- d Partitioning of assimilates of stems and structural roots of forest trees J D Deans
- e Light use efficiency of coppice (9) M G R Cannell
- f Cone initiation its interactions with and consequences for the carbon balance in lodgepole pine (*Pinus contorta*) J McP Dick

T01007 Analysis of windthrow — **R Milne**
- a The silviculture of re-spacing Sitka spruce J D Deans
- b Operation of the Rivox field site (13) R Milne
- d Mechanics of windthrow in commercial forests R Milne
- e* Tree stability interactions within groups of trees under wind loading R Milne

T01008 Mycorrhizas and tree production — **J Wilson**
- a Mycorrhizas and tree growth P A Mason
- b Characterization of sheathing mycorrhizas P A Mason
- c Occurrence of fruitbodies of mycorrhizal fungi in field plantings of different provenances of *Picea sitchensis* and *Pinus contorta* (9) J Wilson
- e* Large-scale production of mycorrhizal inocula J Wilson
- f* Mycorrhizal research links with India J Wilson
- h* Large-scale production of mycorrhizal inocula J Wilson
- i* Training of Philippines research worker (proposal) J Wilson

T01009 Improvement of tropical trees — **R R B Leakey**
- a Domestication of tropical hardwoods R R B Leakey
- b* Domestication of tropical trees by in vitro culture R R B Leakey
- c* Seed production and tree improvement in Cameroon R R B Leakey
- d* World Bank forestry — EFG & ONAREF R R B Leakey
- e* Vegetative propagation of *Eucalyptus grandis* R R B Leakey
- f* Propagation of *Lovoa trichilioides* in Cameroon R R B Leakey

T01010 Tropical forestry and agroforestry — **R R B Leakey**
- a* Forest ecology and training in Cameroon R R B Leakey
- c* Agroforestry and mycorrhizas in E Africa (2) R R B Leakey
- e* Endomycorrhizas and nutrient cycling in Cameroon P A Mason
- f* Ecosystem approach to the establishment of indigenous hardwoods R R B Leakey

T01011 Population ecology of upland herbivores — **B W Staines**
- a Deer in production forests (8) B W Staines

T01013 Ecology of woodland soil fungi — **J Dighton**
- a Role of fungi in nutrient cycling with special reference to *Mycena galopus* in forest soil (9) J C Frankland
- c An assessment of the status of mycorrhizas in the soil ecosystem J Dighton
- d Phosphorus uptake by mycorrhiza of birch (proposal) J Dighton
- e Modelling of ectomycorrhizal competition on tree roots J Dighton
- f Faunal/microbial interaction related to nutrient cycling and agricultural stocking of the uplands J C Frankland

T01014 Soil nutrient dynamics — **A F Harrison**
- a A comparison of biological and chemical assessments of the fertility of soils A F Harrison
- b* Cycling of key nutrients in

	forest soils and their interrelationships		A F Harrison
c	Liming and earthworm inoculation in forests (proposal)		C Robinson
d*	Field methods in terrestrial nutrient cycling studies (proposal)	(9)	A F Harrison
e*	Effects of vitamin addition on nutrient mineralization (proposal)		J Dighton
T01015	**Afforestation: vegetation and fauna response to tree species**		**J M Sykes**
a	Monitoring at Stone Chest, Cumbria		J M Sykes
b	Monitoring of woodlands — long term dynamics of forest ecosystems		J M Sykes
T01016	**Mixtures: interactions between tree species**		**A H F Brown**
a	The Gisburn experiment		A H F Brown
b	The effects of management in lowland coppices	(9)	A H F Brown
c	The effects of different silvicultural systems on flora, fauna, soil, timber production and visual amenity		A H F Brown
d	Soil and water acidity under different trees (proposal)		M Iles
T01017	**Agroforestry: potential mixtures of trees and crops**		**G J Lawson**
a*	Agroforestry experimental assessment of novel biomass systems	(2)	G J Lawson
b*	Review of knotweed control (proposal)		R Scott
T01018	**Regional variations in forest nitrogen dynamics in Europe**		**P Ineson**
a	Regional aspects of forest dynamics in Europe		P Ineson
b*	Nutrient cycling in European forests (proposal)		P Ineson
T01019	**Plant growth in semi-arid environments (Sudan)**		**D K Lindley**
a*	Environmental crisis in the Sudan (a) Rehabilitation of degraded agricultural soils (b) Application of water-storing soil polymers for increased tree seedling survival (c) Alternative supplies of biomass		D K Lindley
T01020	**Forest succession and nutrient dynamics**		**D K Lindley**
a*	The scientific management of renewable natural resources in China		D K Lindley
T01021	**Forest vegetation and pedogenesis**		**P J A Howard**
a	The role of forest vegetation in pedogenesis		P J A Howard
b	Soil biological aspects of nurse effects (proposal)		P J A Howard
T01022	**Nature conservation — new conifer forests (proposal)**		**J E G Good**
T01023	**Woodland ecology**		**J E G Good**
a	Tree planting on opencast sites		J E G Good
T01024	**Squirrel ecology**		**R E Kenward**
a	Grey squirrel damage and management	(8)	R E Kenward
b*	Goshawk population dynamics		R E Kenward
c	Foraging and reserve storage in red and grey squirrels		R E Kenward
T01025	**UNESCO contracts**		**O W Heal**
a*	UNESCO MAB contracts		O W Heal

