1991 — 1992

REPORT

Institute of Terrestrial Ecology

Natural Environment Research Council

The ITE mission

The mission of the Institute of Terrestrial Ecology is to understand the science of the natural environment with particular emphasis on terrestrial ecosystems Priority is placed on developing and applying knowledge in the following areas

- the factors which determine the composition, structure, and processes of terrestrial ecosystems, and the characteristics of individual plant and animal species
- the dynamics of interactions between atmospheric processes, terrestrial ecosystems, soil properties and surface water quality
- the development of a sound scientific basis for modelling and predicting environmental trends arising from natural and man-made change
- the dissemination of this research to decision-makers, particularly those responsible for environmental protection, conservation and the sustainable use of natural resources at national, regional and global levels

The Institute will continue to develop long-term, multidisciplinary research to maintain an international reputation, provide training of the highest quality, and attract commissioned projects By these means, ITE will seek to increase scientific knowledge and skills in terrestrial ecology, and contribute to national prosperity and prestige

Front cover illustration
Hedgerows in the landscape – photographer C J Barr

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Report of the Institute of Terrestrial Ecology 1991–92

Natural Environment Research Council

CONTENTS - Science Reports 1

Forest science

The three reports that follow are taken from a spectrum of research on forests and soils, which is increasingly weighted towards problems in the tropics and the potential impacts of climate change.

The first report, which shows that soil mycorrhizal and saprophytic fungi immobilise radioactive caesium by incorporating it into their fungal hyphae, brings together the expertise at ITE Merlewood on soils, microbes and radionuclides. Other soils work during the year has shown that the conversion of ammonium to nitrate in soils (nitrification) is enhanced when soil temperatures are increased (which happens when forests are thinned or felled), and that this process causes considerable acidification and a release of aluminium, regardless of the pollution climate. This is a new, important aspect of the acidification story. Quite separate studies have shown that nitrogen (N) deposited on forests from the atmosphere seems to get through to the groundwater in greatest amounts when the trees have least demand for nitrogen – when they are young, and when their N demand is met by internal cycling.

The second report quantifies the amount of nutrients contained in *Acacia* trees in Senegal, and the rate of accumulation of N in the soil beneath *Acacia*. This study is one aspect of our work for the Overseas Development Administration on sustainable land use in the tropics. In the Cameroon and Indonesia, we are examining silvicultural methods of converting native rainforest to a sustainable timber-producing forest or agroforest. We find that the conversion process involves risks not only of losing nutrients from the system, but also of upsetting the biotic balance between trees, soil microbes and insect herbivores.

The third report is focused on one particular problem involving an insect herbivore. The existence of the shoot borer, *Hypsipyla*, virtually prevents the exploitation of mahoganies in plantations in the tropics. Our work in Costa Rica has found three-fold family differences in resistance to this pest, indicating the exciting possibility of selecting families and clones that can be commercially exploited, lessening the need to fell mahoganies in the native forests.

One important new area of ITE research in this programme area, which is not represented in this year's Report, is the development of process-based forest models. A team at ITE Edinburgh has developed a number of submodels of the processes of photosynthesis, carbon partitioning, soil processes, etc, which have been assembled into two large models: the **Edinburgh Forest Model**, which couples carbon (C) and nitrogen fluxes, and **Hybrid**, which couples C and water fluxes. These and other models are being used to answer questions concerning carbon sequestration, elevated levels of CO_2, and the effects of N deposition.

The role of fungi in radiocaesium movement in soil

(This work was partly funded by the NERC Special Topic programme on environmental radioactivity)

The Chernobyl nuclear reactor accident in 1986 focused attention on the uptake of radionuclides, particularly radiocaesium, by plants and the transfer of these nuclides to grazing animals and man. Even before the accident, however, there were reports of high radiocaesium activities in the fruiting bodies of fungi, but their potential importance in the role of radiocaesium cycling in the terrestrial environment had not been explored fully.

Following the Chernobyl accident, the radiocaesium content of fruitbodies of two commonly occurring mycorrhizal fungi were determined from a range of sites in upland Britain (Dighton & Horrill 1988). The 2:1 isotopic ratio of ^{137}Cs:^{134}Cs distinguishes Chernobyl fallout from that deposited from nuclear weapons testing in the 1960s. The proportion of the long-lived isotope (^{137}Cs) found in the fruitbodies derived from Chernobyl ranged from 75% to only 8% of the total radiocaesium content (Table 1). The wide range in percentage of radiocaesium from Chernobyl probably relates to local differences in rainfall at the time of the incident. However, the results indicate that certain fungi were able to access and retain radiocaesium derived from other sources, eg nuclear weapons testing, for decades.

Fungal thalli (the hyphal threads extending through the soil) can form long-lived structures which connect parts of the same individual over large distances. Parts of this thallus are able to differentiate to form, for example, fruitbodies (toadstools), and there is movement (translocation) of elements between these connected parts of the

Table 1 Radiocaesium activity in fruitbodies of two mycorrhizal fungi from upland forest sites in Britain (activities decay corrected to 3 May 1986)

Site code	Radiocaesium in fungus (Bq kg^{-1}) ^{134}Cs	^{137}Cs	% ^{137}Cs due to Chernobyl
Lactarius rufus			
Moor House 86	155	3885	8
Moor House 87	530	5511	19
Stonechest	448	3443	26
Spadeadam	1204	7297	33
Spadeadam	582	4243	28
Forest of Bowland	669	1779	75
Inocybe longicystis			
SB	1760	14060	25
S4	735	8737	17

same individual. It is possible, therefore, that the fungi absorb radiocaesium into their hyphae and selectively move it within the thallus, perhaps concentrating it in fruitbodies. Further, fungi may translocate radiocaesium to plants through their close association with plant roots as mycorrhizas. These hypotheses led us to investigate: (i) the ability of fungal hyphae to take up radiocaesium; (ii) the effect of mycorrhizal associations on plant uptake of radiocaesium; and (iii) the possible pathways of internal translocation of radiocaesium within the fungal thalli.

Simple influx experiments were carried out on a range of mycorrhizal and saprotrophic (decomposer) fungal species. The fungi were grown in defined liquid media and offered ^{137}Cs for a limited period. The amount of radiocaesium taken up by the hyphae and its subsequent leaching suggested that some 40% of the radiocaesium presented to the hyphae was retained within the fungal structure (Figure 1) (Clint, Dighton & Rees 1991; Dighton, Clint & Poskitt 1991). Although there was considerable variation between species, it seems that saprotrophic fungi are able to retain more radiocaesium than mycorrhizal fungi (Figure 2).

