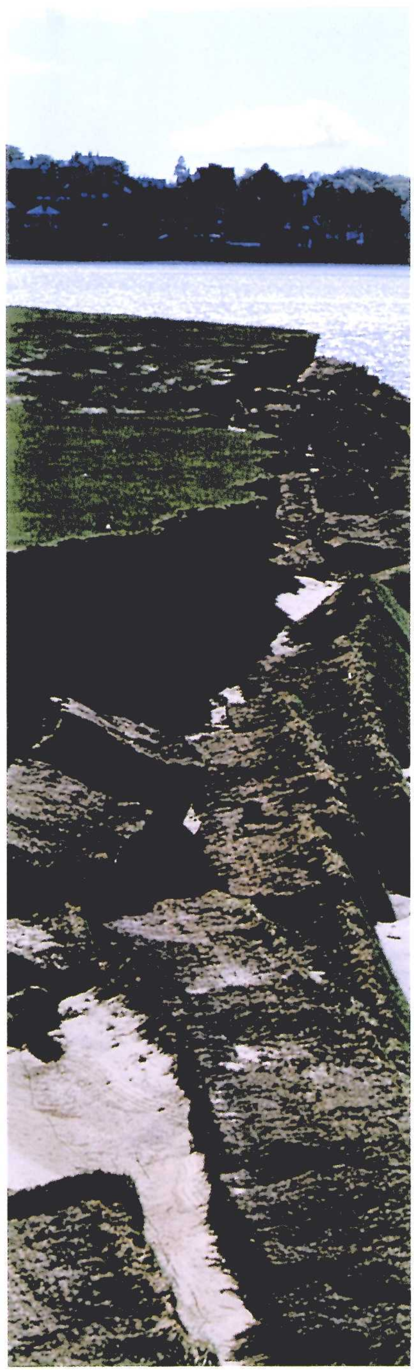
1990 — 1991
REPORT



Institute of Terrestrial Ecology

Natural Environment Research Council

Foreword

Environmental issues continue to grow in importance both nationally and internationally These issues, whether local, regional or global, must be addressed on the basis of sound and up to date scientific knowledge NERC's Terrestrial and Freshwater Sciences Directorate provides a focus for fundamental and applied research in land use and the development of natural resources, the maintenance of environmental quality and the principles which underline management and conservation

Much of this research is interdisciplinary and demands the wide range of expertise in NERC establishments and higher education institutions The Directorate's in-house capability comprises the Institute of Freshwater Ecology, the Institute of Hydrology, the Institute of Terrestrial Ecology, the Institute of Virology and Environmental Microbiology, the Unit of Comparative Plant Ecology (Sheffield University), the Interdisciplinary Research Centre for Population Biology (Imperial College, London), the Unit of Behavioural Ecology (Oxford University) and the Water Resource Systems Research Unit (Newcastle-upon-Tyne University)

The Institute of Terrestrial Ecology continues to provide the major national resource of expertise in ecology and related subjects Its research in areas as diverse as air pollution effects and vertebrate population biology has an international reputation This Report shows the wide range of skills of ITE staff and how essential the research is to the environmental quality and management of the land surface both in the UK and overseas

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

Front Cover Illustration
Salt marsh erosion - photographer R Scott

Report of the Institute of Terrestrial Ecology 1990/91

Natural Environment Research Council

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Forest science

The forest science programme encompasses a wide range of research on trees, forest soils, and on the plants and animals that live in forests. A substantial part of the programme is now concerned with tropical forestry, both in the humid and semi-arid areas.

Five particular achievements deserve special mention. First, forest modelling has been strengthened, with a move towards more comprehensive process-based models of the whole forest ecosystem, implemented on supercomputers. It has been found that increasing carbon dioxide and nitrogen inputs increase the carbon store in soils, and may account for part of the 'missing sink' in the global carbon budget. Second, a Farm Forestry Special Topic is well under way, with some important findings, including the fact that many native woodland herbs (like bluebells (*Hyacinthoides non-scripta*)) can be quite easily introduced to new woodlands by seeds. Third, the long-term experiment on tree species mixtures at Gisburn has been evaluated, revealing the mechanisms of significant synergism, mostly involving increased access to, or availability or turnover of, limiting nutrients. Fourth, long-term work on the pine beauty moth (*Panolis flammea*) is now being wound down, with the significant finding that this moth develops to pest status on lodgepole pine (*Pinus contorta*) because it is then relatively free of insect parasitoids and other predators, compared with Scots pine (*Pinus sylvestris*). Lastly, monoclonal anti-bodies have been selected that are specific for given soil fungi, enabling these fungi to be identified in soils using immunofluorescence. An effort is being made to determine the role of the extramatrical (soil) hyphae of mycorrhizal fungi.

In this year's Report, we have selected one recently completed project (on wind stability), one area of new work (winter moth (*Operophtera brumata*)), and two continuing studies concerning tree nutrition and soil fertility.

Influence of forest structure on the wind stability of Sitka spruce

(This work was partly funded by the Commission of the European Communities)

The United Kingdom is one of the windiest places in the world. We also have extensive new forests of Sitka spruce (*Picea sitchensis*) planted over the last 40 years for timber production. Normal winter gales cause major damage and are a limit to growth (Plate 1). Because of the uniform age of trees in any one plantation, the forester has to manage, usually by cutting or thinning out trees, to maximise the production of sawlogs. This thinning can be carried out when the trees are young (5 years), when it is termed respacing, or when the trees are about 15 m tall (20–30 years). Thinning older forests was the standard method used by the industry for many years, but it was noticed that, for some time after thinning, the remaining trees were very unstable in wind. If the remaining trees did not blow down, then they were able to recover stability after a period of increased growth, but, in order to avoid the period of instability altogether, large areas of forest in windy areas have been left unthinned. Trials in forests re-spaced at an early age showed that there was little risk of the small trees blowing over, and they grew well subsequently, producing good sawlogs at maturity.

The Forestry Commission has developed a Windthrow Hazard Classification, which estimates the age at which trees planted in a specific location will blow down. This system has been useful to the forest manager, but the link between weather and soil conditions and the resulting risk of windthrow is largely empirical. At ITE Edinburgh, a description of tree movement and stresses, based on engineering principles, has been developed in order to provide a mechanistic understanding of the ways in which forest structure influences tree stability.

Plate 1. Windthrow in a stand of Sitka spruce in south-west Scotland

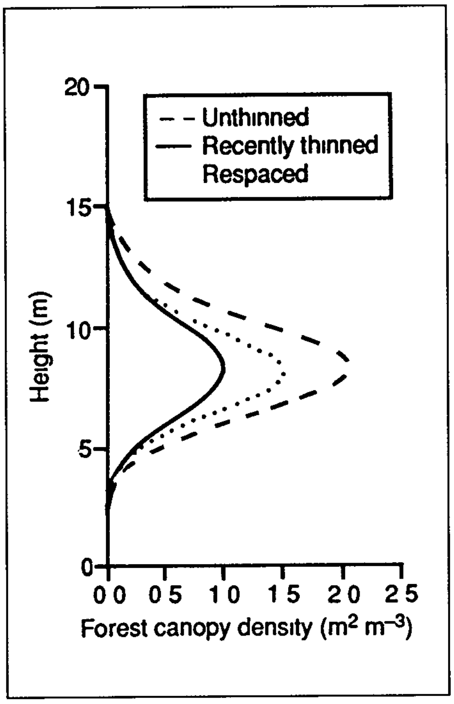

Figure 1 Assumed canopy density distributions in unthinned (3800 stems ha^{-1}), recently thinned (1900 stems ha^{-1}) and early respaced (1900 stems ha^{-1}) Sitka spruce forest plantations

The main variables which affect the wind stability of Sitka spruce plantations are (i) wind speed above and within the different forest canopies, (ii) the bending of the tree stem, which is related to growth habit, (iii) the swaying characteristics, which are related to tree size and canopy structure, and (iv) the strength of the various components of anchorage in the root system (Coutts 1986)

Methods for quantifying these factors were developed and have been used to compare the stresses in the stems of typical trees caused by wind gusts in three contrasting plantation types

i an unthinned plantation with 3800 stems ha^{-1}, where the canopy height was 17 m, within this stand, the sample tree was 15 5 m in height and its stem diameter, at 1 3 m from ground, was 19 cm,

ii a recently thinned plantation reduced to 1900 stems ha^{-1}, but with the canopy height and sample tree size the same as in the unthinned stand,

iii a respaced plantation reduced to 1900 stems ha^{-1} at an early age, giving a canopy height and sample tree height similar to the unthinned stand, but with increased stem and canopy growth in the sample tree, so that the stem diameter and tree canopy weight were larger, by 14%, than in the other stands

Wind speeds

The Meteorological Office maps extreme hourly wind speeds for the United Kingdom These maps include winds occurring during normal depressions and similar climatic conditions, but exclude unusual events which would happen less than once in every 100 years Wind speeds with a return period of 50 years are given, but only for smooth agricultural countryside Extreme wind speed over forests can be estimated from open countryside values, if the 'roughness length' of the canopy is known In collaboration with the Forestry Commission Research Branch, measurements were made of profiles of wind speed above and within the canopy of a 26-year-old Sitka spruce forest near Moffat, in south-west Scotland, and have been used to verify a theoretical description published by Li, Miller and Lin (1985) The distribution of biomass on individual trees in this forest was also measured, and equations relating canopy size and distribution to stem size were developed These models of canopy biomass distribution were applied to the three example forest types (Figure 1), and the wind speed profiles, and roughness lengths, of each forest type were estimated from the theoretical description The 50-year return period wind speed at the top of each canopy type could then be calculated from the extreme wind speed map

The short-term variation in wind speed (ie the gust spectrum) for each forest type was estimated from published data As with the hourly mean wind speeds, the gust spectra were scaled to each forest type, using the estimated roughness lengths

Static stem bending

A computer model of the mechanical structure of the tree (Milne & Blackburn 1989) was used to estimate the bending of the sample stems caused by steady hourly mean winds at the extreme speed The variation in wind force down through the canopy was taken into account, using the previously calculated profile

Dynamic stem bending

The wind gusts by nature, and dynamic effects increase the bending of stems, and hence the load on root systems, particularly if the pattern of wind gusts is coupled to the natural swaying

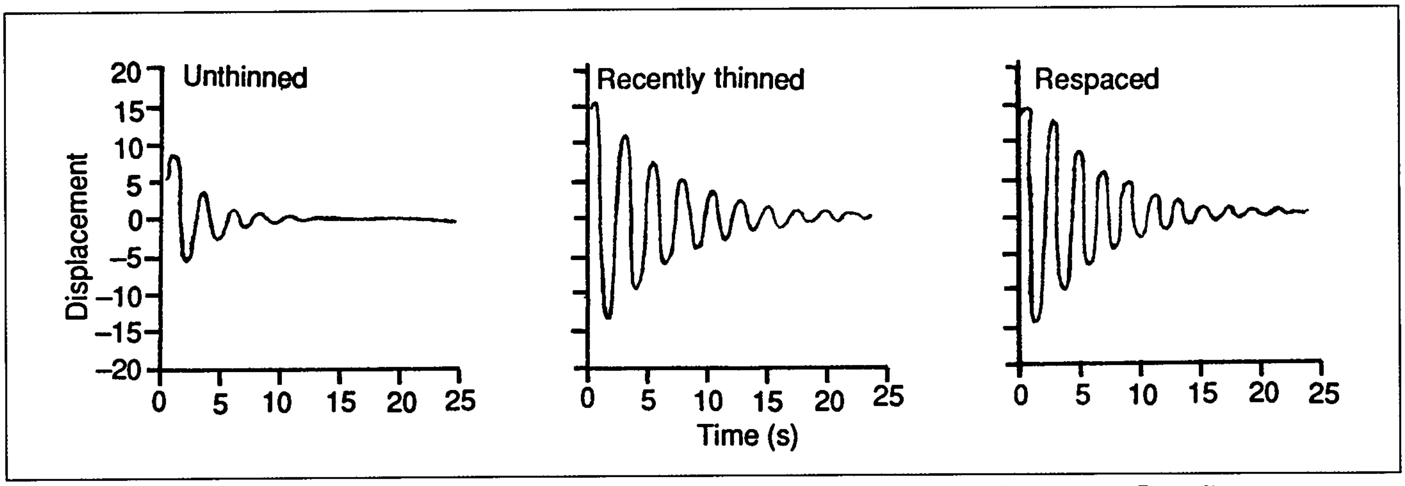

Figure 2 Pattern of damping of sway after initial bending of the sample trees in each of the three forest types (see caption to Figure 1)

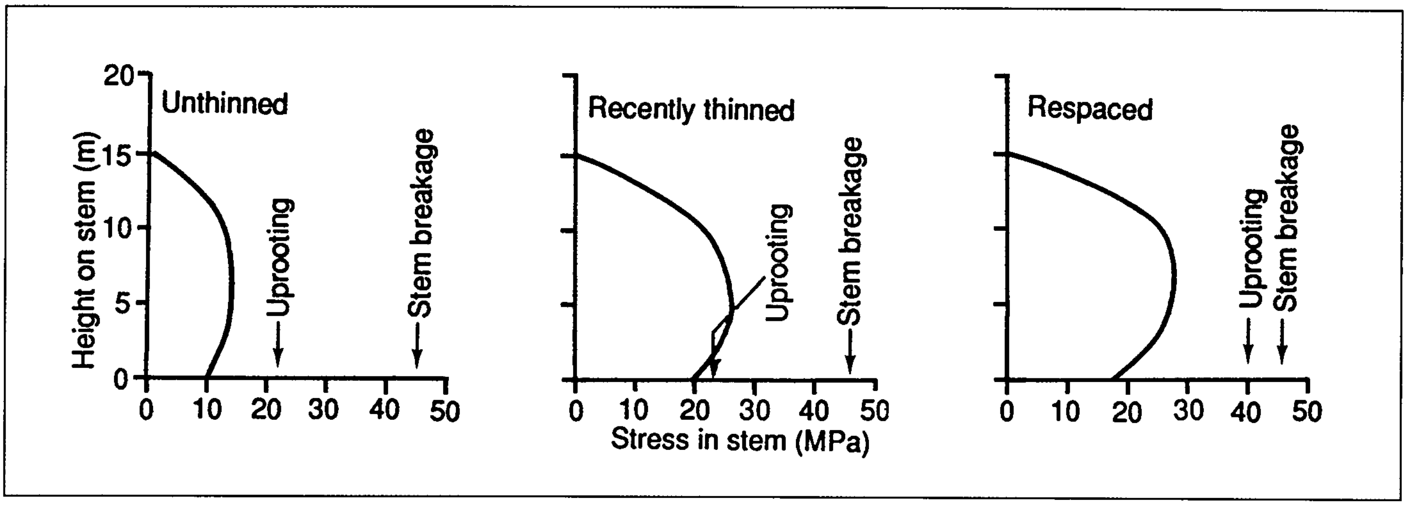

Figure 3 Stress in the outer layers of the stems of the sample trees in the three forest types (see caption for Figure 1) when subjected to a peak gust of wind (as occurs when the mean hourly wind speed is at its 50-year return period maximum) The stress estimated, from published studies, to occur at uprooting and stem breakage is indicated The indicated stress during uprooting for the respaced forest type relates to measurements from stable (brown earth) sites, and for unthinned and recently thinned types from unstable (peaty gley) sites

frequency of the trees The natural frequency of sway in mature Sitka spruce, measured by manual swaying in Moffat forest, is related to the shape and mass distribution of an individual tree (Milne 1991) The damping (ie slowing down) of tree motion, which is important in relation to wind gusts, results from three components – interference between the branches of neighbours, aerodynamic drag on the branches moving through the air, and mechanical forces in the stem and roots In closely planted forests, the first of these components is as important as the other two components combined, in a stand of 3800 stems ha^{-1} the movement of the trees is mainly restricted by branch interference Using the results, the swaying characteristics of the sample tree in the unthinned forest type were estimated For the recently thinned plantation, it was assumed that no branch interference would occur, and that the other characteristics would remain unaltered In the respaced stand, no branch interference was assumed, but the natural frequency and damping values were adjusted to account for the different tree shape and mass On these assumptions, the tree in the unthinned stand swayed less, and stopped swaying more quickly, than those in the thinned and respaced stands (Figure 2)

Peak stresses on tree stems

The dynamics and statics of stem bending were combined with the descriptions of the variation in wind speed, using standard engineering methods for tall slender structures, to calculate the peak mechanical stress in the outer layer of the stem (Figure 3) The peak stress at the stem base was 10 MPa (megapascals) for the unthinned sample, 19 MPa for the recently thinned, and 17 MPa for the respaced The thinning process, therefore, nearly doubles the stress on the tree Trees grown from an early age at the wider spacing have only slightly lower stresses than those in the thinned forest Hence, the observed better wind stability of respaced forests does not appear to be due to differences in structure above the ground