Programme 2 AGRICULTURE AND THE ENVIRONMENT

T02001	**Farming and wildlife**		**B N K Davis**
a	Modern agriculture and wildlife		T Parish
b	Land use and ecology of Swavesey Fens — the fauna and flora in relation to both established and changing management	(9)	T Parish
c*	Pesticide drift and impact	(7)	B N K Davis
T02002	**Historical ecology**		**J Sheail**
a	Historical aspects of environmental perception		J Sheail
b*	Impact of drainage on wildlife	(9)	J O Mountford
T02003	**Grassland ecology and management**		**T C E Wells**
b*	Creating attractive grasslands	(9)	T C E Wells
c	Monitoring floristic changes	(2,9)	T C E Wells
d*	Establishment of low maintenance swards on riverbanks (proposal)		T C E Wells
e*	Knocking Hoe NNR analysis of cutting experiment (proposal)		T C E Wells
T02004	**Amendment of soils**		**T V Callaghan**
a*	Microbial amendment of soil polymers (proposal)		T V Callaghan

Programme 3 LAND RESOURCES AND USE

T03001 Human impact, erosion rehabilitation (2,9) **A Watson**
- a* Human impact in the Cairngorms — A Watson
- b* Revegetation after disturbance (9) — J Miles
- c Ecological impact of downhill skiing developments in North-East Scotland — G R Miller
- d* Aonach Moor development plan — N G Bayfield
- e* Footpath rehabilitation studies for the Yorkshire Dales National Park Committee (2) — N G Bayfield
- f Soil erosion on north-east Scottish farmland (2) — A Watson
- g* Effects of past management on the potential of upland soils to support plant growth (proposal) — G R Miller
- h* Restoration of upland vegetation (proposal) — N G Bayfield
- i* Path revegetation trials on the Pennine Way — N G Bayfield/ G R Miller
- j* Survey of soil erosion and vegetation damage at Cairn Gorm in 1988 — A Watson

T03002 Land use change and ecological impacts (2) **R G H Bunce**
- a An ecological survey of Britain — R G H Bunce
- b Field survey of land cover and landscape features and their recent changes (2) — C J Barr
- c* The environmental and socio-economic effects of CAP (2) — M Bell
- d* Countryside implications of changes in CAP (proposal) (2) — R G H Bunce
- e* Environmental issues, agriculture and forestry land use options in Devon — R G H Bunce
- f* Ecological consequences of land use change (proposal) — R G H Bunce
- g Agricultural environment award (special topic) (proposal) (2) — R G H Bunce
- h* Environmental constraints on the UK wind energy resources (proposal) — R G H Bunce

T03003 EEC Corine biotopes **B K Wyatt**
- a* EEC Programme CORINE Project Biotopes — B K Wyatt

T03004 Upland remote sensing **B K Wyatt**
- a A study of the use of remote sensing for mapping land-cover and monitoring change — B K Wyatt
- e Correction of satellite imagery for topographic effects on land cover classification in mountainous terrain (2) — A R Jones
- f* EEC Less Favoured Areas upland land use — management models (proposal) — B K Wyatt
- g* Discrimination of improved grasslands in the uplands utilizing remotely sensed data — B K Wyatt

T03005 Remote sensing of arid lands (2) **B K Wyatt**
- c* Remote sensing of national forest resources in Morocco pilot study (proposal) — B K Wyatt
- d* Rangeland mapping in the Sahel from remote sensing (proposal) — B K Wyatt