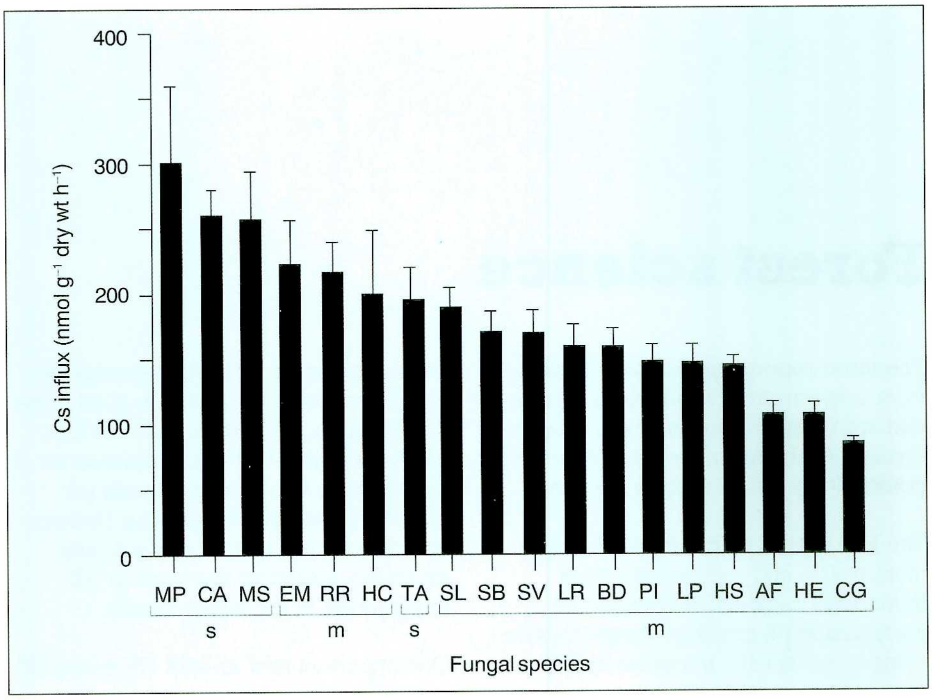

Figure 2. Influx of caesium into fungal biomass. The fungal species (two-letter codes) are grouped according to saprotrophs (s) or mycorrhizal (m) species

When the radiocaesium uptake of common upland fungi is combined with the estimated fungal biomass in upland soils, the results indicate that the whole soil solution content of Cs could be accumulated into fungal tissue. This degree of immobilisation, together with the potential for long-term retention in fungal tissues, indicates that fungi may be very important in regulating radiocaesium movement in soils.

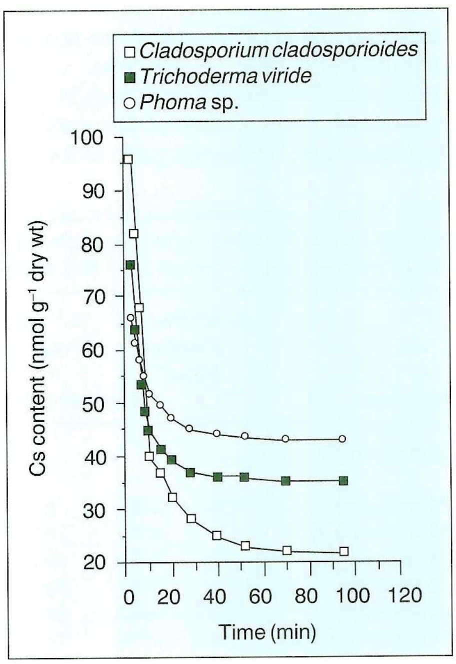

Figure 1. Radiocaesium immobilisation by upland grassland fungi. Leaching of accumulated ^{137}Cs from three fungal species showing that, on average, some 40% of the radiocaesium remains in the fungal structure

It was expected that mycorrhizal associations would enhance the uptake of radiocaesium by plants. However, contrary to the positive effect of mycorrhizas on uptake of nutrients such as phosphorus and nitrogen, the presence of mycorrhizas reduced the total radiocaesium uptake by the heather (*Calluna vulgaris*) plants, compared with the non-mycorrhizal plants (Figure 3). The effect of increasing the concentration of potassium in the external solution caused a greater reduction in Cs uptake in non-mycorrhizal plants than in mycorrhizal plants. Although total uptake was less in mycorrhizal plants, a greater proportion of the Cs taken up was translocated to the shoots than in the non-mycorrhizal plants. Incorporation of radiocaesium into extramatrical fungal tissue would explain the reduced total uptake in mycorrhizal plants, again indicating the potential importance of fungal tissues in Cs immobilisation.

In combination with the University of Liverpool, the internal translocation of radiocaesium within the fungal thallus is being studied. Using modified fermentation systems, quantitative autoradiography and field studies, the effect of fruitbody formation on the directional movement of radiocaesium and the effects of injury on the loss or retranslocation of radiocaesium within the thallus are currently being investigated.

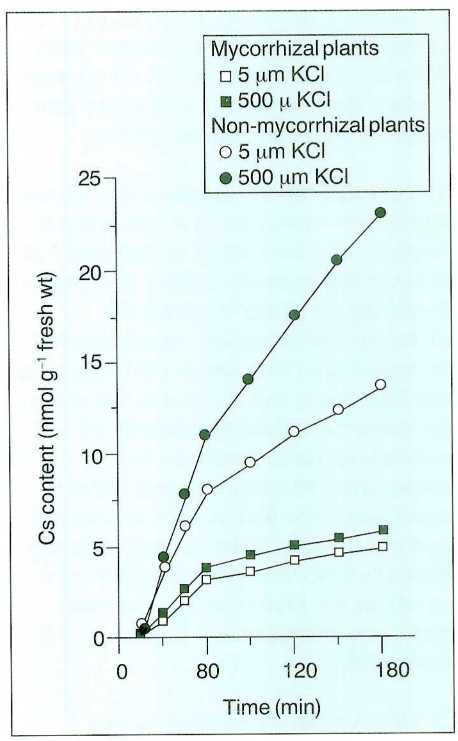

Figure 3. Plot of caesium content against time for young heather plants

As a result of these studies, we hope to have a greater understanding of the role and importance of fungi in the cycling of radiocaesium in soil. Using radiocaesium as an analogue for other elements and radionuclides, the importance of fungi in radioecology is becoming better understood. By establishing experimental protocols for the study of other elements, with appropriate isotope tracers, we should improve our knowledge about the role of fungi in soil nutrient dynamics.

J Dighton and G M Clint

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Plate 1. Sampling for tree and fine root biomass and soil nutrients in a 17-year-old Acacia senegal *stand in northern Senegal*

Soil amelioration by *Acacia senegal* in a Sahelian savannah

(This work was funded by the Overseas Development Administration)

There is an urgent requirement for methods of sustainable agriculture for the economically disadvantaged arid and semi-arid areas of the world, but, with the limited availability of fertilizers, we need to develop and improve low input/ low output systems. The traditional method of land management in many dryland areas is based on a limited period of cropping (3–5 years), followed by a longer period (up to 25 years), during which the land is planted with trees but otherwise left fallow. During this latter period, the annual cycle of litterfall returns nutrients and organic matter to the upper soil layers. Because the tree roots exploit deeper soil layers than crop roots, the plant nutrients deposited at the surface are derived at least in part from soil zones not normally available to crops. In the arid lands, nitrogen-fixing tree species abound, and are typically utilised in the traditional tree fallow system. Thus, the nitrogen content of the soil is built up partly from atmospheric nitrogen. Even where this system of land management continues to be practised, increasing population pressure and the demand for resources have extended the period of cropping at the expense of the time spent under tree fallows. In consequence, the land is being stripped of plant nutrients and yields of both crops and woody products are declining.

The overall objective of this study is to quantify soil amelioration under *Acacia* tree fallows and the subsequent decline in soil fertility under a cropping regime. With this information, a mathematical model is being constructed to describe the nutrient budget. The model will permit the optimisation of rotation lengths under both cycles, enabling maximisation of yield. It is hoped that a satisfactory model can be constructed, based on a few simple driving variables; this model should be 'portable', at least within the Sahel and probably more widely in semi-arid lands.

As part of a major Sahelian reafforestation programme, the German Agency for Technical Cooperation (GTZ: Deutsche Gesellschaft für Technische Zusammenarbeit) has established large plantations of the nitrogen-fixing tree *Acacia senegal* in the pastoral zone of the Ferlo valley in northern Senegal (Plate 1). The first tree planting took place in 1975 and has been extended annually since then. Consequently, there is a well-documented chronosequence of 'tree fallows' in this area which provides an opportunity to monitor both tree growth and soil amelioration. The sandy soil of the Ferlo has a low organic matter content and is typical of edaphic conditions across the Sahel.