The forces required to uproot forest conifers can be measured by using a winch and cable to pull trees over The results of such studies are difficult to generalise, but they do indicate that, in typical peaty gley forest soils (where damage is most common), the stress at the surface of the base of the stem is 26–29 MPa, on average, when a tree overturns In brown earth soils and other 'wind stable' sites, the stem stress is about 40 MPa From these calculations, therefore, we can predict that unthinned stands will generally be stable, because the predicted peak stress of 10 MPa is only about 35% of the stress which occurs at overturning However, in recently thinned forests, the peak stress is about 75% of the stress measured at overturning Assuming that root strength is directly related to the stress at overturning, all trees with root strengths of less than 75% of the average will be at risk Similarly, in the case of respaced forests, the root strength of an individual tree would have to be about 50% of the average for it to be at risk The breaking strength of the wood in the stem is known to be 40–45 MPa, so the risk of stem breakage due to the wind should be small in all forests

These predictions are generally in agreement with qualitative observations in UK forests thinning causes significant increase in wind damage, and respaced forests can be more stable Stem breakage is, however, not unknown, but this mode of damage probably occurs where snow loads are present or where there is a defect in the stem structure

R Milne

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Winter moth on Sitka spruce

From time to time, new insect pests emerge Pest species from other countries are sometimes introduced accidentally, and previously harmless insect species occasionally become pests when new crop varieties or species start to be grown In UK forestry, most attention on the pest complex has centred on two species, the great spruce beetle (*Dendroctonus micans*) which invaded the UK in the 1970s, and the pine beauty moth (*Panolis flammea*), a native species which became a pest of lodgepole pine (*Pinus contorta*), an introduced tree from North America UK forestry is dominated by tree species introduced from North America, particularly Sitka spruce (*Picea sitchensis*), and, in recent years, like lodgepole pine, it has attracted several native insects One of them, the winter moth (*Operophtera brumata*), has become a pest species, demonstrating that trees can acquire some unexpected pests, because, whereas the pine beauty moth made the short leap from Scots pine to lodgepole pine, winter moth moved to Sitka spruce from having been principally associated with oak (*Quercus* spp)

The larvae of the winter moth are common defoliators of broadleaved trees, particularly oaks Minor damage to Sitka spruce has occurred in Scotland since the late 1950s, but this damage seems to have been a result of winter moth larvae moving from other trees or shrubs they had defoliated (Stoakley 1985) In the last ten years, however, Sitka spruce has clearly become a primary host plant of the winter moth The larvae do not cause sufficient damage to kill trees, but, because they can destroy developing shoots, a heavy attack can result in the stunting of tree crowns and in deformed stems Only one forest has been sprayed with insecticide (in 1983) to try to prevent damage, but the attempt was not successful because the larvae tend to feed inside the developing spruce buds (Stoakley 1985) Since 1983, there have been several other outbreaks winter moth appears to have become an established pest in Scotland, with potentially serious implications for Sitka spruce (Figure 4)

Research at ITE Edinburgh has concentrated on trying to establish why winter moth is a pest of Sitka spruce, which factors particularly promote its outbreaks on this tree, and what potential there is for its future development, or even demise, as a pest To answer these questions, we have to understand the ecology of the species, and its host plant

Life cycle of winter moth

Observations on the behaviour of adults and larvae have firmly established that the winter moth can complete its development on Sitka spruce However, in at least one respect – its egg-laying behaviour – the insect is not well adapted to Sitka spruce

Winter moth females are flightless, and lay their eggs on trees after climbing them On broadleaved host plants, eggs are laid in bark crevices

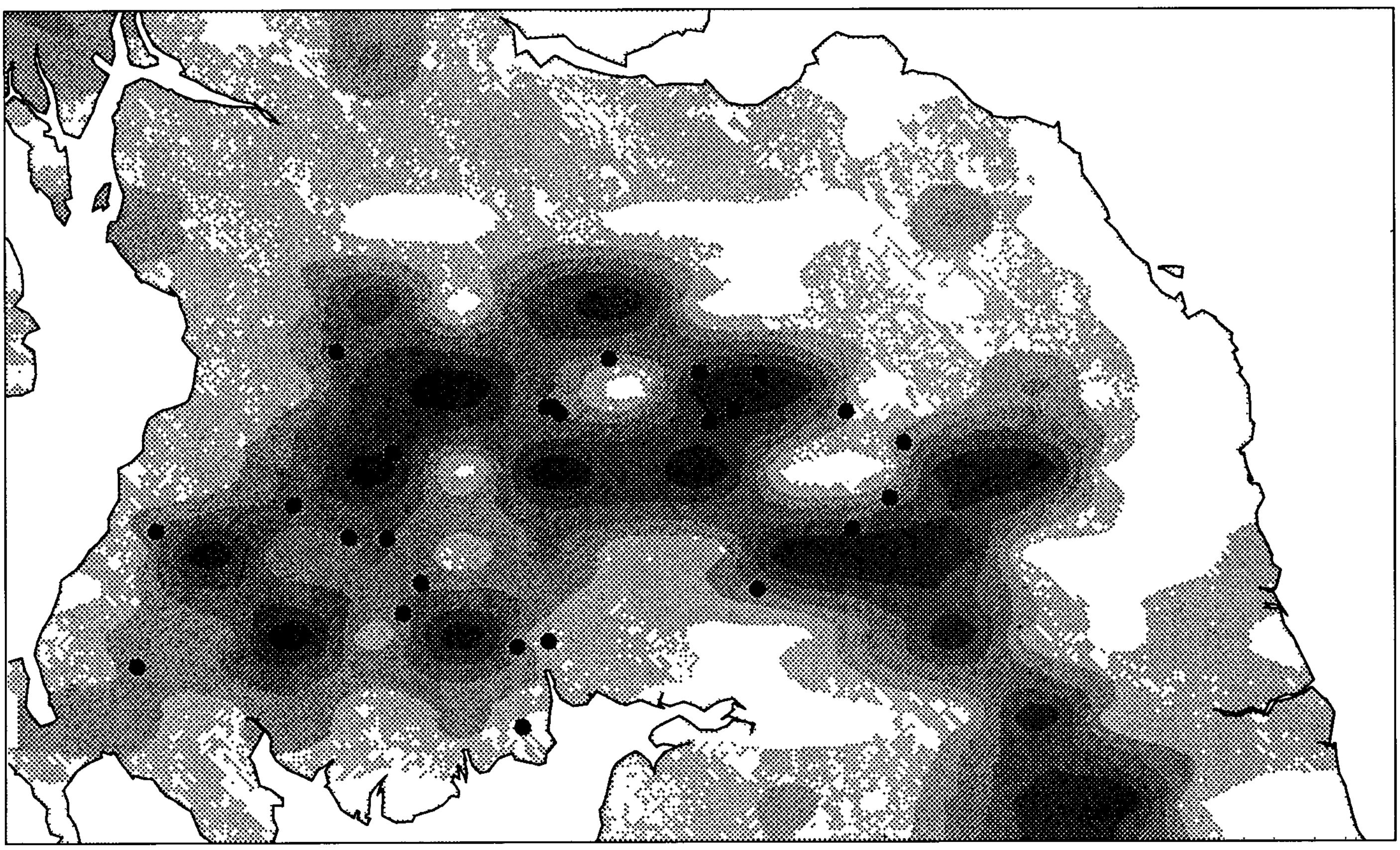

Figure 4 Reported outbreaks of winter moth on Sitka spruce in southern Scotland, 1984–1990 (density of shading represents cover of Sitka spruce)

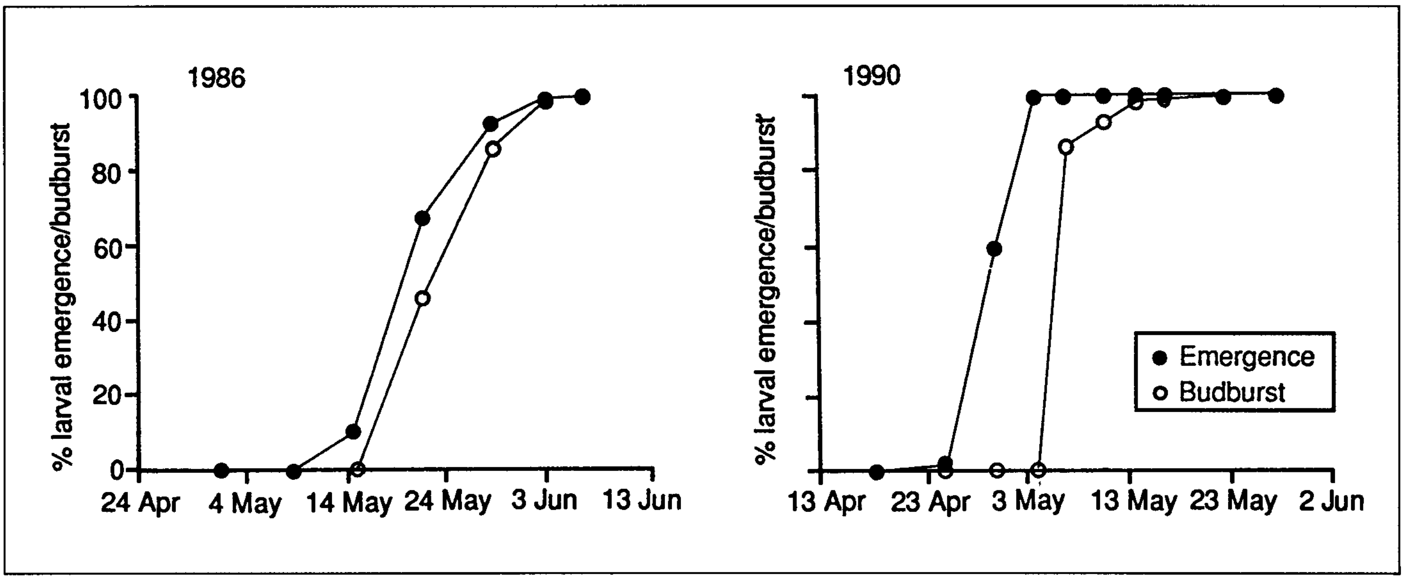

Figure 5 Two examples of the degree of coincidence between winter moth larval emergence and Sitka spruce budburst 1986, when coincidence was close, and 1990, when it was poor (after Watt & McFarlane 1991)

and around the developing buds on which the larvae later feed On Sitka spruce, the winter moth lays its eggs in places where predators will have difficulty finding them – bark crevices, under lichen, and under needle scales The distribution of eggs along the main stem is closely related to the availability of suitable egg-laying sites most eggs are laid near the top of the tree where there are plenty of bark crevices, or slightly further down where the needle scales are neither too loose, as at the base of the tree, nor too close to the stem that it is impossible for the winter moth to lay her eggs underneath, as at the top of the tree However, this adaptation to life on Sitka spruce is countered by the fact that winter moth adults seem unable to walk through densely foliated branches in order to lay their eggs near the developing buds About 30% of eggs are laid on the main stem, and 80% of those laid on the side branches are within 40 cm of the main stem, resulting in a distribution of eggs which appears poor for a bud-feeding insect On the relatively young trees that currently experience winter moth outbreaks, this distribution obviously does not seriously affect the ability of the winter moth to reach damaging levels, but, on older trees, the larvae may experience difficulties in moving from egg-laying to feeding sites within the tree crown At present, winter moth outbreaks are restricted to trees under 15 years of age, but the areas which experience outbreaks are dominated by relatively young stands, so that it is too early to say whether older trees will or will not be affected

Winter moth feeding behaviour

Winter moth larvae are unable to feed on mature spruce needles they are restricted to the current year's foliage On broadleaved trees, the larvae are affected by the age of the leaves, and the relationship between larval emergence and budburst in the spring is thought to be the principal factor determining the abundance of winter moth (Feeny 1976) This relationship was studied in southern Scotland from 1986 to 1990 In two years, the coincidence between larval emergence and budburst was close, in one year it was poor, and in two years larval emergence preceded budburst by about ten days (Figure 5)

The consequences of the variability in coincidence between larval emergence and budburst depend upon the degree to which larval survival (and other aspects of insect performance) are affected by late or early egg hatch On oak, poor coincidence affects larval growth and survival, and the window of opportunity for winter moth larvae is quite small (Feeny 1976) On Sitka spruce, however, this 'phenological' window is much larger, because winter moth larvae are able to colonise and survive on buds before they burst (Figure 6) This factor may be the main reason why winter moth has become established on Sitka spruce

Winter moth outbreaks

Winter moth outbreaks, like those of many other forest pests, appear to start within clearly defined areas of forest This aspect of its behaviour is particularly amenable to study because the poor mobility of the winter moth means that the same parts of a forest can be attacked for several years

Previous work on forest pests in the UK and elsewhere has produced two theories to explain the susceptibility of certain parts of forests to insect attack

i Outbreak epicentres contain trees which are nutritionally more suitable than those elsewhere (eg higher nutrient concentrations, lower concentrations of chemicals with defensive properties in the foliage, or better coincidence between plant and insect phenology)

ii Outbreak epicentres contain fewer (or less effective) natural enemies (eg insect parasitoids, ground beetles) than elsewhere

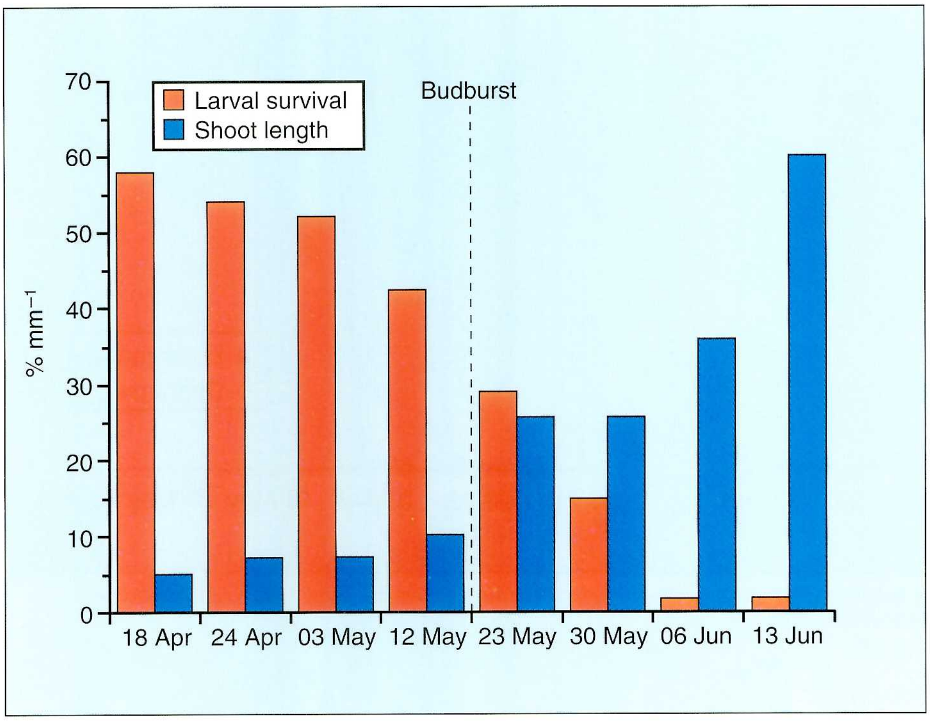

Figure 6. The effect of Sitka spruce shoot stage on the survival of winter moth larvae: the survival of newly emerged larvae is high prior to budburst and declines steadily as spruce shoots develop (after Watt & McFarlane 1991)

These hypotheses were tested at two sites in southern Scotland in a joint study with M D Hunter of the University of Oxford (Hunter, Watt & Docherty 1991). The first hypothesis was rejected because no evidence of any nutritional (including phenological) difference could be found between trees in 'outbreak' and 'non-outbreak' sites. The second hypothesis was also rejected because, far from there being fewer predators present in the 'outbreak' sites, there were many more. Predators appear to respond to winter moth outbreaks, but do little to prevent them. Nevertheless, a study of a winter moth outbreak once underway may not tell us everything about the different processes operating at the start of the outbreak. A lack of natural enemies, for some reason, in one particular year may have triggered the outbreaks which we studied. It may be concluded from this and other studies that the processes which affect the abundance of insect pests in forests at the spatial level remain poorly understood.

Winter moth – the future

The pine beauty moth and winter moth studies show interesting similarities and differences. Both species have made the shift to an introduced conifer, and both have the potential to become serious pests. However, that potential has only been fully realised for the pine beauty moth, to the extent that all large stands of lodgepole pine have been attacked by this insect, and lodgepole pine monoculture forests are no longer being planted in the UK. Winter moth still affects only a small proportion of the total area in the UK planted with Sitka spruce. We do not know whether different strains of winter moth have become adapted to oak and Sitka spruce, or if it has the potential to become further adapted. Whether or not the winter moth becomes as serious a pest of Sitka spruce as the pine beauty moth has become of lodgepole pine depends largely on the answers to these questions.