T03006 Land use data bases (2) **G L Radford**
- a National land characteristics and classification (2) — G L Radford
- d Air photo interpretation of land cover and landscape features and their recent changes — G L Radford
- e* Nature conservation and land use change in Lleyn — A Buse

T03007 Impacts of oil industry **R E Daniels**
- a* Rehabilitation studies at Normandy, Surrey — R E Daniels
- b* Oil well site at Ringmer, Sussex (proposal) — R E Daniels
- c* Monitoring of Wytch Farm oilfield (proposal) (2,9) — R E Daniels
- d* Purbeck Southampton pipeline biological monitoring (proposal) — R E Daniels

T03008 Ecological appraisal of developments **M D Hooper**
- a* Ecological appraisal of A20 (proposal) — M D Hooper
- b* Advice to Halcrows Avalon lakes study (proposal) — M D Hooper
- c* Monitoring the impact of Channel Tunnel construction upon terrestrial and freshwater habitats (proposal) — R C Welch

T03009 Remote sensing of vegetation change **R M Fuller**
- a Vegetation change at Dungeness and Orfordness (2) — R M Fuller
- b Remote sensing techniques for habitat surveys (2) — R M Fuller

- c* Dungeness vegetation survey — R M Fuller

T03010 Ecological Data Unit — **G L Radford**

T03011 Ecological monitoring in Scotland — **B G Bell**

- a* Ecological monitoring in Scottish Environmentally Sensitive Areas (proposal) — B G Bell

T03012 Soil assessment (1,2) — **M Hornung**

- a* Assessment of the principles of soil protection in the United Kingdom (proposal) (1,2) — M Hornung

T03013 Poole Bridge environmental impact assessment — **N R Webb**

- a* Poole Bridge environmental enhancement (proposal) — A J Gray

Programme 4 MANAGEMENT OF AQUATIC ECOSYSTEMS

T04001 Management of aquatic ecosystems — **A E Bailey-Watts**

- a* Effects of acidification on freshwater plants and invertebrates (7) — K H Morris
- c* Status and conservation of British freshwater fish (7) — A A Lyle
- d* Ecology and conservation of charr in Loch Doon — L May
- g* Status of fish populations in acidified waters in Wales (7) — I R Smith
- h Synoptic survey of freshwater ecosystems in Great Britain — K H Morris
- i Coldingham Loch (proposal) — A E Bailey-Watts
- j Rotifer resting eggs to indicate acidification in freshwater environments — L May
- k Crustacean remains in sediment cores (7) — D H Jones

T04003 Eutrophication — **A E Bailey-Watts**

- a* An assessment of the current loading of phosphorus to Loch Leven and a reconsideration of eutrophication control by point-source phosphorus removal (2) — A E Bailey-Watts
- c* Phragmites — root zone method for sewage treatment (2,7) — G J Lawson
- d* Loch Eye, Easter Ross — eutrophication case study (7) — A E Bailey-Watts
- e The effects of phosphorus fertilizers and forestry on algal growth in loch waters receiving run off — A E Bailey-Watts
- f* The analysis of Loch Leven nutrient loading data — A E Bailey-Watts

Programme 7 ENVIRONMENTAL POLLUTION

T07001 Dry deposition — **D Fowler**

- a Monitoring atmospheric concentrations of sulphur dioxide and oxides of nitrogen, and the chemical composition of precipitation at Devilla — D Fowler
- b Measurement of the rate of dry deposition of SO2 on to a Scots pine forest — D Fowler
- c The influence of rainfall acidity on the transport and exchange of gases between plants and the atmosphere — J N Cape
- d* Atmosphere-surface exchange of oxides of nitrogen, ozone and ammonia (NOx, 03 and NH3 dry deposition) — D Fowler
- e* Rural 03, NO and NOx concentrations — D Fowler

T07002 Wet deposition — **D Fowler**

- a The chemical composition of rainfall — J N Cape
- b* Variation of acidic deposition with altitude — D Fowler
- c* The effects of acidic deposition on the terrestrial environment — C Pitcairn
- d* Snow chemistry and deposition on hills (proposal) — D Fowler

T07003 Effects of pollutants on trees (1) — **J N Cape**

- a Interaction of airborne pollutants with natural surfaces, in particular the epicuticular wax of Scots pine (*Pinus sylvestris*) — J N Cape
- b The effect of acid rain on extension growth of Sitka spruce — D Fowler
- c* Forest decline and atmospheric pollutants — J N Cape
- d* The interpretation of throughfall measurements — J N Cape
- e* Review and interpretation of throughfall and stemflow measurements — J N Cape
- f* Organisation of workshop on 'Scientific basis of forest decline symptomatology — J N Cape