This study began in June 1991, and involves staff of the Senegalese Forest Research Institute, Institut Senegalais de Recherches Agricoles, Direction des Recherches sur les Productions Forestières (ISRA/DRPF), the French ORSTOM (Institut Français de Recherche Scientifique pour le Développement en Coopération) research group at Dakar, and the local Directorate of GTZ based in St Louis in northern Senegal. Field work began in November–December 1991.

The first period of field work concentrated on describing biomass and nutrient accumulation in the trees within the age range 3–17 years. Soil nutrient and organic matter content were also examined within the same plantations. The data obtained from destructive harvests of the trees have been used to generate an overall growth curve, both for the trees and their individual components of biomass. Although the trees examined were in separate age classes, tree dry biomass could be

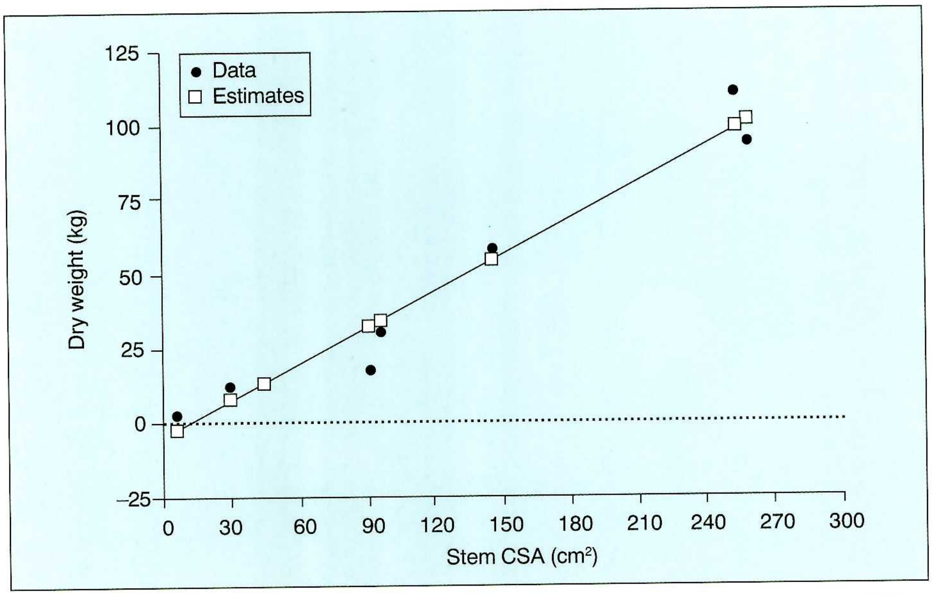

Figure 4. Relationship between above-ground dry weight (kg) and stem cross-sectional area (CSA) (cm^2) at 30 cm height for Acacia senegal *trees growing in northern Senegal*

predicted by a linear regression of biomass on stem cross-sectional area (Figure 4). That this biomass curve is linear to age 17 is probably attributable to the fact that the trees were planted at wide (at least 7 m) spacing and have not yet achieved canopy closure.

Root biomass is excluded from the above data, but information concerning amounts of both fine and coarse roots is being collected.

Analysis of the concentrations of nitrogen, phosphorus and potassium held in the separate components of biomass permit the effect of biomass removal on the site nutrient budgets to be assessed (Table 2). Removal frequently happens when the trees are felled/harvested at the end of the tree fallow period, the larger pieces of wood being removed either for firewood/ charcoal production or for small construction projects.

At age 17, each tree contained about 1 kg nitrogen (N), 40 g phosphorus (P) and 430 g potassium (K). Approximately 40% of the N and P and 46% of the K were contained in woody tissues thicker than 2 cm diameter, and would be lost from the site as a result of fuelwood harvesting. While the N could probably be replaced by nitrogen fixation, the P and K exported in this manner would represent a permanent loss of nutrients.

Table 2. Mean amounts of N, P and K (g) held in the tissues of 17-year-old Acacia senegal *trees growing in northern Senegal*

	Stems and branches >5 cm diameter	Branches 2–5 cm diameter	Twigs 1–2 cm diameter	Twigs <1 cm diameter	Leaves	Fruit
Nitrogen	238	146	127	205	217	47
Phosphorus	9.4	6.7	6.3	8.8	6.0	2.9
Potassium	137	60	54	97	49	34

Table 3. Percentages of N, P and soil organic matter (SOM) in soil at four locations between the stems of adjacent 17-year-old Acacia senegal *trees growing in northern Senegal*

	Stem zone	Mid-canopy	Canopy edge	Mid-way between trees
% N	0.018	0.013	0.011	0.010
% P	0.005	0.004	0.004	0.004
% SOM	1.07	0.97	1.00	0.94

For soil organic matter and all plant nutrients examined in the soil, amounts were greatest in the zone adjacent to tree stems. These values declined systematically as distances from tree stems increased (Table 3), clearly demonstrating the capacity of *Acacia* trees to ameliorate soils.

Using the nitrogen content of adjacent unplanted land as an arbitrary guide to soil fertility pre-planting, initial estimates indicate that the soil in the top 1 m of the 3-year-old plantation had accumulated about 15 kg N ha^{-1}. By age 17, the corresponding figure had increased to about 140 kg N ha^{-1}. These estimates will be refined as more data become available.

Future work will concentrate on achieving the objective of setting the time dynamics for N, P and K fluxes in *Acacia* plantations up to 20 years old. The work will require estimating the soil nutrient status at a larger range of tree ages, considering inputs of nutrients from the atmosphere, in litter both above and below ground, and the leaching of nutrients from the soil layer under examination. Amounts of N fixed by root nodules will also be estimated, and the productivity of crops and the export of nutrients in agricultural products will be assessed.

A recent review of desertification by the United Nations Environment Programme in 1992 indicates that 28% (224 million ha) of the total area of the Sahel is suffering from some form of soil degradation. These results from northern Senegal will contribute to our understanding of the processes of soil degradation and amelioration in Senegal and across the Sahel.

Important contributions to the project have been made by Dr O Diagne (ISRA, Dakar) and M Dione (ISRA, Dahra).

J D Deans and D K Lindley

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Selecting for resistance to the mahogany shoot borer

(This work was funded by the Overseas Development Administration)

Although mahogany (*Swietenia macrophylla*) is one of the most valuable tropical timbers known to man, virtually all of the wood currently sold on world markets is obtained from natural forests. Very few successful plantations have been established, especially in regions where mahoganies are native, primarily because mahoganies are susceptible to attacks by shoot-boring insects (*Hypsipyla* spp.) (Plate 2). These insects have devastated thousands of hectares of mahogany plantations throughout the tropics, and consequently the mahogany shoot borer is one of the best-known insect pests of any tropical forest tree.

Damage is caused by the larvae of the moth; they bore into the apical part of the stem, destroying the terminal shoot and bud, and causing forking or deformation of the trunk. This damage rarely kills the tree, but, as the length of straight bole is shortened, the economic value of the timber is severely reduced. Young trees are particularly susceptible to damage by shoot borers, and may be attacked within the first year of growth.

Although a considerable research effort has been devoted to this pest, no practical control measures have been developed successfully to date (Grijpma 1976). The moth reproduces rapidly, with up to six generations per year, and is able to disperse over many kilometres in search of host plants. Chemical control methods tend to be uneconomic, as repeated applications of insecticide are often necessary. Although slow-release systemic insecticides may provide a degree of protection to young trees, this approach has generally proved ineffective in most circumstances. A programme of biological control has been attempted in Trinidad, involving the release of hyperparasitoids and predatory wasps, but this has also proved ineffective so far.