A D Watt

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Testing for fertiliser requirements for eucalyptus

(This work was funded by Shell Research Ltd)

In commercial forestry, there is a need to optimise yield in relation to expenditure on fertiliser. In most agricultural soils, fertiliser requirements can be assessed by chemical analysis of the soil to detect deficiencies in elements. These chemical tests do not always work well for the poorer soils used in plantation forestry, and foliar analysis has been the recommended diagnosis. However, foliar analysis has also proved to be a poor predictor of nutrient deficiencies on some sites.

Research at ITE Merlewood over the past ten years has been investigating the potential of bioassay as an alternative to, or support for, the conventional soil or foliar analyses. As many British soils are limited in phosphate, a root bioassay to determine the phosphate status of trees was developed first (Harrison & Helliwell 1979). The technique measures the uptake of radioactive phosphorus by excised roots; uptake is greatest by roots taken from deficient trees. Similar bioassays for potassium (Jones, Harrison & Dighton 1987) and nitrogen (Jones, Quarmby & Harrison 1991) have also been developed. The advantage of having all three bioassays is that deficiencies of single elements can be determined, and the interaction

Table 1. Eucalyptus response to fertiliser additions in a field experiment in southern Africa after six months' growth. Values are means

	Fertiliser added (kg ha^{-1})								
	Nitrogen			Phosphorus			Potassium		
	0	70	140	0	40	80	0	20	40
Tree height (m)	1.8	2.5	2.7	1.8	2.6	2.6	1.8	2.6	2.6
Foliar concentration (%)	2.8	3.0	3.2	0.3	0.3	0.3	1.3	1.2	1.1
N uptake	40	32	23	40	28	26	40	29	26
P uptake	602	821	700	602	1119	403	602	897	625
K uptake	165	231	152	165	178	204	165	229	154

between them explored. These bioassays are rapid and easy to perform, and the information from them can be used to determine future forest management options.

Applicability of the bioassays to *Eucalyptus grandis* plantations

The Institute of Commercial Forestry Research set up an experimental eucalyptus plantation in southern Africa, to study timber yield in relation to major nutrients (nitrogen (N), phosphorus (P) and potassium (K)) and trace elements applied as fertiliser. We were asked to use the root bioassay to test the tree response to the treatments. Two rates of N, P and K were applied, half at planting and half at either three or six months (Table 1). All combinations of nutrients at each level were included, together with unfertilised controls.

After six months, tree height was most influenced by the level of N addition (Table 1). The improved N nutrition was shown by increased foliar N and reduced N uptake in the bioassay. Similarly, high levels of P and K fertiliser reduced uptake of these elements in the bioassays. There was, however, no difference in the P and K concentrations in the leaves. Indeed, the stunted control trees had higher levels than those trees receiving fertiliser. Foliar concentrations for all treatments would be considered satisfactory according to current recommended values, which suggests that the bioassay could be more sensitive than foliar analysis. High rates of P and K addition suppressed bioassay N uptake, indicating an improvement in N nutrition.

An early second application of fertiliser improved tree growth at six months of age (Table 2). Both the N and P bioassays showed a root response within a few days of the six month application of fertiliser. Foliar concentrations increased slightly in response to N. The rate of fertiliser added in the field experiment did not allow an analysis of interactions between elements to be explored properly. However, a factorial 3 x 3 NPK fertiliser pot experiment was carried out to look at these interactions in eucalyptus seedlings. As in the field, N was the major factor limiting seedling growth, but the seedling and six-month-old trees responded differently. In seedlings, the addition of N caused an increase in demand for P and K which was not shown in the plantation trees. This result could be ascribed to a high demand for N by seedlings, the growth response to which can lead to deficiencies in other elements.

Table 2. Effect of time of fertiliser addition on eucalyptus growth, foliar nutrient content and index of nutrient deficiency determined within two weeks of the six month addition, in the field trial

	Fertiliser applied at planting	
	3 months	6 months
Tree height (m)	2.7	2.5
Foliar N (%)	2.96	3.14
N uptake	29.8	24.7
Foliar P (%)	0.26	0.27
P uptake	1088	434

The pot study showed that there was a significant relationship between nutrition and stem/leaf ratio. In general, this ratio increased with increased N supply, high levels of P only enhancing the ratio at high N levels (Figure 7). Increased K only increased the stem/leaf ratio at intermediate and high levels of N. This fact may be important in determining nutrient balances for optimising wood production.

Implementation of bioassay as a management tool

At present, the bioassays are being used mainly as research tools in studies relating plant growth and

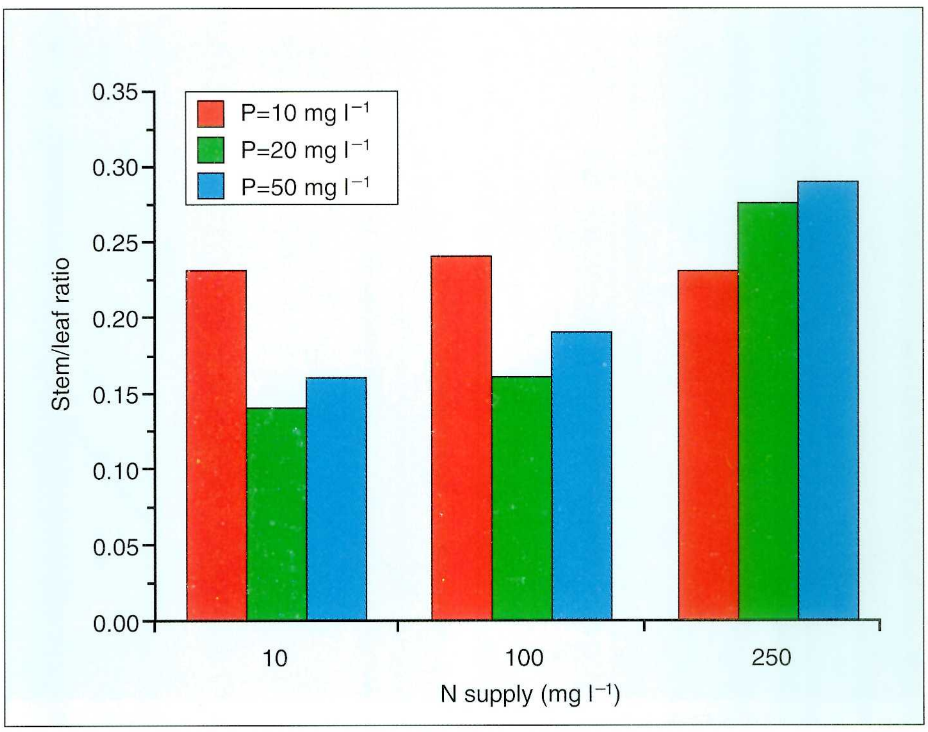

Figure 7. Effect of N and P supply on stem/leaf ratio in eucalyptus seedlings

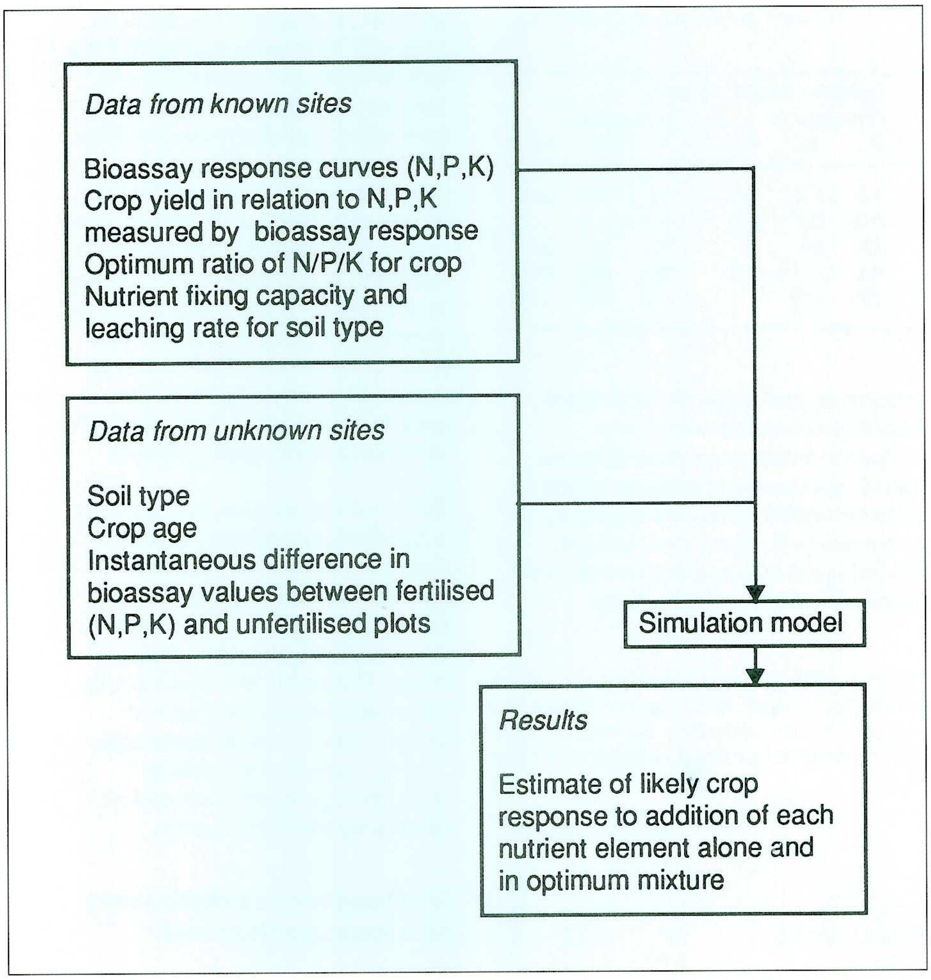

Figure 8. Flow diagram of possible use of bioassays for estimating potential crop response to fertiliser addition

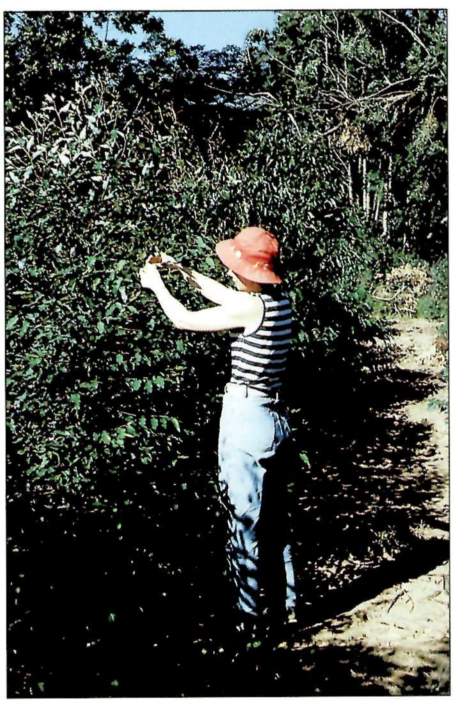

Plate 2. Eucalyptus in southern Africa at six months after planting

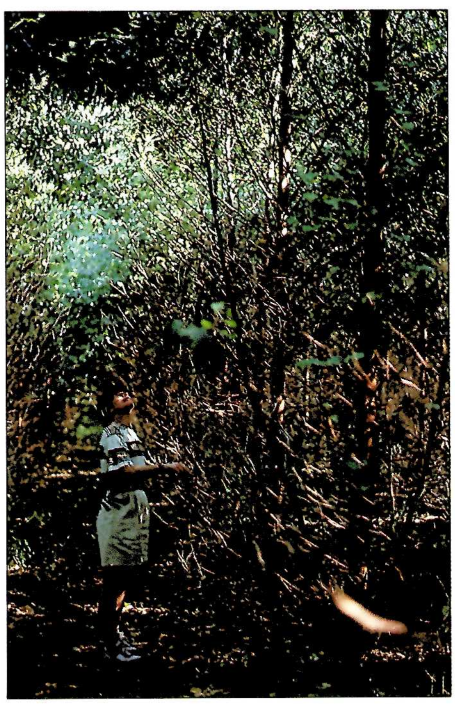

Plate 3. Eucalyptus in southern Africa at 18 months after planting

nutrition to soil nutrient characteristics. However, there is considerable potential for improving current methods to detect nutrient deficiencies, to predict fertiliser requirements, and thus to improve the economic management of plantation forests. In order to develop precise rules for predicting tree growth response to fertiliser addition, other factors must be quantified and used to create an appropriate data base. These factors include the results of a number of trial experiments, under differing field conditions (soil type, climate, etc), where the differences in bioassay nutrient uptake values between fertilised and unfertilised stands have been translated into observed growth/yield increases. An instantaneous measure of the difference in bioassay nutrient uptake between small patches of fertilised and unfertilised forest could then be used as input to a model to predict growth/yield increase in response to the fertiliser (Figure 8).

As we are only beginning to look at eucalyptus, we cannot yet give precise recommendations for fertiliser use, but there are clear indications that the bioassays will fulfil this function. They are already proving to be more sensitive than foliar analysis. Our experience in temperate regions suggests that they can detect plant response to changes in nutrient availability much more rapidly than foliar analysis. It is important to be able to optimise fertiliser addition to fast-growing tree crops such as eucalyptus, which can have a rotation time of seven years (Plates 2 & 3).

J Dighton and H E Jones

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Effects of tropical forest clearance on mycorrhizas and soil fertility in Côte d'Ivoire

(This work was funded by the Overseas Development Administration)

Successful reforestation depends upon developing sustainable and ecologically stable systems of land management, in which suitable conditions are provided for rapid tree growth while, at the same time, ensuring the stability of the ecosystem by maintaining plant species diversity, protecting the soils and soil microflora, and maintaining the forest's physical environment. During the processes of forest clearance and replanting, many changes occur, and the extent of these changes is influenced by the methods of site preparation used. If the effects of different land management practices are understood, the best option can be selected to develop sustainable, economically productive forest.

Previous studies in moist deciduous forest in Cameroon (Lawson *et al* 1990) indicated that intensive mechanical site preparation resulted in a substantial, but short-term, decrease in spore numbers, a shift in their species distribution, and a decrease in the mycorrhizal infection of tree roots. Spore numbers subsequently returned to their original values, however, much of the increase was due to the proliferation of a single species of fungus, which appeared to be associated with invasive weeds. Site preparation also had substantial effects on nutrient availability.

The study in Cameroon monitored changes in spore populations over 18 months, spanning the period from before site preparation to one year after planting. In late 1990, an opportunity arose in Côte d'Ivoire to evaluate changes in spore populations and nutrient availability over a much longer time period, by examining forests which had been cleared and replanted by mechanical or manual methods up to 24 years previously (Lawson *et al* 1991). This study was part of a multidisciplinary evaluation of forest plantations in Côte d'Ivoire, which included environmental, social, economic and institutional issues.

As in Cameroon, soil samples were taken close to *Terminalia ivorensis* (a fast-growing timber tree). These samples were taken in an 'undisturbed forest' control (which had been protected from logging since 1965), in forests which had been cleared mechanically and replanted with *Terminalia* in 1990, 1989, 1985 and 1978, and in forests which had been cleared manually and replanted with *Terminalia* in 1990, 1989, 1975 and 1967. Mechanical clearance methods involved chainsaw and bulldozer felling of trees, with unwanted debris being scraped into wind-rows at approximately 30 m spacing which were repeatedly burnt and raked until clear. Manual methods used until recently involved chainsaw felling of marketable trees and hand clearance of the understorey. In 1989 and 1990, however, a much more intensive method of hand clearance was used, in which the sites were extensively cleared, charcoal burning was carried out, and the remaining debris was partially burnt. After collection, the samples were divided, part being used for mycorrhizal studies and part for chemical analysis.

Effects on mycorrhizal populations

There was a substantial increase in total numbers of spores (Figure 9) in the years following clearance, with the increase being greater and more rapid in the manually cleared sites. Spore numbers then declined slowly in the manually cleared sites, reaching levels comparable to those in the natural forest after 24 years. The oldest mechanically cleared site was only 12 years old at the time of sampling, and showed no evidence of any decline in spore numbers.

A high number of spore types was found in the samples, with 41 types being distinguished, of which four were almost certainly new species (in Cameroon 17 types were found). The number of types, like the number of spores, varied with time. In the undisturbed forest, a mean of eight types per sample was found, this figure increased after site disturbance to 14 in the 1989 manual and 1985 and 1975 mechanical plantings, and then decreased in the older manual plantings, so that the mean number of types in the 1967 manual planting was not significantly different from the control. However, the total number of types found in the 1967 manual planting was 30, nearly double the number in the undisturbed forest, and six of the original types (each <1% of the control population) had been lost.