T07004	**Physiological responses to pollutants**	**(1)**	**D Fowler**
b	Pollution studies using open top chambers in western Europe (proposal)		D Fowler
c	Responses of conifer trees to artificial acid mist		C G M Henderson
d*	Accumulation and effects of atmospheric particulates on forests		A Crossley
T07005	**Effects of pollutants on spruce**	**(1)**	**M G R Cannell**
a*	Frost hardiness of red spruce in relation to forest decline and effects on red spruce of winter exposure to SO_2 and NO_2		M G R Cannell
T07006	**Radionuclides in vegetation and soil**	**(2,3)**	**A D Horrill**
a*	The distribution and dynamics of radionuclides in relation to land use in west Cumbria	(3)	A D Horrill
b	The concentrations and movement of americium in a coastal ecosystem in Cumbria		A D Horrill
e*	Post-Chernobyl radiation levels in soils and vegetation (proposal)		A D Horrill/ G R Miller
f	Uptake of radiocaesium by plants and the role of mycorrhizal fungi in mediating uptake (proposal)		J Dighton
g*	Radioactivity in wildlife in the UK (proposal)		A D Horrill
h*	The evaluation of data on the transfer of radionuclides in the food chain (proposal)		A D Horrill
T07007	**Radionuclide-animal transfers**	**(2)**	**B J Howard**
a*	Radionuclides in tissues and foods of coastal birds		V P W Lowe
b*	Sheep feeding trials		B J Howard
c*	Radioecology of 137Cs and 134Cs in sheep pasture systems following the Chernobyl accident		B J Howard
d	Comparative radioecology of Ag-110m and Cs-137		N A Beresford
e*	The dynamics of radionuclide uptake by sheep	(2)	B J Howard
f*	Field assessment of the effect of bentonite application on upland pasture on the caesium uptake by sheep	(2)	N A Beresford
T07008	**Geochemistry of radionuclides**		**F R Livens**
b*	Relationships between soil organic matter and the actinide elements		F R Livens
c	Terrestrial geochemistry of transuranic elements		A S Hursthouse
d*	Radionuclides in freshwater systems		F R Livens
T07009	**Soil microbial response to pollutants**		**P Ineson**
a*	Effects of forest fumigation with SO2 and 03 on roots and mycorrhizas of trees		J Dighton
b	Air pollutants and decomposition processes		P A Wookey
c*	Effects of air pollution (proposal)		P Ineson
d	Effects of atmospheric pollution on mycorrhizas (proposal)		J Dighton
e	Effects of sulphur dioxide on litter-decomposing fungi in deciduous woodland		J C Frankland/ P Ineson
T07010	**Fluorine pollution studies**		**D F Perkins**
T07011	**Acid waters in Wales**		**M Hornung**
a*	Acidification of waters in Wales		M Hornung
b*	RAINS project (proposal)		M Hornung
T07012	**Pollution in Wales**		**T W Ashenden**
a	Interactive effects of grazing and air pollution on vegetation	(2)	T W Ashenden
b*	Pollution study of Wales		T W Ashenden
T07013	**Ecosystem pollution by fluoride and trace metals**		**K C Walton**
a	Fluoride in predatory mammals		K C Walton
b	National survey of fluoride in predatory birds		D C Seel
c	Fluoride and magpies		D C Seel
d	Trace metals in terrestrial ecosystems		K C Walton
T07014	**Pollution analyses and their interpretation**	**(2)**	**I Newton**
a*	Birds and pollution		I Newton
c*	Autopsies and analyses of otters		H M Hanson
T07015	**Data on toxic chemicals**		**S Dobson**
a*	Chemicals in the terrestrial environment	(2)	S Dobson
b*	Development of data profiles on chemicals from the IRPTC working list	(2)	S Dobson
c*	Development of data profiles on chemicals from the IRPTC working list		S Dobson
d*	Task group meeting on DDT and its metabolites, 2, 4, D,		

lead, cadmium and mercury for the IPCS (World Health Organisation) programme of environmental health criteria documents — S Dobson