Plate 2. The withered terminal shoot of a young mahogany tree killed by the activity of the larvae of the shoot borer Hypsipyla grandella. *The new shoots beginning to resprout may eventually form a forked tree of no commercial value*

An alternative approach to controlling the shoot borer is currently being developed by ITE Edinburgh, in collaboration with research groups at the Centro Agronomic Tropical de Investigacion y Ensenanza (CATIE) and the International Institute of Biological Control (IIBC), Trinidata (Newton 1990). The basis of the approach is to test whether resistance to the pest exists in natural mahogany populations, and then to incorporate any resistant material identified in a genetic improvement programme. This identification is achieved by screening a range of plant material, collected from different geographical origins, in a series of field trials. These trials have been designed to permit an analysis of the genetic basis of any resistance traits observed. If resistant genotypes are identified, then these may be cloned using the low-technology vegetative propagation techniques which have been developed by ITE over the past 18 years.

Initial results from the trials so far established have been highly encouraging. Within the first eight months of growth, different provenances and open-pollinated (half-sib) families of Spanish cedar (*Cedrela odorata*) have displayed significant variation in their susceptibility to shoot borer attack (Figure 5). This is the first time that such variation has been recorded, and it may reflect genetic variation in the production of either those chemicals which attract the moths to the plants, or those which are toxic to the larvae, such as some phenolic compounds. Interestingly, those families (or groups of related seedlings) which have been least attacked by shoot borers have also tended to be the fastest growing. Some individual trees have reached over 6 m in height within their first year.

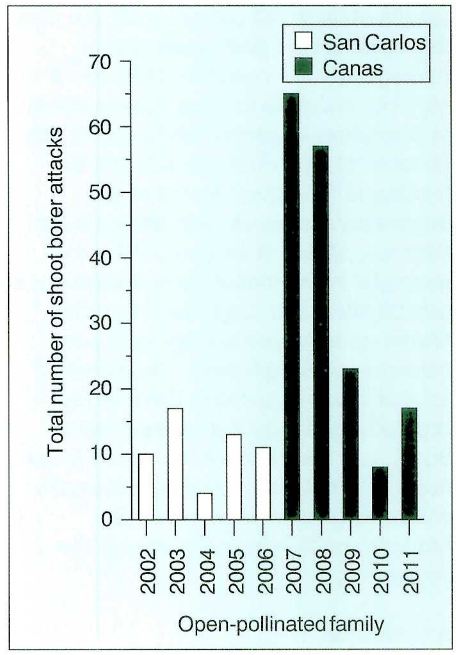

Figure 5. The variation in susceptibility to shoot borer attack displayed by ten families from two provenances of Spanish cedar in a field trial in Turrialba, Costa Rica. Assessments of attack were made every two weeks over the first 24 weeks after establishment, by counting each individual attack locus. A more detailed set of analyses of the whole trial (25 families) is presented by Newton et al. *(1992)*

Other patterns of resistance have also been observed in the field trials. Some trees are apparently able to recover after attack, by vigorous growth of the apical shoot. A few months after the destruction of the terminal shoot, the recovery has been so complete in some cases that the trees appear never to have been damaged. The ability to tolerate pest attack in this way may also be under some degree of genetic control. Previous work on Spanish cedar has identified particular provenances native to Colombia and Venezuela which are characterised by vigorous apical growth (Chaplin 1980). As part of the current project, we are investigating the genetic variation in apical dominance in Spanish cedar by decapitating young plants artificially, as a form of simulated pest damage. Using this technique, it may be possible to screen seedlings at the nursery stage for their innate ability to recover from attack.

Additional field data are required to verify the genetic basis of the patterns of resistance observed. However, the results obtained to date support the idea that selection for pest resistance in mahoganies is a realistic objective It may be desirable to plant such material in silvicultural systems which lessen the chances of pest outbreak still further, leading to the development of an integrated system of pest management (Newton, Mesen & Leakey 1992) For example, when mahoganies are grown in combination with crop plants or other timber species, some degree of pest control is often obtained The potential for this kind of approach has already created a great deal of interest within South and Central America, and it is our hope that, in future, planting mahogany will become a practical option for farmers and foresters throughout the region

A C Newton

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Land use, agriculture and the environment

Issues of **scale** are particularly important when considering land use at all but the most trivial and local levels. Consequently, this TFS programme reports on studies which focus on the upper part of the range of scales which are covered by terrestrial ecology. At the largest scale, the satellite mapping of Great Britain has perfected a product which will set a baseline for vegetational mapping of Britain's land cover, and hence a means of assessing and evaluating land use change. Thus, an invaluable starting point will be established for scientific research, a wide range of applications, and as an aid in formulating policy.

Fragmentation of natural habitat is the inevitable consequence of intensive and varied land use, and is particularly characteristic of landscapes in north-western Europe. The inter-relationship of habitat patches is an important consideration in landscape ecology. The study on birds in woodland fragments of East Anglia has focused on the turnover of species and is one of the first of its kind. The loss of hedges in Britain since the last war is well known. An important reassessment of more recent changes has emphasised the importance of the management of surrounding land in determining the ecological characteristics of hedgerows, particularly the diversity of the ground flora. Hedgerow management itself appears to be less important. Insect diversity in farm woodlands has been confirmed to increase with greater diversity of both tree and ground flora species and with the prevalence of dead wood.

Ecological impact assessments are the 'bread-and-butter' of many workers on land use change and its effects. These are exemplified by work described on assessing the effects of a water abstraction scheme proposed for the floodplains of the lower Spey. Such studies represent the small-scale work of the programme, just as the land cover represents its larger-scale aspects.

Satellite mapping of Great Britain

(This work was funded by the British National Space Centre and the Department of the Environment)

Taking stock is vital to the sensible management of any resource. In the intensively managed landscape of Great Britain, it is particularly important to evaluate and balance the conflicting needs of many potential land uses. This demand is ever-increasing as we are forced to think at regional, national and even global scales in assessing environmental impacts and managing their consequences.

Yet the land cover of Britain has not been fully mapped since school children undertook the exercise in the early 1960s. Their output took the form of paper maps, so analysis was a laborious manual task. Relating land cover to other information such as soils, topography, human population or pollution was of limited feasibility. However, the recent growth in computer-based geographical information systems (GIS) now allows us to build sophisticated landscape evaluation procedures into the planning process. Clearly, up-to-date land cover information is vital if the results are to be meaningful.

Earth observations from satellites now provide data which can map the complex patterns of the British landscape. The data come in digital form, so automated classification of land cover is possible; moreover, the output is compatible with sophisticated GIS analyses.

ITE's early experimental approach to satellite mapping (Fuller *et al.* 1989; Jones & Wyatt 1989) developed methods to derive land cover information at a field-by-field scale. The methods have now been transferred to operation at the national scale (Fuller, Jones & Wyatt 1989). With financial assistance from the Department of Trade and Industry and the Department of the Environment, ITE is compiling a digital map of land cover across all of Britain. This map, together