The proportions of types also varied with type of clearance and time since clearance. This variation was particularly marked in the mechanically cleared plots, where the type which had dominated the samples from the

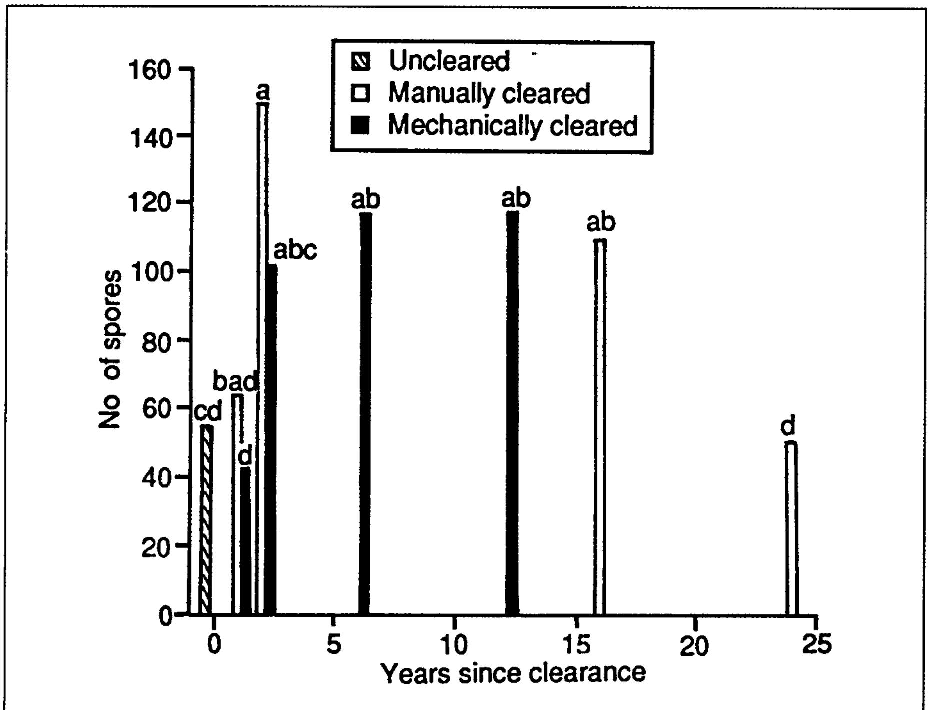

Figure 9 Number of mycorrhizal spores in the soil after clearing forest in the Côte d'Ivoire in different ways (manually or mechanically) and replanting with Terminalia ivorensis *trees. Columns with the same letters (a,b,c,d) are not significantly different at P=0 05*

undisturbed forest and which was dominant or co-dominant in the manual series lost its dominance in the 1979 planting to another type which was rare in the undisturbed forest

Effects on soil chemistry

Significant changes in soil chemistry occurred with time and clearance method The young manually cleared sites showed large increases in pH, extractable phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), whilst the mechanically cleared sites showed small reductions in pH, total nitrogen (N), extractable P, and all cations except K Loss-on-ignition (organic carbon) and N both tended to peak in mid-rotation After 10–20 years, levels of nutrients tended to return to those observed in the natural forest, with the exception of potassium which remained high

Levels of extractable P were extremely low (<1 mg kg^{-1}) in the undisturbed forest, mechanically cleared plantations, and in the older manually cleared plantations Effective mycorrhizal associations are likely to be important in these circumstances for tree growth

Manual *versus* mechanical clearance – implications for sustainability

Tree yield data available for these forests were limited However, the extra costs of mechanical clearance did not appear to be justified by enhanced tree growth

In terms of mycorrhizal spore populations, manual clearance appeared preferable to mechanical clearance because

- spore numbers increase rapidly during the first two years after manual clearance, a period when the trees are competing with weeds and rapid growth is vital, and
- the balance of spore types is akin to that of the undisturbed forest, thereby increasing the likelihood of maintaining root infection with appropriate fungal species

In terms of soil chemistry, manual clearance is also preferable because

- levels of available phosphorus and cations are significantly higher,
- soil organic matter is not removed from the site, thereby protecting the soil's cation exchange capacity, and
- an increase in pH may avoid possible toxic effects of metals such as aluminium and manganese

In terms of other effects, manual clearance avoids severe soil compaction caused by bulldozers, but requires more intensive weeding, because herbaceous species are also stimulated by the larger supply of nutrients following manual clearance and burning (Lawson *et al* 1991)

J Wilson and G J Lawson

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Land use, agriculture and the environment

In the 1989–90 Annual Report, the contributions to research on land use, agriculture and the environment were a good cross-section of 'broad-brush' approaches to the subject, and were especially valuable in demonstrating the relevance of global and holistic consideration of some of the issues involved in this very broad programme This year's reports are more specific in the questions they attempt to answer, although they do, once again, illustrate the wide range of topics which this particular programme includes

There are clear signs of the development of work on land use to embrace many aspects which tend to be unfamiliar to ecologists The social and economic context of many land use issues has become increasingly relevant, and many workers, at least outside ITE, are now beginning to collaborate in joint ecological/economic/social projects It is expected that this approach will be needed by ITE ecologists working in the land use area in the near future

Another non-ecological factor of land use change is the administrative and organisational aspect, closely linked to policy issues The year has seen radical changes to the structures of official nature conservation in the UK, and the effects of these changes have yet to be fully experienced The Forestry Commission is another important user of land which is to undergo extensive restructuring It would be unwise and unrealistic to ignore these changes on the grounds that ITE's interest in land use, agriculture and the environment is purely scientific

Less clear-cut in policy and administrative terms, but arguably more relevant to land use overall, are the clear indications of the most radical change in agriculture to occur since the end of the Second World War and the 'twin peaks' (as it has been expressed) of the Agriculture Act and Town and Country Planning Act, both passed in 1947 The switch from producing cheap food as virtually the only function of agriculture to a pluriactive response to the perceived needs for greater concentration on production of environmental 'goods' will have profound effects on land use research, and will strengthen the need for ecologists to collaborate with economists and social scientists It is also certain to increase the value of such components of ITE's programme as the Countryside Survey 1990, ECOLUC (ecological consequences of land use change), remote sensing applications, and Geographical Information Systems

During the year under review, it has become increasingly clear that 'landscape ecology' (*sensu* meta-population dynamics) will be a major point of growth during the next few years It will be important to steer a course between too narrow an interpretation of the field of study and too broad a one Patch dynamics and an appropriate appreciation of scale effects will be two key elements However, any attempt to include all aspects of ecology at the local scale in considering ecological processes at the 'landscape' scale is almost certainly doomed to failure Collaboration of land use ecologists with population theorists and field workers will be required

Impacts of extrusion cutting of peat in Northern Ireland

(This work was funded by Department of Environment (Northern Ireland))

This outline summarises part of a wider review of the impacts of mechanical extraction of blanket peat, which included contributions from the Institute of Hydrology and the Institute of Freshwater Ecology The study examined the possible consequences of blanket peat extraction by extrusion and other methods, and involved a literature review, interviews with interested agencies and individuals, and site visits

Blanket peat deposits up to several metres thick are widespread in Northern Ireland, and occur on level to steeply sloping ground It is only since 1981 that tractor-mounted extrusion cutters, originating in Sweden and Finland, have made possible the large-scale, cost-effective, machine extraction of peat from blanket bogs Cutting is undertaken with a disc or chain cutter, which extracts peat from a slot in the bog, and extrudes it on to the surface in continuous lines (Figure 10) The extruded peat is left to partially dry out, before being turned by hand or machine, cut into short lengths, and stacked to complete the drying process It is then removed for use as fuel Although extrusion cutting appears to be largely for domestic use, the rapidity and extent to which this technique has been adopted have caused concern about the short- and long-term impacts

Other methods of extraction include hand cutting (small scale, low impact), machine milling (large scale, high impact, but little used on blanket peat), and face cutting (peat cut from a face using a mechanical digger and then transported and extruded on to ground elsewhere to dry)

Ecological resources of blanket peat

Peatlands are extensive in Northern Ireland (about 170 000 ha, Cruickshank & Tomlinson 1988) Peat structure and depth can vary greatly within a small area, and striking differences in colour and texture are visible when a section of bog is exposed

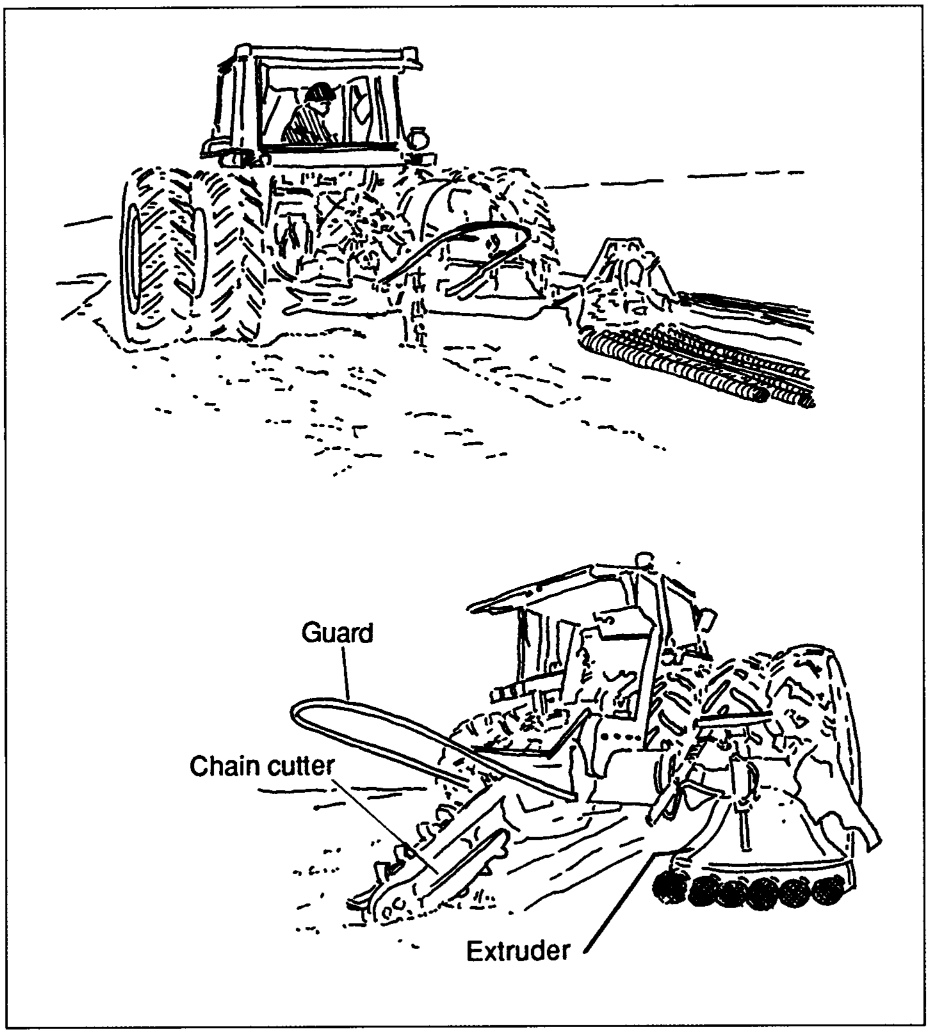


Figure 10 Tractor-mounted extrusion cutter

Intact bogs can be considered to have two distinct layers (Figure 11) The 'acrotelm' (Ingram 1982) is at the surface, only partly saturated, little humified, and mainly aerobic The 'catotelm' underneath is saturated, humified, and anaerobic Ingram (1982) and Bragg (1988) have shown that the shape of raised bogs and even individual peat mounds can be related to the balance between water input, mainly from rain, and output, mainly via groundwater discharge Maximum dimensions are limited by the driest period through which the bog can survive without the catotelm suffering significant desiccation Hobbs (1986) and others observed that, when peat dries out, it undergoes an irreversible decline in its water-holding capacity, and undergoes wasting by aerobic decomposition For peat surface stability, the catotelm must be permanently saturated In this respect, it is quite distinct from mineral soils, which can, in most cases, survive cycles of desiccation without changes to structure or water-holding capacity

The vegetation of intact blanket bogs is quite distinctive, and different from raised bogs, with characteristic species such as *Campylopus atrovirens, Pleurozia purpurea*, purple moor-grass (*Molinia caerulea*), bell-heather (*Erica cinerea*), billberry (*Vaccinium myrtillus*) and crowberry (*Empetrum nigrum*), as well as the more universal acid bog species such as heather (*Calluna vulgaris*), cross-leaved heath (*Erica tetralix*), deergrass (*Trichophorum cespitosum*) and cotton-grass (*Eriophorum* spp) (Dierssen 1979, Kirkpatrick 1988) Areas of cutover or partially cutover bog tend to have a more varied flora, with higher proportions of grasses, such as mat-grass (*Nardus stricta*), wavy hair-grass (*Deschampsia flexuosa*) and sweet vernal-grass (*Anthoxanthum odoratum*)

Peatlands form an important habitat for waders and some waterfowl, such as the white-fronted goose (*Anser albifrons*), although none is exclusive to Ireland or restricted to blanket bogs

Invertebrates are numerous on blanket peatlands, but the number of species is comparatively small, and their distribution mainly widespread Flushes of insects (particularly Tipulidae) are an important source of food for birds like pipits (*Anthus* spp) and red grouse chicks (*Lagopus lagopus*)

Heavy mechanical extraction may substantially reduce the grazing value of bogs, and the invertebrates could be severely affected Overall, although the main impacts of cutting are clear, little detailed information is so far available on ecological changes

Many blanket peat areas are used as rough grazings, and attempts have been made to improve them by drainage, fertilising and reseeding Little reclamation is being undertaken at present because of changes in the system of agricultural support

Impacts

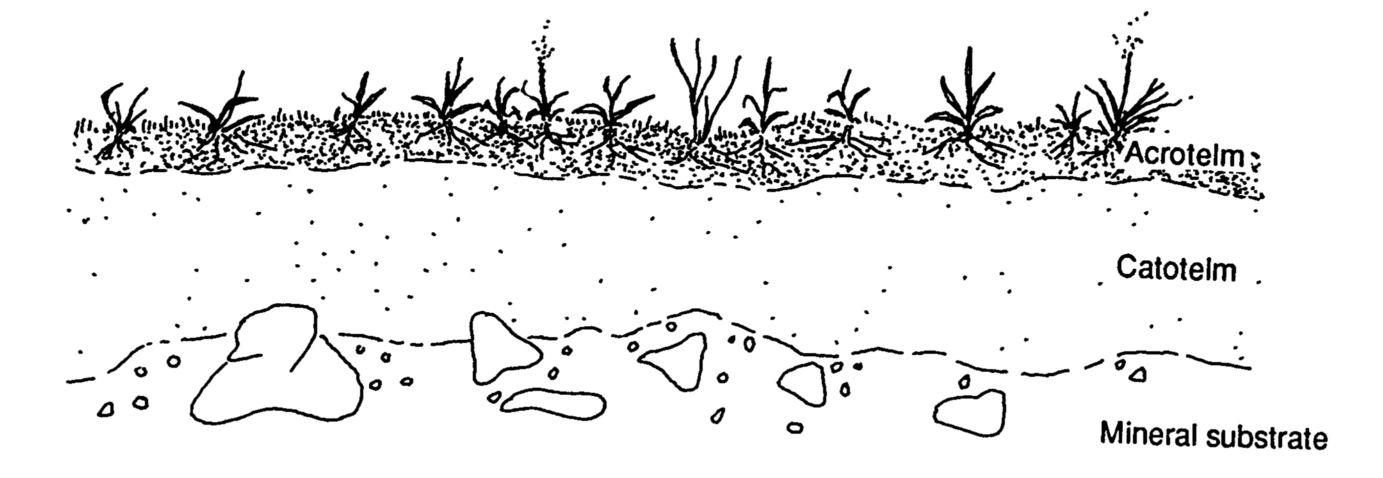
Extrusion cutting has four main types of impact (Figure 12)

- changes in surface topography, drainage and peat structure substantially modify the existing bog surface characteristics,
- burial by extruded peat kills or reduces the vigour of bog vegetation,
- the physical integrity of the peat is destroyed, and
- aeration and drainage are modified by slot cutting

Some species of plant are more resistant to these types of damage than others, but repeated cutting eliminates most of the plant cover (Table 3)

Possible uses of cutover bog

In general, little thought is given to the use of cutover bog, but the type and



Feature	Catotelm	Acrotelm
Water content	Constant	Variable
Water table	Very little change	Frequent fluctuations
Hydraulic conductivity	Low	High
Aeration	Anaerobic	Aerobic
Organisms	Anaerobic bacteria	Living vegetation, aerobic bacteria and other micro-organisms
Peat type	Mainly amorphous	Mainly fibrous