T07016 Residues and effects — F Moriarty

a Residues, and effects on individuals, of pollutants in freshwater organisms — F Moriarty

b Factors influencing the metal burden of freshwater animals — P E T Douben

T07017 Aquatic chemistry — K R Bull

c* Classification and comparison of river and lake catchments using computing techniques — K R Bull

d Concentrations of aluminium in streams during storm events and after the application of lime to streams and stream catchments — K R Bull

e* Dipper egg examination — K R Bull

f* Remote sensing of Eskdale and Dunnerdale — K R Bull/ B K Wyatt

T07018 Acid rain and amphibia — C P Cummins

a Life history of the common frog (8) — C P Cummins

T07019 Uptake of nitrogen derived from atmospheric pollution by tree root systems (proposal) — A F Harrison

T07020 Ecological effects of climatic change — O W Heal

a Ecological effects of climatic change (proposal) — M G R Cannell

Programme 8 POPULATION ECOLOGY

T08001 Insect pests (1) — A D Watt

a The population ecology of the pine beauty moth — A D Watt

b The population ecology of the winter moth in Sitka spruce plantations — A D Watt

T08003 Population ecology of upland birds — A Watson

a Population dynamics of red grouse — A Watson

b* Demographic effects of nest predation on golden plovers and other moorland waders — A Watson

c* Population ecology of capercaillie — R Moss

d Grouse aviary — R Moss

e* Epidemiology of the nematode, *Trichostrongylus tenuis* in red grouse — J L Shaw

f* Afforestation and moorland birds and predators (proposal) (1) — R A Parr

g* Waders of agricultural land (2) — N Picozzi

T08004 Population ecology of predators — H Kruuk

a* Badger social organization and range utilization — H Kruuk

b Monitoring otters in Shetland — Phase II — J W H Conroy

c Herons and pollutants in aquatic ecosystems — M Marquiss

d* The effect of food availability on behaviour and distribution of otters (2,3) — H Kruuk

e Occurrence of some heavy metals and PCBs in otters in Shetland (7) — H Kruuk

f* The effects of land use on populations of otters and fish in NE Scotland a feasibility study (3) — H Kruuk

g* Piscivorous birds in Scottish salmon rivers (proposal) — M Marquiss

h* Ecology of the pine marten (proposal) — D Balharry

i* Effect of water temperature on the behaviour and ecology of the European otter (*Lutra lutra*) — P S Taylor

T08005 Population ecology of seabirds — M P Harris

a* Puffins and pollutants (7) — M P Harris

b* Development of monitoring of seabird populations and performance — M P Harris

T08006 Plant strategies: response to environmental stress — T V Callaghan

a Plant responses to environmental stress at high altitudes (9) — T V Callaghan

T08007 Vertebrate population dynamics: swan genetics — P J Bacon

a Population genetics of mute swans — P J Bacon

T08008 Butterfly studies (9) — J A Thomas

a* The conservation of the large blue butterfly — J A Thomas

b The ecology and conservation of the black hairstreak butterfly — J A Thomas

c The ecology of the brown hairstreak butterfly — J A Thomas

d Adonis blue populations — J A Thomas

e* Woodland fritillary butterflies — J A Thomas

T08009 Butterfly/ant interactions (9) G W Elmes

- a Social biology of *Myrmica* species — G W Elmes
- b Protein electrophoresis — B Pearson
- c Large blue butterfly/myrmica ant interactions (9) — J A Thomas
- d Population ecology and adaptive speciation of *Myrmica* (9) — G W Elmes

T08010 Basic wader biology (9) J D Goss-Custard

- a Predator — prey interactions between the oystercatcher, *Haematopus ostralegus*, and its prey, particularly the mussel, *Mytilus edulis*, on the Exe estuary and adjacent coastal areas (9) — J D Goss-Custard
- b Winter feeding ecology of juvenile oystercatchers on the Exe estuary — J D Goss-Custard
- c Habitat contraction, breeding density and reproductive output in waders a feasibility study — J D Goss-Custard
- d* *Spartina* and waders (proposal) — J D Goss-Custard

T08011 Genecology of grasses and saltmarsh/coastal communities (2,3,9) A J Gray

- a Iso-enzyme studies in *Sphagnum* — R E Daniels
- b Demographic genetics of *Agrostis setacea* populations — A J Gray
- c Spartina population ecology particularly the genecology of *Spartina anglica* — A J Gray
- d* Furzey Island saltmarsh and mudflat monitoring — A J Gray
- e* Highcliffe cliffs — stabilization and rehabilitation (9) — A J Gray
- f* Genetic variation in *Phragmites* (proposal) — R E Daniels
- g Nitrogen economy of *Drosera* species (proposal) — R E Daniels