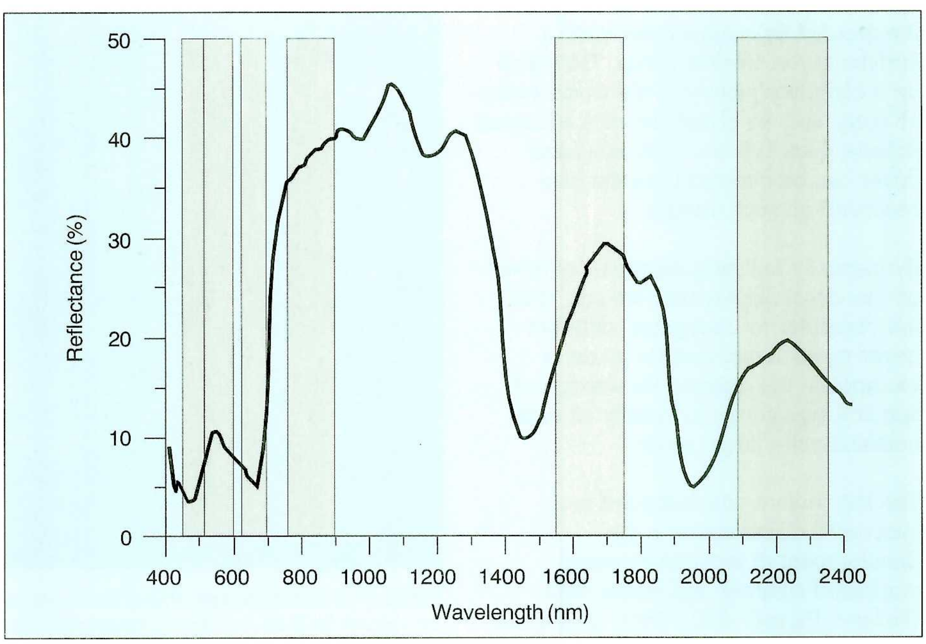

Figure 6. Landsat's Thematic Mapper wavebands (shaded) superimposed on a spectral profile of reflectances by vegetation

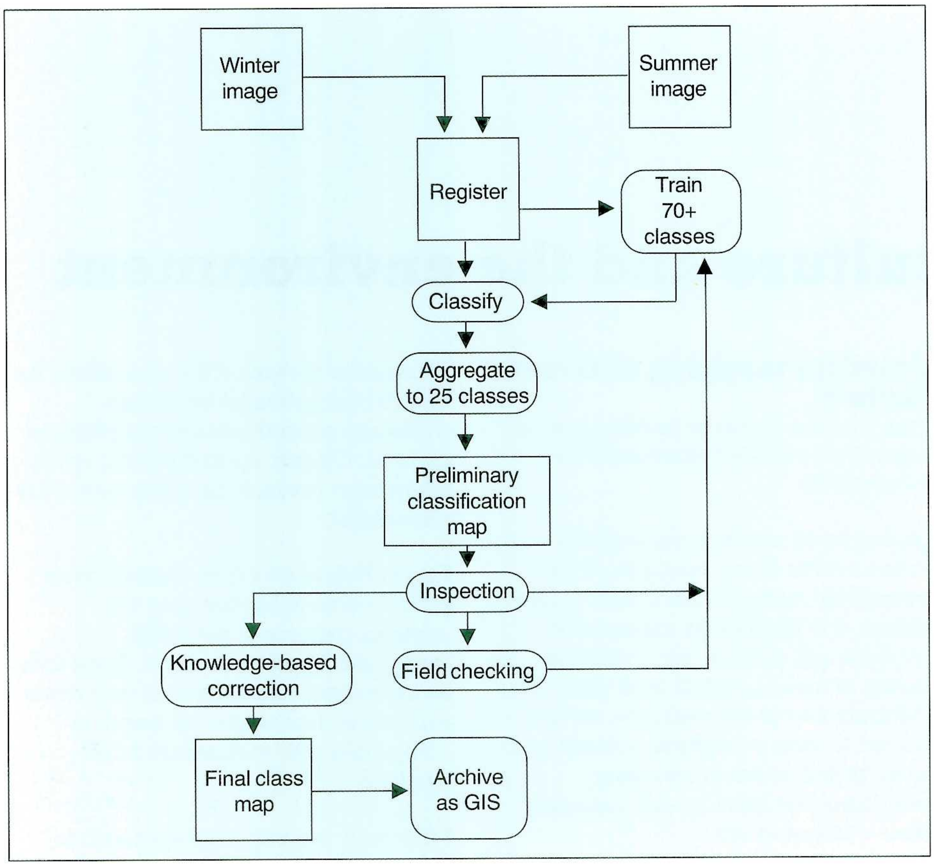

Figure 7. An outline of the methods used in mapping the land cover of Great Britain from satellite images

with data from a sample-based field survey of Britain, forms a project called Countryside Survey 1990.

The Landsat Thematic Mapper (TM) sensor records the reflected solar radiation in seven wavebands of the spectrum (Figure 6), from 30 m cells on the ground. By scanning the earth's surface as the satellite orbits, TM builds up a complete picture of the world every 16 days, and we obtain the data as digital scenes, each 185 km x 185 km. Land cover can be inferred from the data recorded on such images.

By manually outlining examples of cover, on the visual display unit, we can 'train' the computer to 'recognise' different cover types. It can then be made to extrapolate the derived knowledge of spectral signatures, to identify all cells containing the target cover.

The key feature which has led to a successful classification is the development of techniques using combined summer and winter data (Fuller & Parsell 1990). Thus, we exploit seasonal differences in vegetation to improve the accuracy of the semi-automated mapping procedures. We can distinguish urban areas, which are bare all year round, from arable crops with a cycle of cover and bare ground, from semi-natural vegetation, present all year: we also improve distinctions between deciduous and evergreen types of woodland and herbaceous vegetation. The results, so often disappointing if using single-date images, have thus been raised to levels which are acceptable to most potential end-users. A range of specially developed 'knowledge-based' procedures draw on contextual information to help correct any discrepancies which remain. A coastline mask guarantees that maritime and terrestrial communities are satisfactorily separated. A process of selective filtering removes other discrepancies, eg where arable areas are found in the urban environment. Generalised masks of uplands and lowlands allow us to distinguish more accurately between moorland and heathland.

The procedures outlined in Figure 7 are being used to map 25 cover classes, with a minimum mappable area of 1 ha.

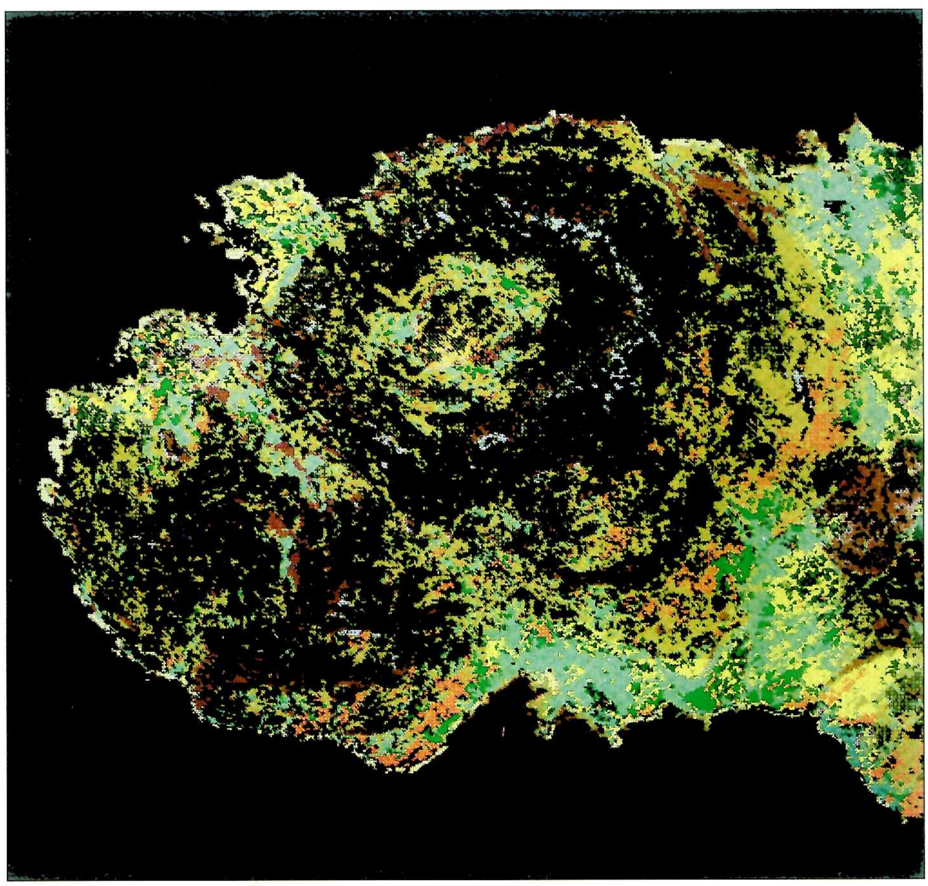

Figure 8. A 12.5 km square area of land cover map at Ardnamurchan Point, western Scotland. The map shows the bare rock (grey) forming the rim of a long-extinct volcano, with concentric patterns of moorland grass (tan) and mixed grass/dwarf shrub communities (dark green) on the hillsides within and outside the crater (source: Remote Sensing Applications Development Unit)