Figure 11 Features of the catotelm and acrotelm layers in peat

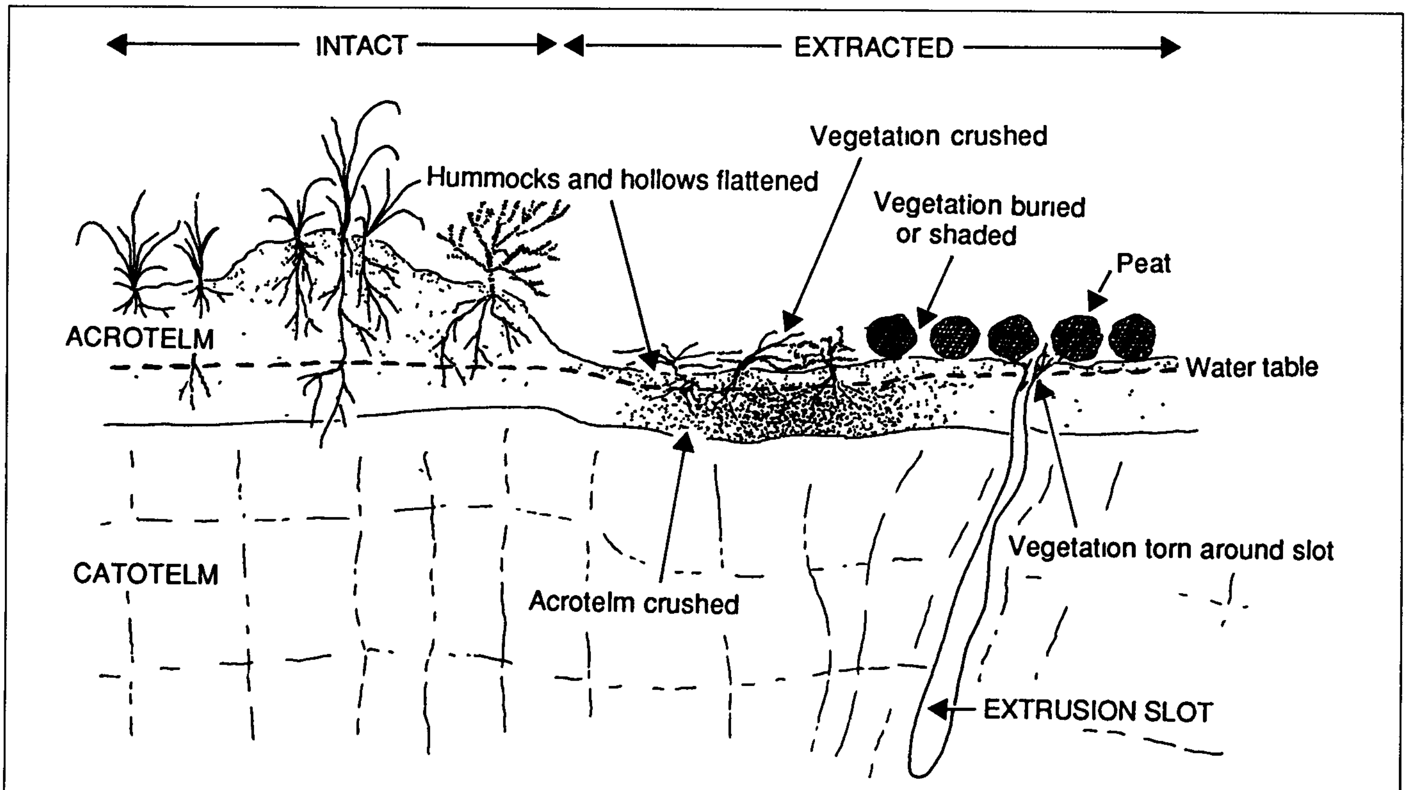


Figure 12 Impacts of extrusion cutting on vegetation

Table 3 Effects of extrusion cutting on vegetation cover and species composition of a lowland blanket bog near Cookstown Data are visual estimates of the cover of principal species only (t=trace)

	Intact	2 cuts	4–5 cuts
Heather (*Calluna vulgaris*)	60	35	0
Hare's-tail cotton-grass (*Eriophorum vaginatum*)	15	15	3
Common cotton-grass (*E angustifolium*)	2	t	t
Deergrass (*Trichophorum cespitosum*)	0	10	2
Purple moor-grass (*Molinia caerulea*)	2	t	0
Bog asphodel (*Narthecium ossifragum*)	t	0	t
Sphagnum spp	25	15	0
Hypnum cupressiforme	10	5	0
Campylopus introflexus	0	0	t
Polytrichum spp	5	t	t
Cladonia spp	2	0	0
Bare ground	t	5	95

severity of extraction clearly have a substantial influence on possible subsequent uses (Figure 13) The severe damage which results from heavy extrusion cutting or from even more damaging operations, such as surface milling, will substantially reduce, or eliminate, virtually all the bog vegetation and limit subsequent use to rough grazings, waste land, or forestry In contrast, hand-cut peat areas often retain the vegetation, and may sometimes have a higher nature conservation value than intact bog

Mitigation procedures

Possible ways to minimise the impacts include

- reducing the frequency or density of cutting to avoid severe damage,
- selecting only that ground easily drained and well suited to extrusion cutting,
- designating areas of high nature conservation value,
- reinstating damaged ground by manipulating drainage, seeding, turfing, or fertilising and surface landscaping or moulding

The effectiveness of these management practices has not yet been tested Small-scale trials, coupled with the monitoring of sites with a known history of extraction, could provide valuable information about impacts, which could be useful in formulating guidelines for extraction to reduce environmental impacts

N G Bayfield, N Picozzi and B W Staines

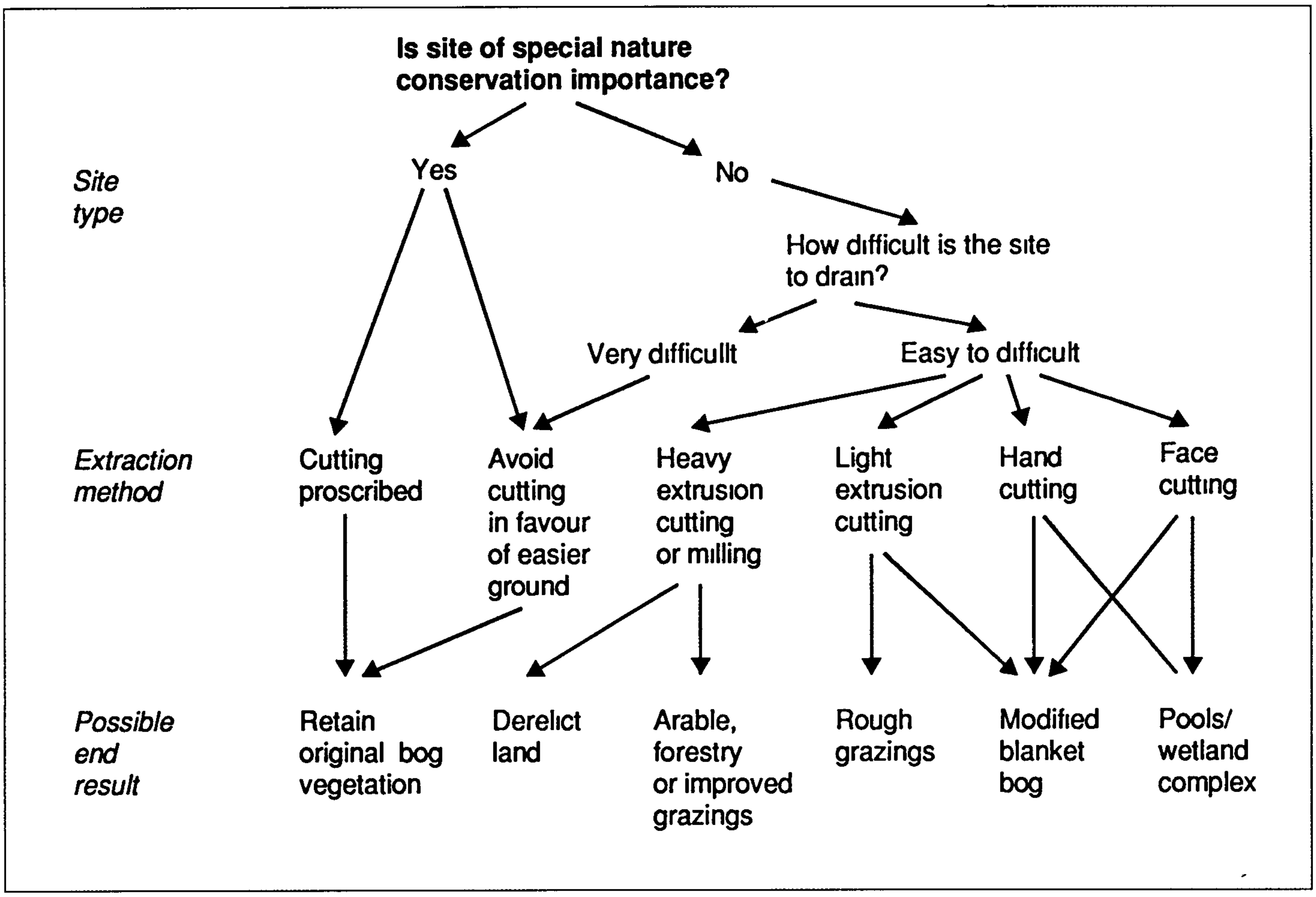


Figure 13 Potential uses of cutover bog in relation to site type and method of extraction

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Advantages and disadvantages of the bracken habitat

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

The aim of this study was to construct an environmental balance sheet for bracken (*Pteridium aquilinum*), taking into account both the conservation value of bracken-dominated communities and the ecological effects of the continuing spread of bracken. In addition, the ecological impacts of controlling bracken stands by conventional techniques, such as cutting and spraying or by the release of an alien biological control agent, were assessed. Where published data were lacking, information was obtained from people involved with bracken management.

The conservation value of bracken-dominated communities

In its natural woodland habitat, bracken forms part of many diverse communities, occasionally achieving dominance in gaps and clearings, but it is usually suppressed as the tree canopy develops. Where bracken achieves dominance, its dense shade and large quantities of litter suppress other species, both in woodlands and in the open.

Most bracken-dominated communities fall into the bracken/goosegrass (*Pteridium aquilinum/ Galium aparine*) community of the National Vegetation Classification (NVC) (Rodwell 1991b). This community is species poor, especially when compared to the heathland and moorland communities that it often replaces. Between four and six species of higher plant are usual per square metre (Grime, Hodgson & Hunt 1988), and in some areas no species of higher plant are found.

Occasionally, bracken-dominated stands form part of a relatively species-rich community, for example where they help to preserve a vernal flora on cleared woodland sites. These communities usually correspond to the bracken/ blackberry (*Pteridium aquilinum/ Rubus fruticosus* agg.) community of the NVC (Rodwell 1991a). Common species in this bracken/vernal flora include bluebell (*Hyacinthoides non-scripta*) and wood sorrel (*Oxalis acetosella*), but sometimes rarer woodland plants are found, like chickweed wintergreen (*Trientalis europaeus*). The survival of woodland plants under bracken means that their associated invertebrate species may also be preserved. Hence, woodland butterflies like the high brown fritillary (*Argynnis adippe*) and the heath fritillary (*Mellicta athalia*) are found in bracken in the open. Bracken communities in the New Forest are the habitat of one nationally rare plant – the wild gladiolus (*Gladiolus illyricus*).

In moorland areas, only 15 species of bird breed in bracken, as opposed to 33 in heather (*Calluna vulgaris*) and 25 on acidic grassland (Ratcliffe 1977). The 18 species lost when bracken invades heather include some of national importance, eg the hen harrier (*Circus cyaneus*), greenshank (*Tringa nebularia*), and twite (*Acanthis flavirostris*). Only a few birds are specifically associated with bracken, usually through the loss of alternative habitats; the primary example is the whinchat (*Saxicola rubetra*).

Although bracken stands offer cover for nests and burrows, the poor

Plate 4. Bracken invading moorland on the North York Moors

ground vegetation means that herbivores like voles are uncommon. Moreover, if bracken invades heathland or moorland, then many reptile species are lost because of the lack of open basking areas.

Ecological effects of continuing bracken expansion

Large areas of semi-natural vegetation will be lost if bracken continues to spread unchecked. In particular, the absolute amounts of moorland (Plate 4), grassland and lowland heathland will be reduced, and their conservation value will decline further as these habitats become fragmented. Basically, bracken expansion results in a loss of habitat diversity in Britain, because its communities are fairly uniform across the UK, whereas those being replaced represent a range of diverse elements. The extensification of agriculture in Britain may increase the spread of bracken from linear features, such a hedgerows, into new areas, and the effects of climate change are unknown.

Plate 5. Patchwork of bracken and heather communities, Hutton-le-Hole, north Yorkshire

On moorland (Plate 5), the continuing spread of bracken could lead to a decline in species like merlin (*Falco columbarius*) and red grouse (*Lagopus lagopus*). A reduction in the area of moorland vegetation would probably lead to overgrazing on the remainder, which in turn might encourage the spread of bracken and accelerate moorland degradation to grass. The loss of suitable feeding areas for sheep and grouse may result in farming or shooting becoming unprofitable, and risks the change from multiple land use in the uplands (sheep, grouse, deer, tourism, conservation) to a single land use – forestry.

Ecological effects of bracken control

Three major problems are associated with the control of bracken using cutting or herbicide:

i. the need for continual retreatment to prevent regrowth;
ii. slow colonisation by other species, and
iii. invasion by undesirable 'weedy' species (Plate 6).

Plate 6. Poor vegetation development two years after spraying with asulam

Slow colonisation by other species is a particular problem following herbicide treatment on slopes, as no bracken canopy is left to prevent soil erosion before other species can invade. Colonisation can be speeded up by disturbing the litter layer, by burning it or incorporating it into the soil.

The invasion of 'weedy' species is a result of bracken raising the nutrient status of the soil, and thus reduces colonisation by 'desirable' species. For example, at Cavenham Heath in Suffolk, heather, the dominant plant outside the bracken canopy, took from four to ten years to establish where bracken had been controlled, whilst grasses and sedges were faster (Marrs & Lowday 1991). Sowing 'desirable' species helps to speed up the development of the desired vegetation, but 'follow-up' management is essential for the restoration of plant communities of conservation interest.

Special case – the release of alien insects to control bracken

Two South African moths are at present regarded as possible agents for the biological control of bracken in the UK (Lawton 1990). The effect of a successful release and subsequent establishment of these insects on bracken is unknown, but any such release would be irreversible and indiscriminate. Woodland where bracken is not generally a problem could be affected, as well as those few areas where it has a high conservation interest. The most significant problem would occur if only a small proportion of the potentially large areas affected were to receive follow-up treatment.

Cutting and spraying share the advantage that they can be targetted to sites which already possess some ground vegetation and require the minimum of follow-up management, and to advancing fronts to prevent further spread. However, both techniques are costly. Whilst the release of biological control agents presents problems, it does offer an inexpensive solution.

The ecological effect of the continuing expansion of bracken and its control is only one factor in setting priorities for a bracken control campaign. Changes in farming subsidies and the continuing poor profitability of farming in the uplands, as well as the increased use of upland areas for recreation and shooting, must also be taken into account. Similarly, further research into the incidence of Lyme disease (transmitted by sheep ticks and often associated with bracken litter), and increasing evidence linking bracken to certain cancers are further considerations.

R J Pakeman and R H Marrs

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Farm woods

(This work was partly funded from the Joint Agriculture and Environment Programme (JAEP) and the Forestry Research Coordination Committee (FRCC))

Farm woods are small and some are isolated. New woods, planted under the British Government's Farm Woodland Scheme, are also normally on soils that are more alkaline and fertile than soils of long-established natural woodland.

Even the most isolated farm woods experience a constant influx of animals and plants. These may establish and breed in the wood, they may move on to new sites, or they may simply die out without issue. ITE's studies of farm woodland centre on the processes of dispersal and movement of organisms in space and time.

Biodiversity in agricultural landscapes

A study of biodiversity in agricultural landscapes, conducted jointly by ITE and the University of York, is exploring island biogeography concepts in farmland mosaics to assist wildlife conservation. The study is examining species/area effects, minimal areas, effects of connectivity, and the relation of isolation to species persistence and turnover rates.

Invertebrate assemblages are being sampled by pitfall trapping, which catches mainly spiders and ground beetles, while vascular plants have been surveyed in 33 farm woods in the vale of York. There was a large and highly significant effect of area (larger woods had larger floras), but other factors, such as shape, isolation and the presence or absence of conifers, had no marked effect.

Rodents in farm woods

A survey of 68 deciduous woodlands in East Anglia yielded information on factors influencing the distribution of grey squirrels *(Sciurus carolinensis)*. Squirrels are more likely to occur in larger woods (Figure 14), in woods close to another wood of at least 5 ha, in mature woods, and in woods with oak (*Quercus* spp.), beech (*Fagus sylvatica*) or hazel (*Corylus avellana*). The use of woods for breeding, as indicated by the presence of dreys, was also investigated; density of oak trees and density of trees with a diameter greater than 50 cm were found to be important determinants, as was the proximity of another wood of at least 0.5 ha.

Small mammals were sampled in 39 woods ranging in size from 0.05 ha to 4.5 ha, also in East Anglia (Plate 7). The presence or absence of woodmice (*Apodemus sylvaticus*) and bank voles (*Clethrionomys glareolus*) was examined, and their density was estimated. The aim was to determine the minimum area of woodland that can support populations of the two woodland species, and to assess the extent to which habitat isolation and connectivity may affect the persistence and dispersal of 'island' populations. For each woodland, 17 habitat variables were recorded, including degree of isolation, measured by distance from neigbouring woodland, and connectivity, measured by the number and length of hedgerow connections.