T08012 Spider ecology (9) P Merrett

- a Recolonisation by spiders on Hartland Moor (9) — P Merrett
- b Ecology of *Eresus niger* — P Merrett
- c Population genetics of the *Pardosa monticola* group of spiders — R G Snazell
- d* Review of Araneae (spiders) (proposal) — P Merrett

T08013 Studies of amphibia and reptiles C J Reading

- a Breeding success and survival in the common toad — C J Reading
- b Ecology and population dynamics of the grass-snake (*Natrix natrix helvetica*) — C J Reading

T08014 Population dynamics of birds I Newton

- a* Population ecology of sparrowhawks (*Accipiter nisus*) — I Newton

T08015 Bats R E Stebbings

- a* Population ecology of bats — R E Stebbings
- b* Specialist advice on bats — R E Stebbings

T08016 Plant species dynamics T C E Wells

- a Population studies on orchids — T C E Wells

T08017 Physiology and reproduction in birds A S Dawson

- b Physiological factors causing deferred sexual maturity in birds — A S Dawson
- c Environmental control of breeding cycles in birds — A S Dawson

T08018 Vegetation dynamics (2,9,13) T W Parr

- a Roadside studies — T W Parr
- b Modelling sports turf (9) — T W Parr
- c Field plot survey — Monks Wood (13) — R Cox
- d Amenity grass — assembly of equipment to study water relations (13) — T W Parr
- e* Experimental propagation of reed (proposal) — T W Parr
- f* Effects of growth retardants on roadside verges (proposal) (9) — T W Parr
- g* *Phragmites* seedlings — T W Parr

T08019 Birds on farmland (2) A Village

- a Kestrels in farmland — A Village
- b* Birds on arable farmland (proposal) (2) — A Village

T08020 Pesticides and vertebrate physiology (2,7) I L Boyd

- a Ecology of reproduction in wild rabbits the influence of environment on reproductive rates — I L Boyd
- b* Bats and pollution (proposal) — I L Boyd
- c Interactive effects of pesticides on birds (proposal) (2) — A S Dawson

T08021 Butterfly abundance J P Dempster

- a* Butterfly monitoring scheme — M L Hall
- b Food resource limitation in the orange-tip butterfly — J P Dempster

T08022 Mammalian studies — **V P W Lowe**
- a Ecology of red deer on the Isle of Rhum — V P W Lowe
- b Taxonomic studies, as a basis for mammalian autecology — V P W Lowe

Programme 9 COMMUNITY ECOLOGY

T09001 Community ecology — **B G Bell**
- a Biological monitoring of the Forth Valley — B G Bell
- b Interactions between mosses and vascular plants (in abeyance) — N G Bayfield
- c Ecology of rock-colonising mosses in Britain — P J Lightowlers
- d Taxonomy of bryophytes — B G Bell
- e Bryophyte ecology conference, Edinburgh, 1988 — P J Lightowlers

T09002 Interactions between grazing and vegetation (1,2,8) — **G R Miller**
- a Quantity and quality of seeds produced by montane plants (2) — G R Miller
- b* Effects of grazing on *Nardus* and *Calluna* moorland (2) — D Welch
- c Development of subalpine scrub at northern Corries, Cairngorms SSSI (1) — G R Miller
- d* Response of *Gentiana nivalis* to sheep withdrawal (proposal) (2,8) — G R Miller

T09003 Vegetation and soil dynamics (1,12) — **J Miles**
- a Vegetation dynamics and soils — J Miles
- b* Cellulose decomposition in the subantarctic — D D French
- c The effects of birch on moorland soils and vegetation (1) — J Miles
- d Effects of soil chemistry on decomposition (1) — D D French
- e Vegetation succession and soils in developing birch woods (Succession under birch woods) (1,12) — A J Hester
- f Early changes in soils under birch and heather (1) — A J Ramsay

T09004 Geochemical cycling — **M Hornung**
- a* Geochemical cycling in the uplands — B Reynolds
- c Invertebrates, upland grassland management, and geochemical cycling (proposal) — A Buse

T09005 Forestry practice and nutrient cycling (1) — **M Hornung**
- a* Effects on site properties of clear-felling in upland forests (1) — P A Stevens
- b* Effect of forest management on soil (proposal) — M Hornung

T09006 Effect of grazing on vegetation (2,3) — **D G Hewett**
- a Sand dune management in Wales — D G Hewett
- b Long-term trends in upland vegetation (3) — J Dale
- c Ecology of arctic-alpine species in Snowdonia — C Milner