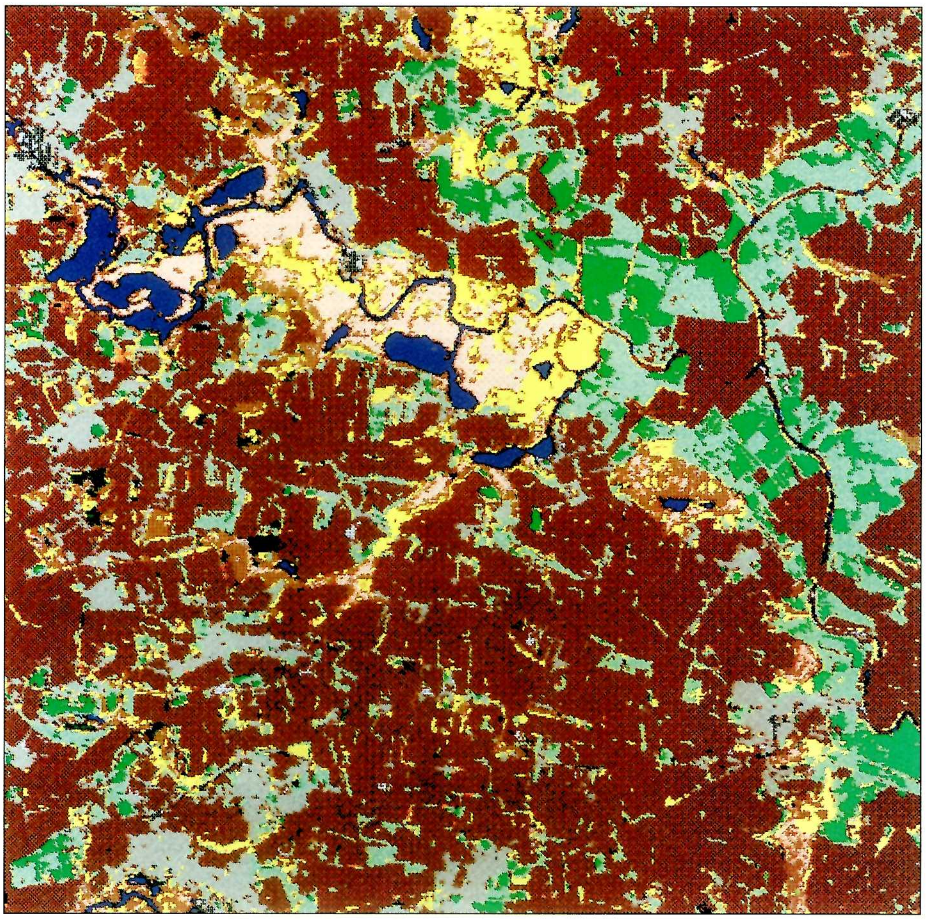

Figure 9. A 12.5 km square area of land cover map showing the River Bure from Horning to Acle. The map shows the wet carr woodlands (pink) and managed reed beds (yellow) of the upper Bure and Ant, with grazing marshes (green), set in a landscape of predominantly arable farmland (dark brown) (source: Remote Sensing Applications Development Unit)

Figures 8 and 9 give contrasting examples of two areas at full resolution. Figure 8 shows the crater of the long-extinct volcano at Ardnamurchan Point in western Scotland, with its rim of bare ground, and concentric patterns of moorland grass and heather communities. Figure 9 shows the River Bure, in the Norfolk Broads, with its reed fens, wet carr woodlands and grazing marshes, set in a landscape of arable farmland.

The main output product is a digital data base which records the dominant land cover in each 25 m cell of the British National Grid. The final data base will occupy about one gigabyte of computer disk, allowing magnetic or optical storage as feasible options to provide immediate access to data for anywhere in Britain. Alternatively, summaries at the 1 km square level will comfortably fit on to floppy disk for handling in microcomputers.

A field survey in 1990 is used to validate the data. Samples were selected from a stratification of the 250 000 squares in Britain: the strata were based on a statistical evaluation of topographic and thematic map data (Bunce & Heal 1984). The field records included details on soils, plant species and their cover, boundaries, land use and management (Barr 1990).

The two surveys in combination have strengths that neither can offer in isolation (Figure 10). The sample survey can be used to estimate detailed information for any other combination of 1 km squares in Britain, but such estimates can vary with local factors. The satellite data can provide information for any particular area, but with limited detail. However, used in combination, the satellite maps can show actual patterns of grasslands, and the field survey can estimate the proportion which is semi-natural. The satellite map can show total arable land, and the field data can give specific crop estimates. The estimated density of oak (*Quercus* spp.) trees in an area can be improved with a knowledge of the extent of deciduous woodlands. Such estimates can be made at full 25 metre resolution. Additionally, the 1 km summary of the land cover map, together with the stratification of 1 km squares and the field-based estimates, will form the basis

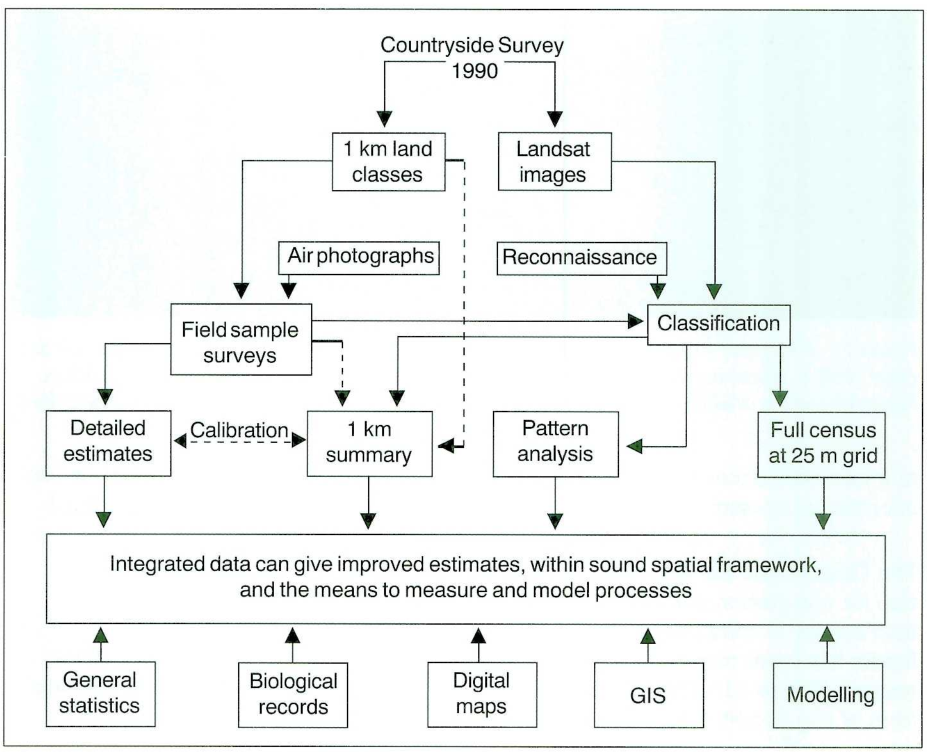

Figure 10. The integration of a sample-based field survey with a full map of land cover for Great Britain in ITE's Countryside Survey 1990 project