Plate 7. In East Anglia, small mammals have been sampled in woods ranging in size from 0.05 to 4.5 ha

There was no evidence of any effect attributable to isolation, but the density of woodmice was lower where woodlands were surrounded by wheat, a crop in which they are known to be resident for much of the year. A small amount of live-trapping in wheat and rape crops indicated that both bank voles and woodmice were using these habitats. Thus, these small mammals may disperse through arable land, lessening the seemingly island-like nature of farm woods.

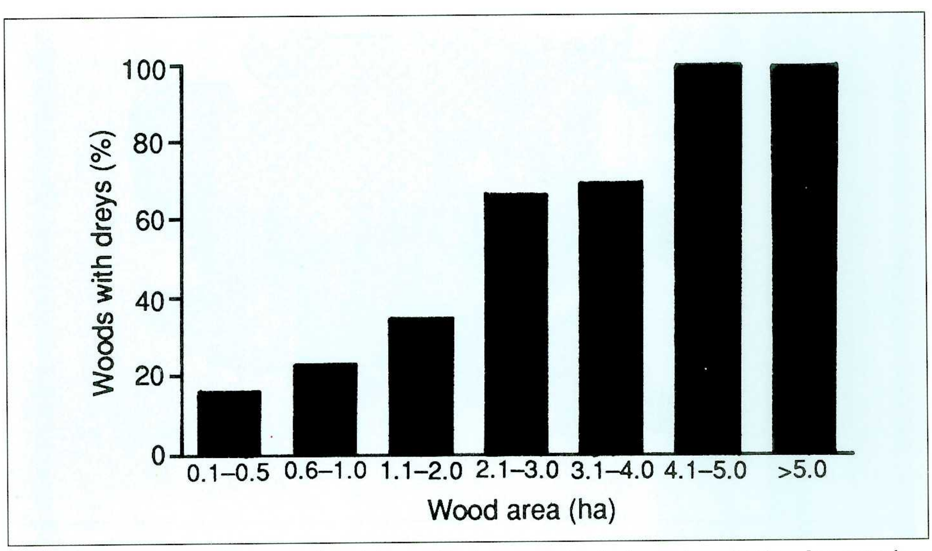

Figure 14. The chance that a wood contains resident grey squirrels depends on its size. In a sample from East Anglia, woods larger than 4 ha contained at least one drey

Plants in farm woods

The dispersal of plants to farm woods is a slow and chancy process. In a pioneering study of a fox covert in Lincolnshire, Woodruffe-Peacock (1918) found that plant propagules were constantly being introduced by wind, in pheasant seed, in mud, in bird droppings, and on clothing, hair and fur. Most arrivals did not persist: the few species that did took more than a century to arrive. Bluebell (*Hyacinthoides non-scripta*) and wood anemone (*Anemone nemorosa*) both arrived late; once bluebell had arrived, it spread effectively by seed, but wood anemone persisted only as a single, slowly spreading, clone.

Although chance plays a part, many aspects of colonisation and establishment can be predicted. In a project on vegetation development in new farm woodland, based at ITE Monks Wood and the Soil Survey and Land Research Centre, Silsoe, information from a wide range of sources is being brought together in a predictive model. The ITE surveys of woodland (Bunce 1982) and the wider countryside (Bunce, Barr & Whittaker 1981) provide information about species present both in objectively placed quadrats and in particular habitat features. A 1/75 subset of 2 km squares was sampled by the Botanical Society of the British Isles in 1987 and 1988; these data can be smoothed to obtain an estimated probability of occurrence for particular species (Figure 15) in 2 km squares across Britain.

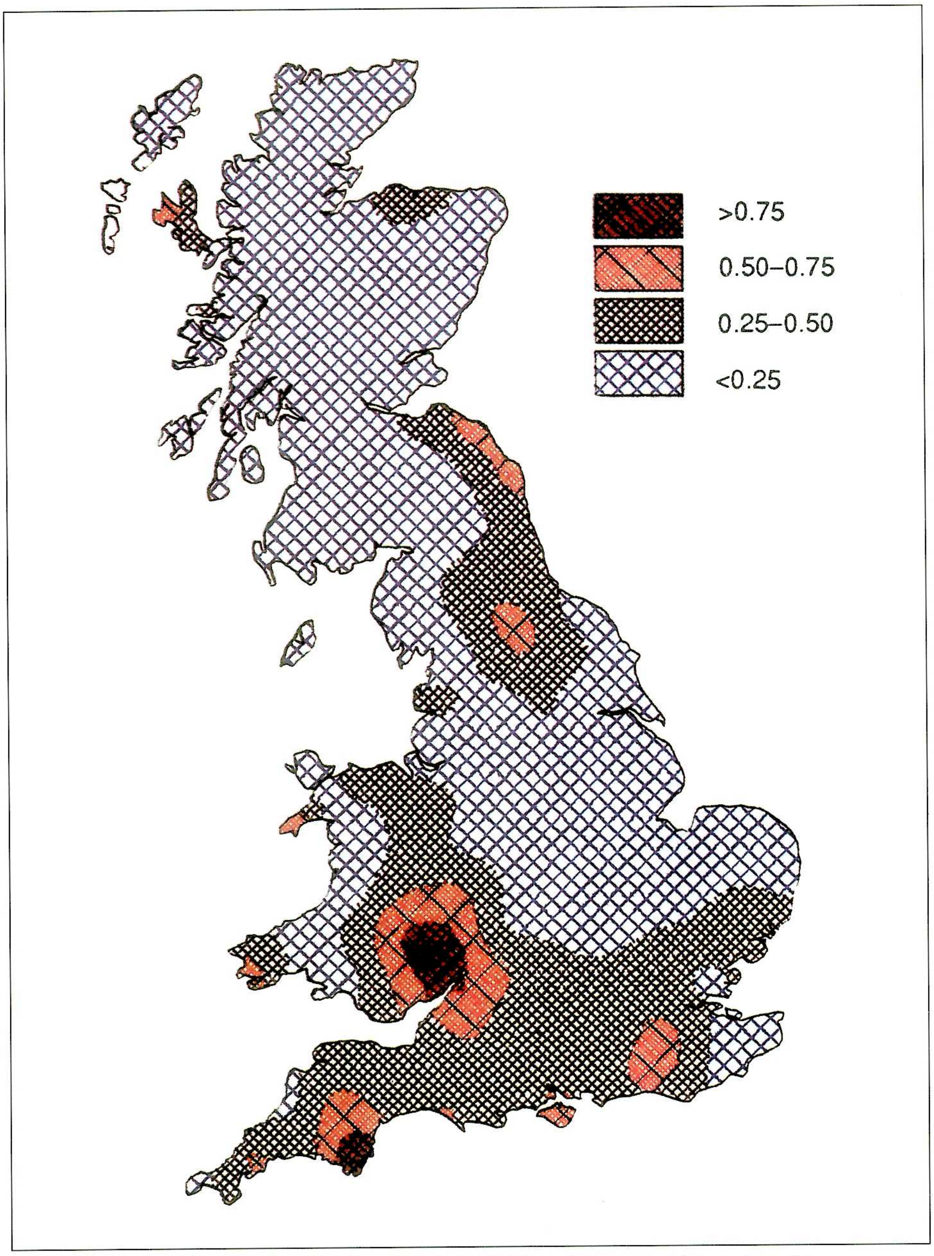

*Figure 15. The probability of finding wood speedwell (*Veronica montana*) in a given 2 km square ('tetrad') varies widely from one part of Britain to another; only in districts where the species has a high frequency in the landscape is it likely to invade new farm woods*

Combining these sources of information with data on soil type and plant autecology, we can estimate the probability of a species occurring near a site and being suited to colonise the site after the establishment of farm woodland, by the use of generalised linear modelling.

In another project, conducted jointly by ITE Monks Wood and Imperial College (Silwood Park), the uncertain process of colonisation is being speeded up by the deliberate introduction of field-layer species. This work started with a pilot experiment in 1981 at Milton Keynes, where the Development Corporation has established much new woodland. In 1987, a large-scale fully replicated experiment was set up, with 18 species sown in six sites. The establishment and reproduction of these species have been observed and related to environmental factors. Bluebell and red campion (*Silene dioica*) have established excellently. Most species had some success; the only total failure was giant bellflower (*Campanula latifolia*), whose seedlings were never seen.

Farm woods and habitat creation

The rate of woodland planting in lowland Britain appears set to increase to a level not seen since the early 19th century. Given that some species may take centuries, perhaps millenia, to colonise a wood naturally, there seems little reason not to assist nature by helping them to arrive sooner. Even so, we may not succeed in creating the type of community we want. Much depends on matching species and site, and also on introducing species at an opportune moment, and under a suitable tree canopy.

Perhaps farm woods should not be created merely with the aim of copying the small woods already present in the landscape. Non-indigenous wildlife may also be of value if they can reproduce and sustain viable populations in the environment. However, we do need a reasonably clear idea of the ecological consequences of our actions. To introduce a highly aggressive species such as rhododendron (*Rhododendron ponticum*) may be an attractive option in the short term; it can provide valuable cover for mammals and birds, and it is colourful when in flower. In the longer term, it will very likely form a continuous understorey, which suppresses almost everything else, including tree regeneration.

The aim, then, is to establish a harmonious whole, in which introduced species will thrive but not become overwhelmingly dominant, and where there is a place for a wide variety of animals as well as plants. ITE's research is showing how to achieve this objective.

M D Hooper and M O Hill

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Butterfly Monitoring Scheme

(This work was partly funded by the Nature Conservancy Council (NCC))

Most insects have short life histories, with one or more generations each year; as a result, they are able to respond rapidly to changes in the environment. The most widely known group of insects are butterflies, which

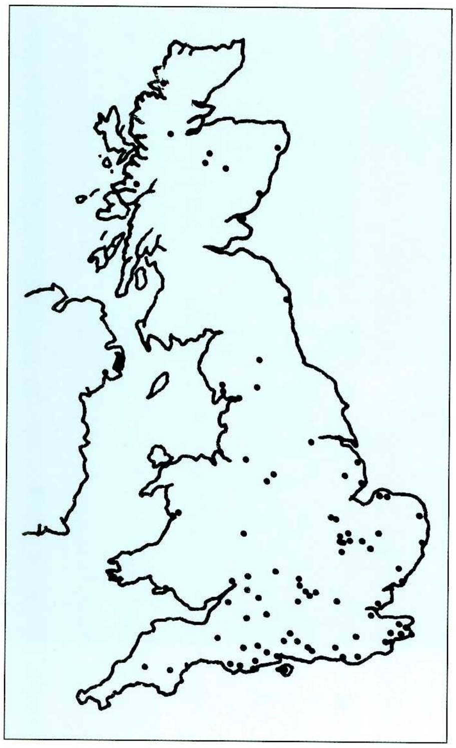

Figure 16. Location of sites in the Scheme in 1990

are colourful, easily identified, and fly by day. The Butterfly Monitoring Scheme (BMS) was set up in 1976 as a joint project between ITE and NCC (from April 1991 the Joint Nature Conservation Committee), to monitor the abundance of butterflies in Britain (Pollard 1977, 1991a; Pollard, Hall & Bibby 1986). The aims of the Scheme are:

i. to provide information at regional and national levels on changes in butterfly numbers, and to detect trends which may affect the status of the butterflies;
ii. to monitor changes in butterfly numbers at individual sites and, partly by comparison with results elsewhere, to assess the impact of local factors such as habitat change.

Fifteen years of data have now been collected, with contributions from over 100 sites across the whole of Britain, and with 96 sites expected to submit records at the end of the 1991 season (Figure 16).

At each site, the recorder makes a series of counts, walking a fixed route once a week from April to September, and noting any butterflies seen within 5 m. To provide standardisation, walks are only carried out between 1045 and 1545 hours British Summer Time, and then only if the weather meets specified criteria. The transect route is divided into sections, usually according to changes in habitat, so the Scheme provides valuable information on the habitat preferences of different species, and also enables an objective means of assessing the effects of management on butterfly numbers at each site.

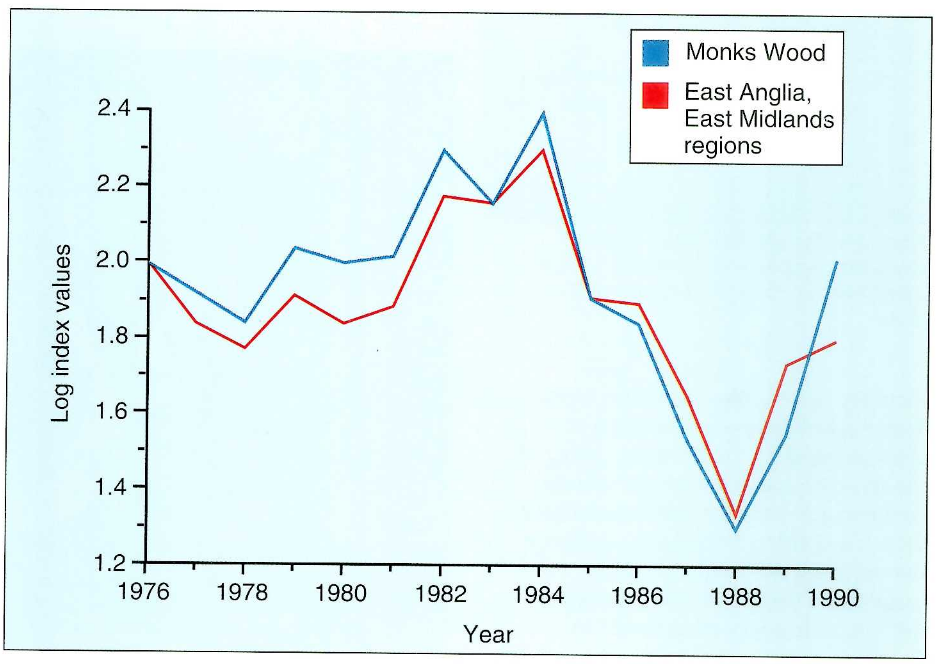

Figure 17. Fluctuations in index values of one species, the hedge brown (Plate 8), comparing one site with all sites in East Anglia and East Midlands regions

Plate 8. The hedge brown butterfly

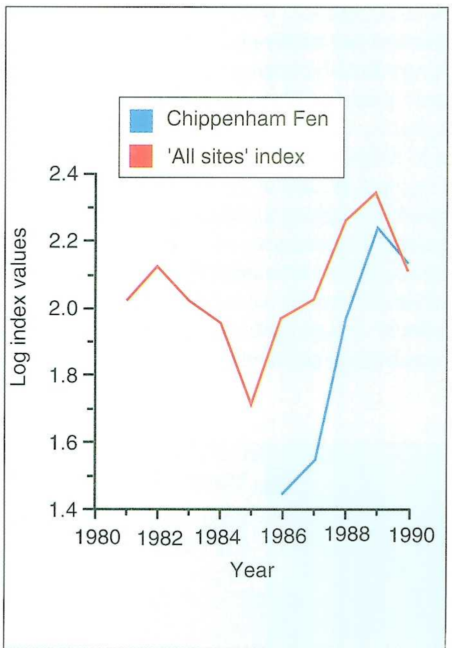

Figure 18. The speckled wood butterfly colonised Chippenham Fen NNR in 1986, at a time when national index values were rising

Virtually all the different habitat types found in Britain are represented at sites covered by the Scheme. Many of the sites are nature reserves, where recording is done by reserve wardens who are able to provide the regularity of consistent recording which is essential. Few of the sites represent the typical modern countryside in Britain, but changes in land use have meant that many butterfly species survive mainly on reserves where the habitat is managed specifically for them.

At each site, the mean weekly count of each species is totalled to provide an annual index of abundance. This index is not a population estimate, but it has been shown to be related to population size (Pollard 1977). The annual indexes of abundance from all the sites in different regions are then collated to provide regional indexes. Fluctuations in regional indexes (the regional trends) can be used as a baseline for comparison with specific sites, to assess the effects of local management. Regional and national trends are calculated using the ratio of the changes in the annual index of abundance. Data from sites for which there is an index of abundance in two consecutive years are used to calculate the ratio estimate, which is simply the sum of the index values in year 2, divided by the sum of the index values in year 1. For comparative purposes, the collated index was set at an arbitrary figure of 100 in 1976 (Figure 17). Further work on methods of analysing results from the Scheme is currently being undertaken.