T09007 Impact of barrage schemes (8) — **J D Goss-Custard**
- a* Wash birds and invertebrates — J D Goss-Custard
- b* Predicting post-barrage densities of invertebrates and shorebirds birds — J D Goss-Custard
- c* Cardiff Bay barrage feasibility study (proposal) — C J Reading

T09008 Ecology of wetlands — **S B Chapman**
- a Root dynamics of *Calluna vulgaris* on lowland heathland in southern Britain — S B Chapman
- b Autecology of the marsh gentian — S B Chapman
- c Review of Coombe Rigg Moss (3) — S B Chapman
- d Ecological assessment at Holm Hill/Riggs Green Copse (proposal) — S B Chapman

T09009 Grassland/scrub studies (2) — **M G Morris**
- a Grassland management — invertebrates — M G Morris
- b Study on scrub succession on chalk at Aston Rowant NNR — L K Ward
- c Juniper studies — L K Ward
- d Scrub management at Castor Hanglands NNR — L K Ward
- e* M3 butterfly bridge evaluation — M G Morris

T09010 Heathland studies (2,3) — **N R Webb**
- a Hartland National Nature Reserve survey — A A Abbott
- b Heathland invertebrates — N R Webb
- c* Restoration of heathland — N R Webb
- d* Restoration experiments for New Forest gas pipeline — N R Webb
- e* Dorset heathland survey — N R Webb
- f* Ecological survey at Feltham, Middlesex (proposal) — R E Daniels

g	Population biology in peatland angiosperms (proposal)		R E Daniels
h*	Ecological appraisal of Lyndhurst bypass (proposal)		S B Chapman
i*	Heathland turfing experiments (proposal)		N R Webb
j*	Survey of exploration well site at Colemans Hatch A in East Sussex (proposal)		N R Webb
T09011	**Phytophagous insects**		**L K Ward**
a	Phytophagous insects data bank		L K Ward
b	Weevil studies		M G Morris
T09012	**Vegetation management, especially to combat erosion**	**(1,2,3)**	**L A Boorman**
a	Sand dune ecology in East Anglia		L A Boorman
c*	Plant establishment in woodland	(1)	L A Boorman
d*	A survey of sand dunes in relation to grazing		L A Boorman
e*	Studies on saltmarsh erosion treatment (proposal)		L A Boorman
f*	Salt marsh management in NW England (proposal)		R Scott
g*	The role of vegetation in the sea defences of East Anglia (proposal)		L A Boorman
T09013	**Plant/animal interactions**	**(2)**	**B N K Davis**
a	Insect faunas of *Helianthemum* and *Genista*		B N K Davis
b	Plant succession in a limestone quarry		B N K Davis
c*	Creation of butterfly habitats on a landfill site		B N K Davis
*	European insect fauna of *Urtica* species		B N K Davis
e*	Design and management of urban green space		B N K Davis
T09014	**Invertebrate ecology and management**		**R C Welch**
b	Invertebrate fauna of native and introduced broadleaved trees in Britain	(1)	R C Welch
c*	Management guidelines for the conservation of invertebrates, especially butterflies, in plantation woodlands		R C Welch
T09015	**Heathland and nitrogen cycling**		**R H Marrs**
a	Heathland management research		R H Marrs
b	Long-term studies of vegetation change at Moor House NNR	(3)	R H Marrs
c	Nitrogen mineralization in tropical forest soils		R H Marrs
d	Reducing soil fertility on abandoned agricultural land for the restoration of native vegetation (proposal)		R H Marrs
T09016	**Distribution and dynamics of vegetation**		**C Sargent**
a	Railway resource monitoring	(3)	C Sargent
b*	Structure and dynamics of motorway vegetation		C Sargent
c*	Nitrogen fertilizer experiment in the Somerset levels		C Sargent
d*	British Rail-sponsored grassland experiments (proposal)	(2,3)	C Sargent
e*	Forest research in Szechuan (proposal)	(3)	C Sargent