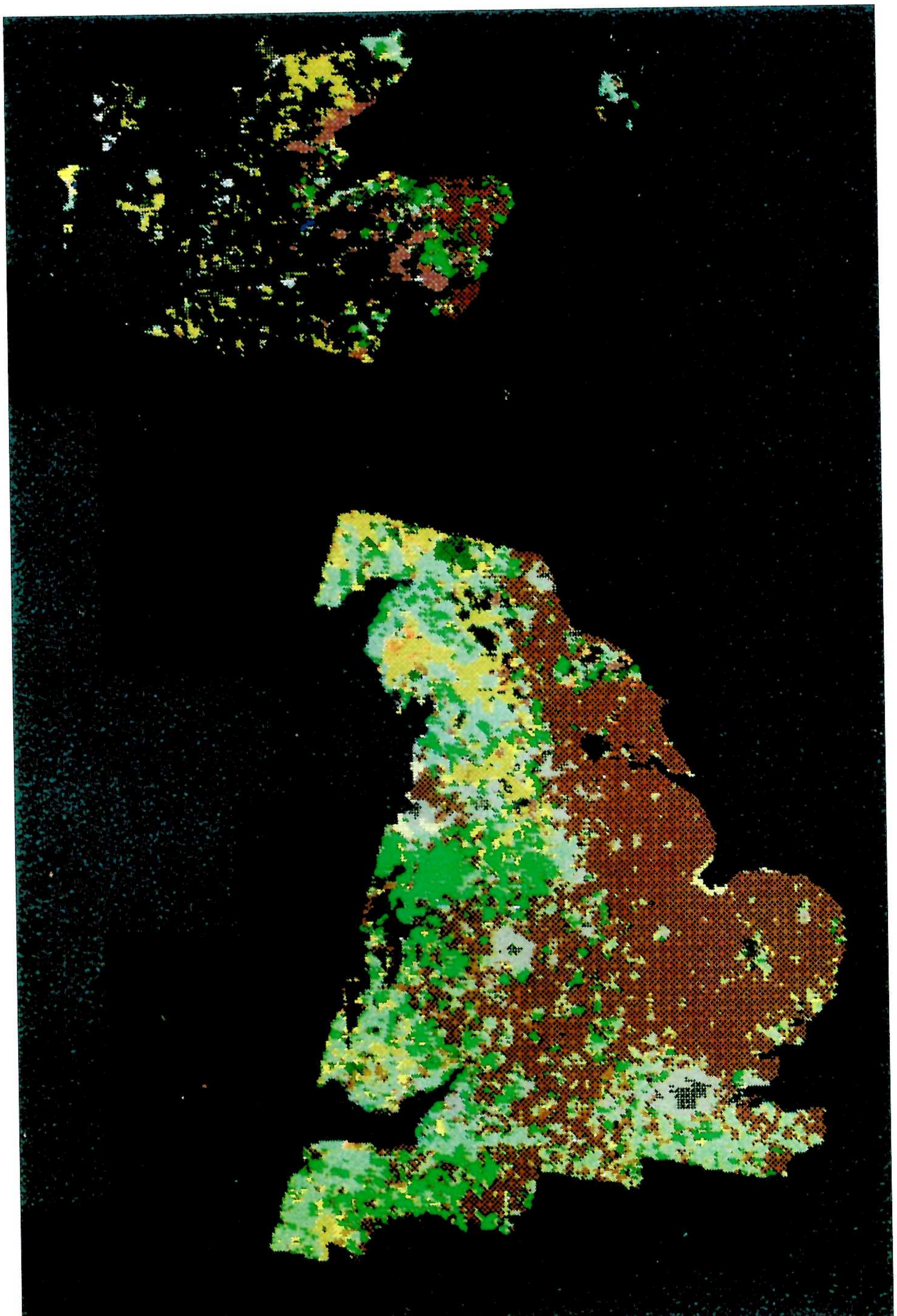

Figure 11. A reduced and much-simplified map of the land cover of Britain, showing progress to date (May 1992) in classifying the cover of all of Great Britain from satellite images. The detail shown in Figures 8 and 9 is available for all this area (source: Remote Sensing Applications Development Unit)

of a microcomputer-based countryside information system.

The Countryside Survey 1990 project is due for completion in mid-1993. The field survey is complete, and 80% of Britain has been mapped from satellite images (Figure 11). The outputs, in the form of maps, both paper and digital, environmental data bases, and integrated GIS have many uses, of which examples include:

- studying species distributions and movements in relation to habitat patterns
- relating species variety to landscape diversity
- detecting, measuring and explaining changing land cover
- predicting environmental impacts of developments
- modelling land use in relation to water quality
- examining 'critical loads' of pollutants and their impacts on landscape and land cover
- estimating carbon budgets for modelling the greenhouse effect

The present study focuses on mainland Britain. However, the Commission of the European Communities is developing land cover maps for all of the Member States under its CORINE (Co-ordinated Environmental Information in the European Community) programme. The land cover information is produced with a much coarser resolution, using a minimum classifiable area of 25 ha. The cover classes are also generalised, though information on land use is added, eg defining airports or recreation areas. The standardised procedure in Europe has so far used visual interpretation of photographic copies of Landsat images. Conversion back to a digital format requires the manual digitising of all polygon outlines. Thus, the process is labour-intensive with a greater element of subjectivity. Experiments have already demonstrated the potential for converting ITE's high-resolution cover maps into the generalised CORINE product, using largely automated methods. The procedure will be quick and therefore relatively inexpensive, and will make revisions more efficient. The impact of generalisations will be better understood. Furthermore, we will be able to place the detailed cover of Britain into the generalised European context. Just as experimental work produced operational techniques for automated mapping within Britain, so it is hoped that current experimental procedures for automated CORINE mapping might become operational in the near future.

In a landscape which is constantly changing, it is necessary to know the quantity and distribution of existing land resources, to assess changes which occur, and to understand how ecology, people and environment interact. With such information we can predict and thereby manage changes for the good of all. The digital land cover map forms the most fundamental of raw material for all such evaluations. For the first time ever, Britain has such a digital land cover map, available to those concerned with managing land use. What is more, the development of an automated methodology makes such mapping easily repeatable, so that the information can be readily updated, and suitable for extension to other areas of the world. This development sets the scene for environmental management long into the future.

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Plate 3. Aerial photograph of East Anglia (courtesy of J L Mason)

Habitat fragmentation, landscape ecology and birds

Much of Britain's wildlife is confined to small patches of semi-natural habitat set in a highly modified, and predominantly agricultural, landscape. The fragmentation of natural habitats is most pronounced in lowland agricultural areas, of which the fenland of East Anglia is an extreme example. For the plant and animal populations of the fragments, the intervening landscape may be of little or no value for their maintenance and survival. Indeed, for many species, the agricultural land may be hostile or act as an impediment to dispersal. However, populations of the fragments of semi-natural habitat do not function in isolation, either from each other or from the surrounding land types. The consequences of habitat fragmentation must therefore be addressed at the landscape scale. This is the aim of the emerging discipline of 'landscape ecology': to investigate the effects and processes of land use mosaics on the distribution, abundance and diversity of wildlife (Balent & Courtiade 1992).