Applications of the Butterfly Monitoring Scheme

The two aims with which the Scheme was set up have been fulfilled (Pollard *et al.* 1986). It is possible to detect when species begin to show any distinct regional or national trends. The Scheme has highlighted the effects of management at several sites. The data can document the arrival, and subsequent establishment, of a species new to a site (eg the arrival and establishment of the speckled wood (*Pararge aegeria*) at Chippenham Fen NNR (Figure 18), and, conversely, can provide early

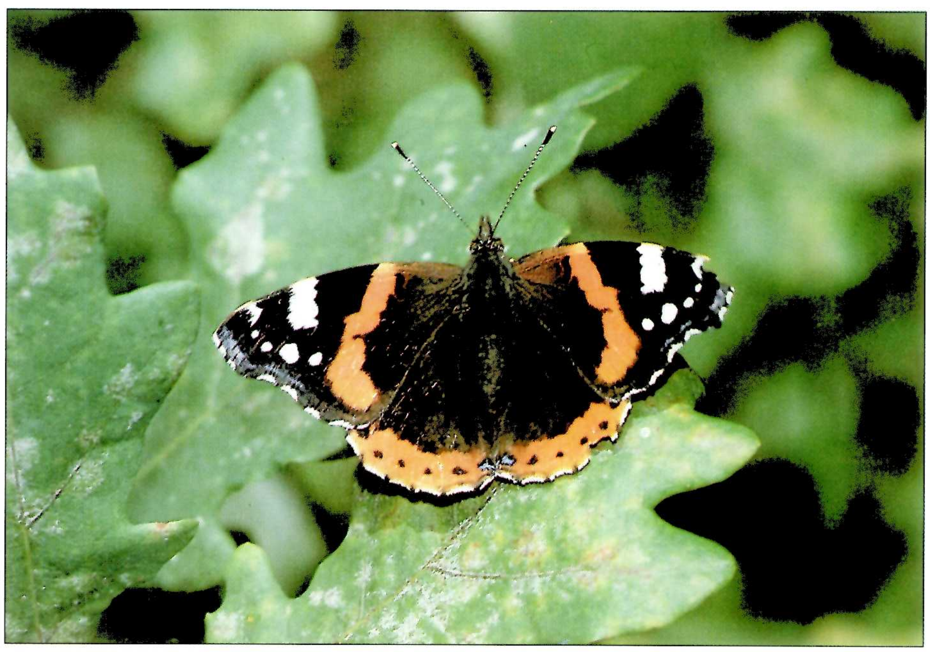

Plate 9. The red admiral butterfly, a common migrant

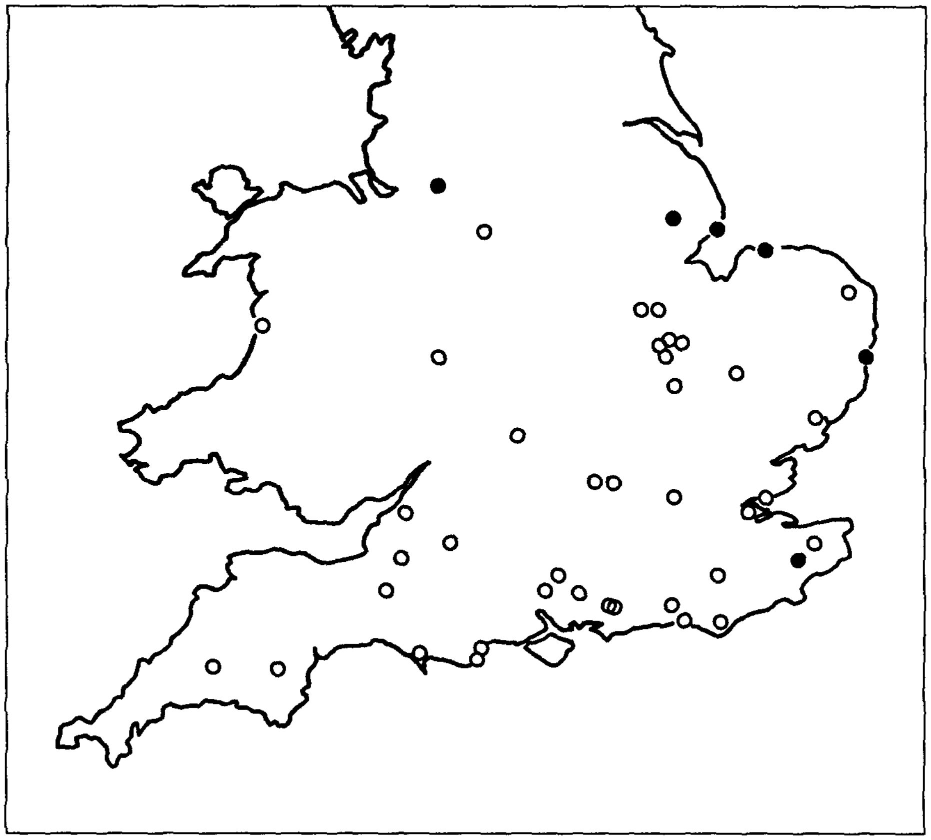

Figure 19 Sites in the Scheme at which the comma has been recorded in four or more consecutive years, during a period of at least eight years of recording Closed circles indicate sites which have been colonised in the recording period

warning of a species decline They can be used to show increases in the range of species The week-by-week recording has also shown the arrival and subsequent spread of migrant species (Plate 9) (Pollard, Hall & Bibby 1984)

Climate change

It has already been shown (Pollard 1988) that the Scheme can provide data to demonstrate the response of species to weather, and it is ideally placed to assess the effects of any change in climate on butterfly species in Britain In particular, changes in the phenology of species can be detected, for example, a warmer climate may lead to some species emerging earlier in the year, or to single-brooded species having two generations Many species in Britain are at the northern limit of their range in Europe, and only occur in the extreme south of the country The Scheme will rapidly detect if species increase their range, and become established further north Changes in the range of the comma (*Polygonia c-album*) (Figure 19) and hedge brown (*Pyronia tithonus*) (Plate 8) (Pollard 1991b) have already been noted The Scheme can be used to document any trend in the colonisations, or extinctions of species, that could result from changes in climate For example, common migrants from the Continent could begin to breed in this country Species may change their distribution within a site The Adonis blue (*Lysandra bellargus*) needs a very warm microclimate, and only breeds on south-facing slopes with very short turf, but, if the climate warms, it may begin to breed in areas with longer turf, or on north-facing slopes

Conclusions

The Butterfly Monitoring Scheme is the only long-term survey of its kind in Britain It is of prime importance for detecting and modelling the response of short-lived species to environmental changes, such as weather patterns or land use

ITE is continuing to collaborate with the Joint Nature Conservation Committee and its consultant on this project, Dr E Pollard, to operate the Scheme and to analyse and interpret the results

T J Yates and P T Harding

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Global environmental change

This new programme was set up in November 1990 to include expected major strategic research initiatives in the area of global change and terrestrial science. Biospheric processes play key roles in such global threats as desertification, species loss, and climate change caused by the 'greenhouse effect'; research is needed to reduce uncertainties in predicting these threats in order to frame policies for countering them. This area has achieved international importance, and will be central to decisions at the United Nations Conference on Environment and Development in Brazil in 1992.

The influence of the biosphere is exercised through the exchanges between the plant/soil system and the atmosphere of water, energy, momentum, carbon dioxide, and other trace gases. Rates of cycling and the sizes of reservoirs, especially the soil carbon pool, both affect and are affected by changes such as global warming. Land use change and management may exacerbate or ameliorate these changes.

All TFSD institutes and most existing programmes contain relevant ongoing projects, and formally the programme consists at present of the new TIGER (Terrestrial Initiative in Global Environmental Research) projects and the Arctic Ecology Special Topic. Both commenced in 1991 and involve TFSD institutes and university research teams. TIGER is managed centrally within the Directorate, co-ordinated by Dr M A Beran of the Institute of Hydrology; the Arctic Ecology Special Topic is co-ordinated by Dr T V Callaghan from ITE Merlewood.

The Global Environmental Change Programme will grow as substantial new projects commence in 1991.

Effects of elevated atmospheric carbon dioxide on montane grasslands

(This work was partly funded by an NERC Post-doctoral Research Fellowship with University College of North Wales and ITE Bangor, and by the CEC under 'EPOCH' (European Programme On Climatology and natural Hazards))

From recent models of global climate change, there is a general scientific consensus which predicts a doubling of the present-day atmospheric concentration of carbon dioxide (from 340 $\mu\lambda\ l^{-1}$ to 680 $\mu l\ l^{-1}$) within the next 100 years (Houghton, Jenkins & Ephraums 1990; Department of Environment 1991). This rise in CO_2, coupled with a concomitant increase in surface air temperature, is likely to have a profound effect upon natural and semi-natural plant communities (Cannell & Hooper 1990).

To date, most of the available data on the effects of elevated CO_2 on vegetation in temperate regions have been derived from short-term treatments (days to weeks), often carried out on important crop species under controlled environment conditions (Cure & Acock 1986). Very little is known about the possible effects of long-term exposure of natural plant communities to elevated CO_2 under field conditions. This lack of knowledge applies especially to the montane and arctic–alpine species, which may be particularly sensitive.

The montane bent-grass/fescue rough pastures (*Agrostis capillaris/ Festuca ovina*) are important semi-natural grassland communities of the European uplands. We need to understand how major upland grass species, which are often growing under extreme climatic conditions, will respond to enhanced CO_2 concentrations and changing

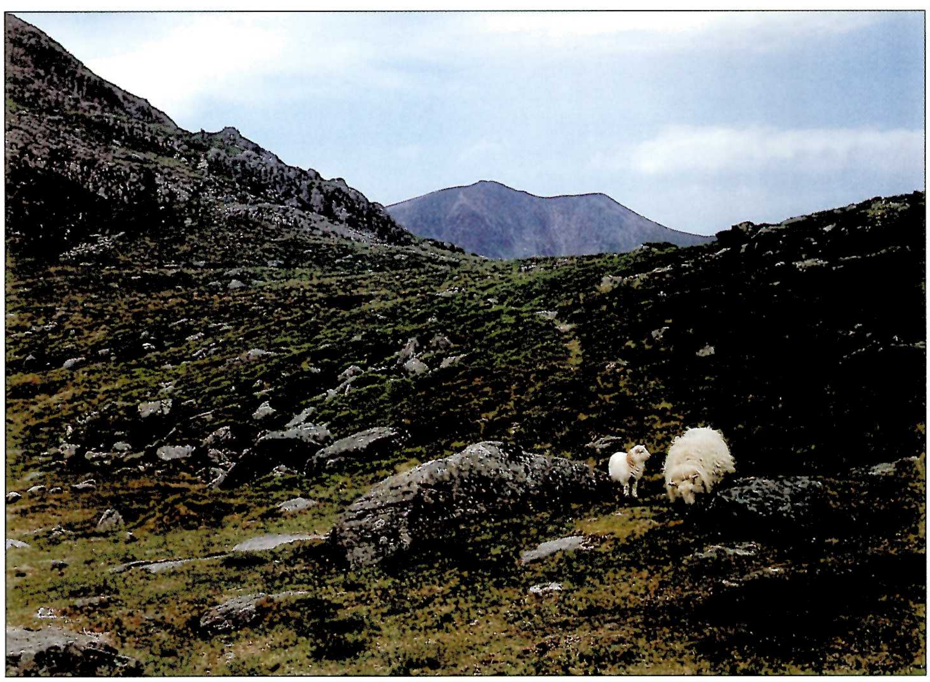

Plate 10. Montane grassland, Llyn Bochlwyd, Snowdonia

climate. This information is particularly important with respect to the economic grazing value of these upland regions.

A collaborative project between ITE and the University College of North Wales (UCNW), Bangor, is investigating the effects of elevated atmospheric concentrations of CO_2 on the growth and physiology of a number of perennial montane grass species in north Wales (Plate 10). The emphasis of the project lies in linking the altered growth of such plants to the underlying physiological processes: an essential link in establishing predictive models of the effects of elevated CO_2 on natural plant communities.

Open-top field chambers, designed and built at Bangor (Plate 11), are being used to grow plants in controlled elevated atmospheric concentrations of CO_2. The environmental conditions in the chambers are more similar to field conditions than can be achieved in closed systems (Ashenden, Baxter & Rafarel 1991).

In an initial experiment, common bent-grass (*Agrostis capillaris*) was grown singly in pots with optimal nutrient supply for a period of three months (October–December 1990), at either ambient (340 $\mu l\ l^{-1}$) or elevated (680 $\mu l\ l^{-1}$) concentrations of CO_2. Those plants grown under elevated CO_2 revealed the largest accumulation of dry matter, accompanied by changes in the proportion of shoot to root growth. The increase in shoot and root dry matter over the growth period was significantly higher in the plants grown with elevated CO_2 (Figure 20). 'High CO_2' plants initially showed a lower shoot/root ratio, reflecting an increase in the rate of root growth (Figure 21). After 56 days, however, the difference in shoot/root ratio between 'high' and 'ambient' plants was much reduced. This early increase in the rate of root growth may lead to an initial advantage in sequestering a potentially greater nutrient pool from the soil. The mechanism could be an important factor determining the competitive ability of this species when grown in mixed-species turf. Total leaf area is considerably enhanced in plants grown under elevated CO_2 from 40 days after initial exposure (Figure 22). This factor is correlated with increased tillering of these plants, which may provide a basis for increased assimilate production, in turn promoting further growth.

In addition to growth analysis, a wide range of quantitative physiological and metabolic measurements are being taken, including single leaf, whole plant and whole canopy photosynthesis and respiration, stomatal conductance, and analysis of assimilate partitioning using radioactive carbon (^{14}C) tracer studies. Short-term experiments are examining the rate of acclimation of

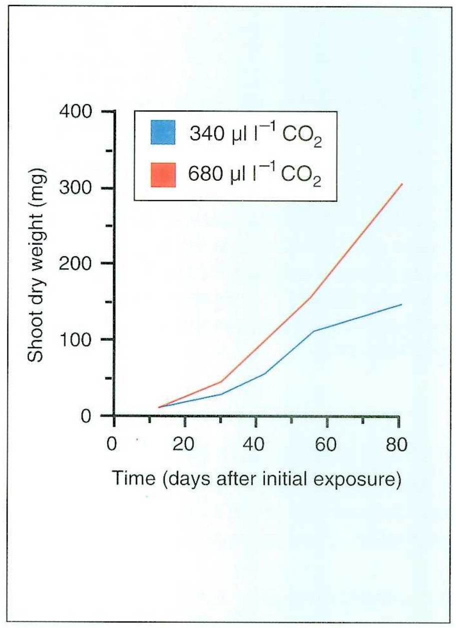

Figure 20 i. Total shoot dry weight of common bent-grass grown at ambient (340 $\mu l\ l^{-1}$) and elevated (680 $\mu l\ l^{-1}$) concentrations of CO_2. Data represent the mean of seven separate determinations

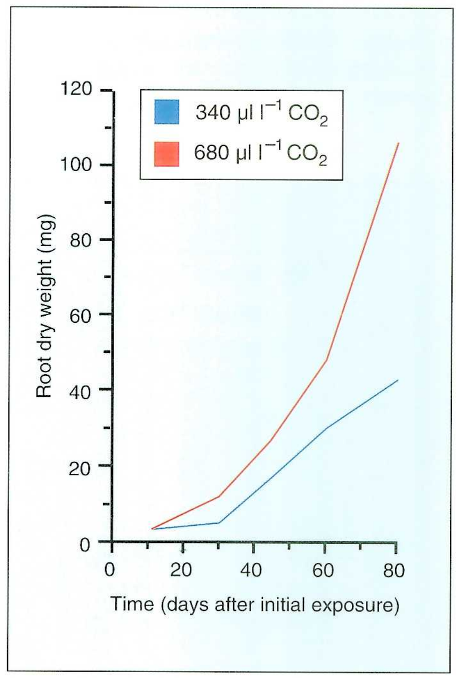

Figure 20 ii. Total root dry weight of common bent-grass grown at ambient (340 $\mu l\ l^{-1}$) and elevated (680 $\mu l\ l^{-1}$) concentrations of CO_2. Data represent the mean of seven separate determinations

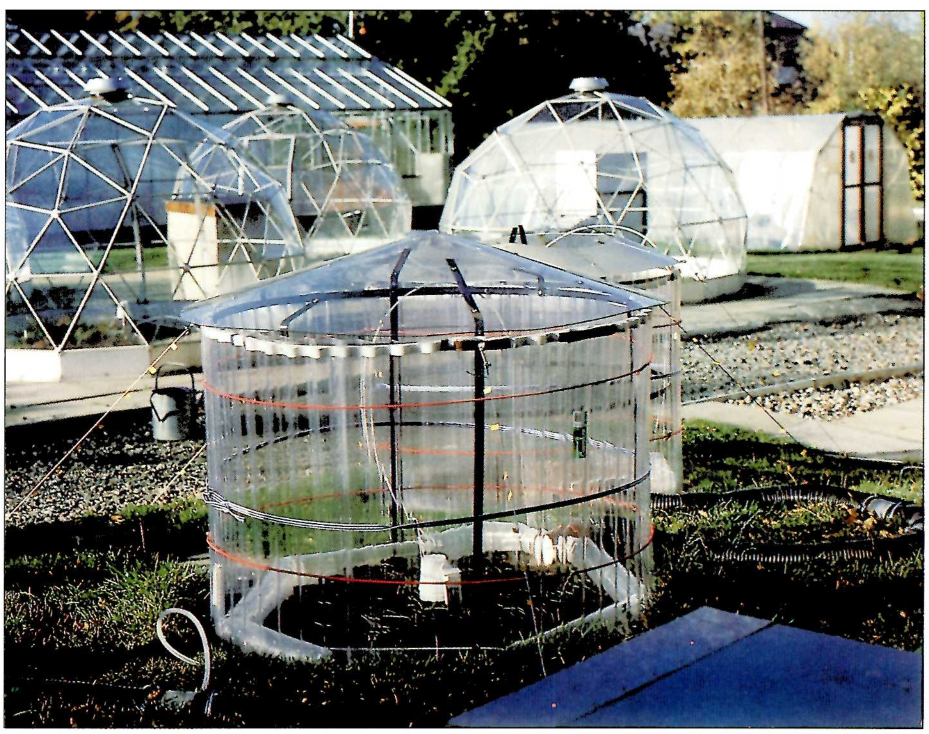

Plate 11. Opentop CO_2 fumigation chamber

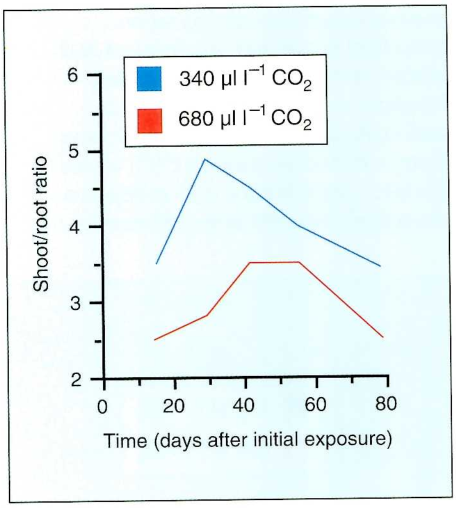

Figure 21. Shoot/root ratio of common bent-grass grown at ambient (340 µl l^{-1}) and elevated (680 µl l^{-1}) concentrations of CO_2 Data represent the mean of seven separate determinations

plants to elevated CO_2 by measuring photosynthetic capacity and the activity of the major enzymes of photosynthesis.