Programme 11 FRESHWATER BIOLOGY AND CHEMISTRY

T11001	**The dynamics of plankton and fish populations with special reference to long-term changes**		**A E Bailey-Watts**
a	Long-term changes in zooplankton	(9)	L May
b	Predation on freshwater zooplankton	(9)	D H Jones
c	Species succession and population dynamics of the phytoplankton of Loch Leven with special reference to the effects of nutrients and zooplankton grazing	(2,9)	A E Bailey-Watts
e	Zooplankton communities in freshwater lakes	(9)	D H Jones
f	Zooplankton population dynamics	(9)	L May
g	Morphometric studies of British lampreys		K H Morris
T11002	**Hydraulic conditions in rivers and lakes and their ecological implications**		**I R Smith**
a	The influence of events on population growth	(13)	I R Smith
b	Hydro-climate services		I R Smith
c	Aerial remote sensing of Lochs Leven, Lomond and Tay — 1984		A A Lyle
d	Mixing and spatial variation in lakes		I R Smith
e	River condition scale	(4)	I R Smith

T13001	**Glasshouse and plant support**		**R F Ottley**
a	Glasshouses and nursery support and development		R F Ottley
b	Landscaping the new extension at Edinburgh (Bush)		R F Ottley
c*	Landscaping at Elphinstone Research Centre		R F Ottley
d*	Plant culture for Inveresk Research International		R F Ottley
e*	Potato culture for Inveresk Research International		R F Ottley
T13002	**Library services**		**J Beckett**
a	Utilization of STATUS in ITE libraries cataloguing		S M Adair
T13003	**Services at ITE Banchory**		**(B W Staines)**
b*	Ecological advisory appointment with SDD (proposal)		J Miles
c*	Caring for the high mountains — conservation of the Cairngorms (proposal)		J W H Conroy
T13004	**Chemical support**		**J A Parkinson**
a	Chemical support studies		J A Parkinson
b*	Analyses for certification of EEC international tree leaf reference materials		J A Parkinson
c	Radiochemical development		F R Livens
T13005	**NERC mass spectrometer service**		**C Quarmby**
a	Mass spectrometer service (stable isotope facility for 15-N analysis)		C Quarmby
T13006	**Publications**		**C Milner**
a	Graphics and publications		C B Benefield
b	Publication of collected data (proposal)		D C Seel
T13007	**Biometrics support**		**D K Lindley**
a	Biometrics and modelling support services at Merlewood		D K Lindley
b*	Analysis of Harwell data (proposal)		D K Lindley
T13008	**Engineering**		**C R Rafarel**
a	Engineering development (mechanical and electronic)		C R Rafarel
b	Microprocessor development studies		C R Rafarel
T13009	**Remote sensing applications — centre of excellence**	**(3)**	**B K Wyatt**
b	Local applications of remote sensing		R E Daniels
c	NERC Remote Sensing Applications Centre in TFS		B K Wyatt
T13010	**Digital cartographic service**		**G L Radford**
T13011	**Biological Records Centre**		**P T Harding**
a*	Biological records centre botanical recording schemes		C D Preston
b*	Biological records centre vertebrate recording schemes		H R Arnold
d	The distribution and ecology of non-marine isopoda		P T Harding
e*	Biological records centre terrestrial and freshwater invertebrate recording schemes		B C Eversham
g*	Biological records centre general		P T Harding
h*	Population fluctuations in annual legumes		C D Preston
i*	Biological records centre data bank		D M Greene
T13012	**Information, systems and survey**	**(2)**	**M O Hill**
a	Effects of grazing in Snowdonia		M O Hill
b	Artificial intelligence in information systems		M O Hill
T13013	**Statistical advice 1**		**K H Lakhani**
a	Estimation of population parameters	(8)	K H Lakhani
b	Statistical consultancy (proposal)		K H Lakhani
T13014	**Statistical advice 2**		**M D Mountford**
a	Analysis of common birds census		M D Mountford
b	Estimation of abundance of populations with seasonal pattern		M D Mountford
c	Statistical consultancy in ITE		M D Mountford
T13016	**Statistical and computing services in Wareham**		**R T Clarke**
a	Statistical and computing services at Furzebrook (proposal)		R T Clarke
b	Statistical and computing services at the River Laboratory (proposal)		R T Clarke
c	Statistical research (proposal)		R T Clarks
T13017	**Biometrics and modelling in Edinburgh**		**R I Smith**
a	Biometrics and modelling at Bush (proposal)		R I Smith
T13018	**Management information systems**		
a	TFS Management information system		P A Ward

T13025	**Contract chemical analyses at Merlewood**	**J A Parkinson**
a*	Chemical analyses for Nature Conservancy Council i Orkney waters ii Speyside lochwater	J D Roberts
b*	Chemical analyses for universities	J A Parkinson

Annex 3

Publications by ITE Staff 1986-87

† = not employees of ITE

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