Similar experiments are planned on other montane grasses to ascertain species-specific responses to elevated concentrations of CO_2. In particular, do CO_2-enriched plants merely grow faster, and therefore become larger over time, or does the actual plant structure itself change? To address these questions, detailed investigations are being made of root and shoot growth at elevated CO_2. Such studies will provide information on whether the ratio of shoot/root growth is affected by plant size or an alteration in assimilate partitioning between root and shoot.

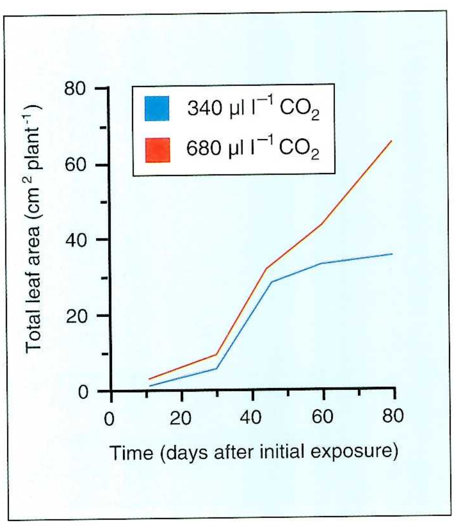

Figure 22. Total leaf area of common bent-grass grown at ambient (340 µl l^{-1}) and elevated (680 µl l^{-1}) concentrations of CO_2. Data represent the mean of seven separate determinations

Once individual species responses are known, competition studies between the major pasture species will be undertaken in pot experiments, artificially sown multi-species swards on natural soils, and in representative turves/cores of intact soil and vegetation removed from the field.

These experimental investigations also form an integral part of a co-ordinated network of measurements made at different locations and under different climatic conditions across NW Europe within the CEC EPOCH programme. Results gathered throughout Europe will be collated to form a major input to a predictive model of the effects of climate change on grassland production, currently being developed by Dr J Thornley at ITE Edinburgh.

R Baxter* and T W Ashenden
(*Post-doctoral Research Fellow at UCNW/ITE Bangor)

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Wetland biogeochemistry and the consequences of global warming

(This work was partly funded by the Welsh Office, Royal Society, and University College of North Wales, Bangor)

Wetlands occur on areas of land which are waterlogged because of high rainfall and poor drainage. They cover a substantial area of Britain and Ireland (about 8.6%) , and are essentially unbalanced ecosystems where the rate of productivity exceeds that of decomposition. As a consequence, the partially decayed plant material accumulates as peat.

The stability of these ecosystems is largely governed by the extent to which they are waterlogged. The waterlogging is caused by the poor solubility of oxygen in the overly abundant water. As a result, anaerobic conditions develop which reduce the efficiency of microbial breakdown of the organic material. There are a number of ways in which man's actions can undermine this stability. The first is by deliberate *direct* intervention, for example by increasing drainage. Two of the many instances of such exploitation are drainage for agriculture and/or afforestation, and the cutting of peat for fuel. The consequences of such direct intervention have received a great deal of media attention in recent years. The main focus has been on the loss of habitat for the many interesting species which are indigenous to wetlands. However, relatively little consideration has been given to how man's activities might indirectly damage wetland ecosystems. Such damage could be induced by, for example, atmospheric deposition or global warming.

It has been suggested that global warming could result in an increase in the number of high-pressure areas (anticyclones) that are experienced in the UK (Meteorological Office 1989). This change could lead to an increased number of droughts because of a weakening of the rain-bearing westerlies which have largely governed our weather conditions. These drier conditions could seriously undermine the stability of wetland ecosystems, by inducing a transition to a more aerobic state.

Among the more obvious consequences of this scenario would be losses of

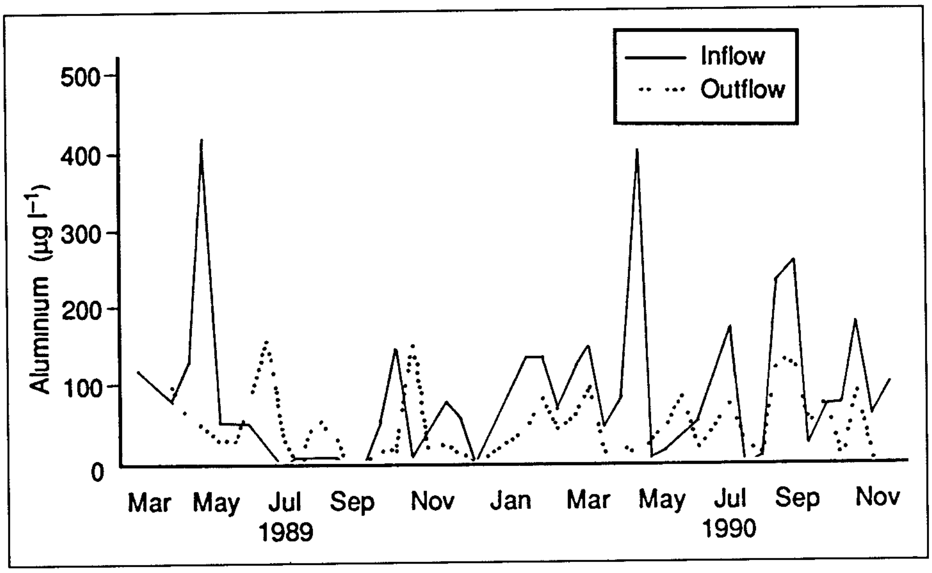

Figure 23 The effect of the central wetland on total monomeric aluminium concentrations in streamwater

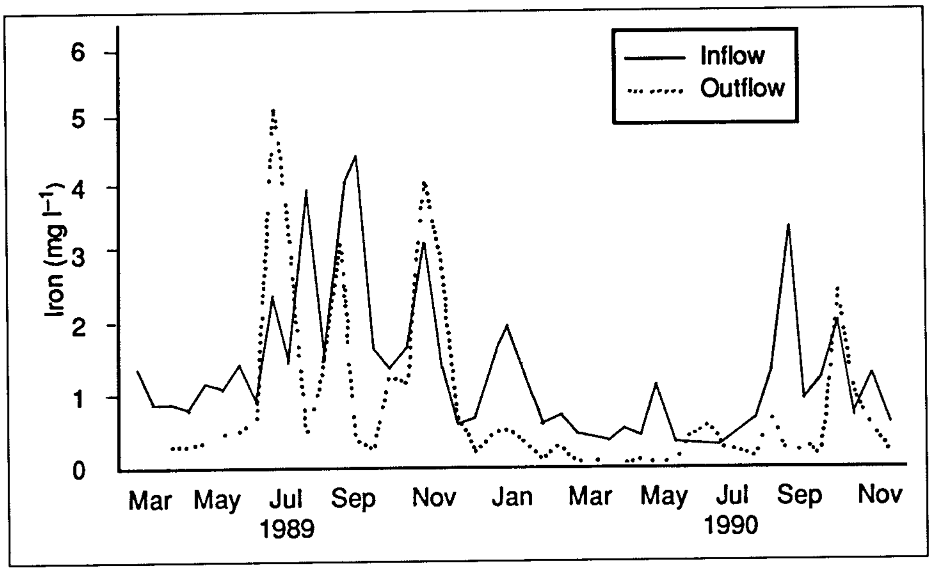

Figure 24 The effect of the central wetland area on iron concentrations in streamwater

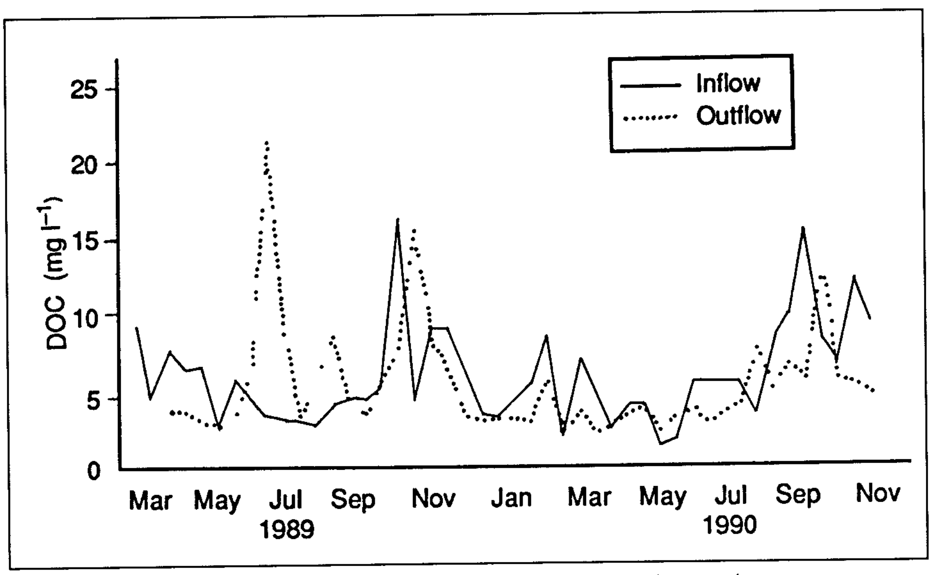

Figure 25 The effect of the central wetland on DOC concentrations in streamwater

wetland habitat similar to those occurring in response to man's direct intervention In addition, however, the proposed climate change could affect our environment beyond the bounds of the wetlands themselves A change to more aerobic conditions will affect the biogeochemical processes which control gaseous emissions and solute leaching from the wetlands For example, increased emissions of greenhouse gases such as nitrous oxide and carbon dioxide will add to the global warming problem However, this effect may be offset, to some extent, by a reduction in methane production

The nature and timing of solute losses from wetlands might also change,creating problems for water treatment As part of a large-scale monitoring programme investigating streamwater quality in a forested catchment in mid-Wales, fortnightly samples have been taken since February 1989 from water flowing into and from a wetland located in a base-rich subcatchment of Llanbrynmair Moor The wetland has no effect on the annual mean concentrations of most major anions and cations (Emmett & Reynolds 1991) Within a year, however, the wetland significantly affects the fluctuations in streamwater solutes of particular interest to water quality managers, eg colour, aluminium, dissolved organic carbon (DOC), and iron

During the summer drought of 1989, elevated concentrations of a range of solutes were recorded, including aluminium, iron and DOC For many solutes, the maximum concentrations of 1989 were recorded in the water flowing from the wetland during this period For example, the maximum concentration of total monomeric aluminium was 160 $\mu g\ l^{-1}$ (Figure 23), of iron 5 $mg\ l^{-1}$ (Figure 24), and of DOC 21 $mg\ l^{-1}$ (Figure 25) These figures compare with means over the two-year period of 49 $\mu g\ l^{-1}$, 0 9 $mg\ l^{-1}$ and 5 4 $mg\ l^{-1}$, respectively

New research currently under way at ITE Bangor (in collaboration with the University of Wales, Bangor, and the Institute of Hydrology) aims to quantify the impact of the possible climate change upon emissions of the greenhouse gases – carbon dioxide, methane and nitrous oxide, and also the leaching of solutes, such as sulphate, nitrate, ammonium, iron and

Plate 12. *Greenhouse gas collection equipment in a peaty flush at Plynlimon, mid-Wales*

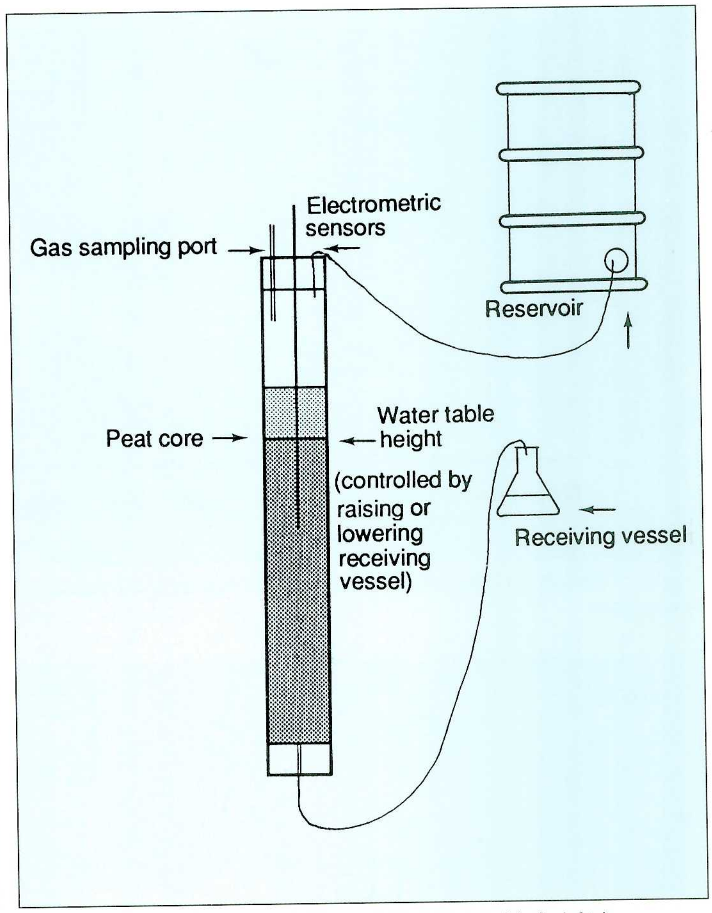

Figure 26. Apparatus for controlling wetland water table height in laboratory studies

manganese. The effects of climate change upon general microbial activity will also be determined by measuring the activities of the electron transport system and of the enzyme which degrades the humic material (phenol oxidase).

The proposed reduction in the wetland water table is to be simulated using two independent, but complementary, approaches.

i. A field-based collaborative study with the Institute of Hydrology, in mid-Wales. Water entering a peaty flush at the Plynlimon experimental catchment is being reduced by diverting it through a system of pipes to a point below the wetland area. The effects will be compared with an undisturbed control flush lying within the immediate vicinity. Plate 12 illustrates gas sampling equipment (foreground) in the manipulated flush, with the control flush visible further up the valley.

ii. A laboratory study, involving the manipulation of peat cores within a constant temperature laboratory, where the water table can be altered in a controlled manner using a newly designed perfusion system (Figure 26). The laboratory-based approach makes it easy to follow chemical changes with depth in the peat profile, and provides a number of features which complement the field operations. For example, the laboratory enables superior control over environmental conditions, and, in addition, the closer proximity of the equipment to the analytical facilities makes feasible a wider range of analyses. The system can be used to 'screen' for those parameters most worthy of study in the more logistically difficult field studies.

Ultimately, the results of this research should greatly enhance our ability to predict the likely impacts of the 'greenhouse effect' upon wetlands.

C Freeman, B A Emmett and B Reynolds

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For further information please contact:

Institute of Terrestrial Ecology (North)
Bush Estate
Penicuik
Midlothian
EH26 0QB

Telephone: (031) 445 4343/6

Institute of Terrestrial Ecology (South)
Monks Wood
Experimental Station
Abbots Ripton
Huntingdon
PE17 2LS

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