The land cover map of Britain, compiled from remotely sensed Landsat data by the Environmental Information Centre (EIC) at ITE Monks Wood, provides land use information at a landscape (and countrywide) scale, with field patterns mapped on a 30 m grid. Thus, habitat fragments of specified types can be readily identified, counted and measured. Their spatial distribution in the landscape, in relation to each other and to other habitats and land uses, can be analysed and related to information about wildlife populations. Such information can be collected in the field or may already be held in existing data bases, such as that of the Biological Records Centre (BRC) at Monks Wood. Changes in land use and in the distribution and abundance of certain habitat types between years can also be monitored.

East Anglia has the lowest density of woodland fragments in lowland Britain (Plate 3) and is therefore an ideal region in which to study the effects of habitat fragmentation on wildlife populations. Birds comprise one of the most widespread and generally conspicuous groups of woodland species (with high powers of dispersal), and thus are excellent subjects for study. Many woodland songbirds are also short-lived, so changes in species composition and abundance can be measured over relatively small timescales. In a study of bird populations of farm woods in East Anglia, species numbers and composition have been recorded annually in 164 woods ranging in size from 0.05 ha to 30 ha (Figure 12). This enables us to examine how the species numbers change from wood to wood and from year to year in relation to the various characteristics of each wood (including area, perimeter, shape, degree of isolation, habitat structure and surrounding land use).

In 1990 and 1991, woodland area accounted for a large proportion (75%) of the variation in breeding bird species numbers, with more species in the larger woods. This relationship did not differ significantly between the two years. The rate of increase in species numbers was greatest in woodland areas up to about 2 ha (Figure 13). Stepwise multiple regression analysis showed that the length of hedgerow within 0.5 km made the next most significant contribution to the variation in breeding species numbers (4%), but that it was nowhere near as important as woodland area. Some other characteristics of the woodlands and of the surrounding land use also made positive contributions, but these were all very small (<1%). The influences of various measures of wood isolation (including distance to nearest

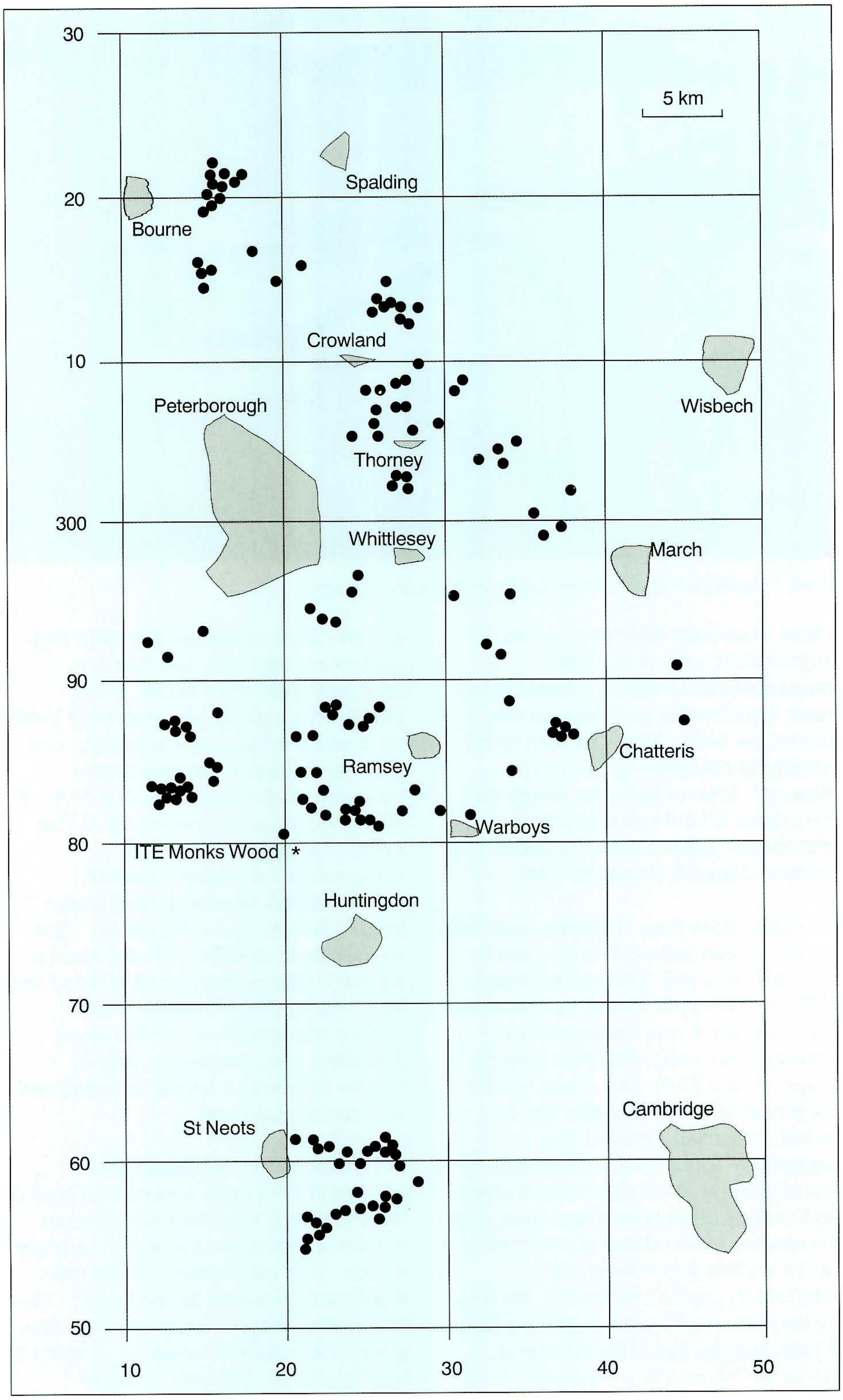

Figure 12. Map showing locations of study woods (black dots)

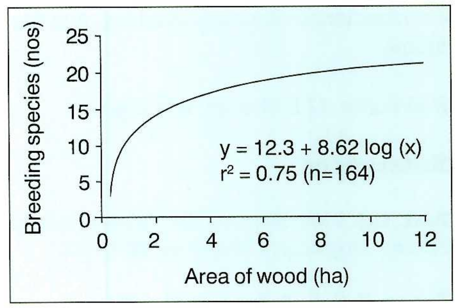

Figure 13. Relationship between number of breeding bird species and area of wood (1990)

wood, area of woodland within 0.5 km and 1.0 km, and the distance to the nearest centre of human habitation) are currently under investigation. However, we do not anticipate that the effects of isolation on the woodland bird fauna will be very large.

Area was also the key factor in determining the changes in species composition between the breeding seasons of the two years. Local species extinctions and colonisations were more common in small woods than in large ones. For example, wrens (*Troglodytes troglodytes*) disappeared from 36% of the woods of less than 2 ha, but from only 18% of the woods of 2 ha or larger. Changes in species composition – in which both extinctions and colonisations are accounted for – can be expressed as relative turnover rate (RTR) (Wiens 1989). The RTR of breeding species between 1990 and 1991 was much higher for small woods and increased most rapidly as woodland area decreased below about 2 ha (Figure 14).

Consideration of Figures 13 and 14 shows that small woods contain fewer breeding species, and that their populations are less stable than those of larger woods. Thus, as habitat fragments get smaller, the likelihood of local species extinctions increases. Once a species has disappeared from any one wood, recolonisation depends on the arrival of immigrants from other woods. This factor, in turn, depends on the availability of surplus individuals to act as colonists and on their dispersive abilities. When populations are small and the distances between woods are large, recolonisation may not occur and local extinctions can then accumulate and spread, leading to the loss of species from large areas.

The effects of fragmentation must also be considered for individual species. Different species have different habitat requirements and responses to woodland isolation (Opdam, Rijsdijk & Hustings 1985). Great spotted

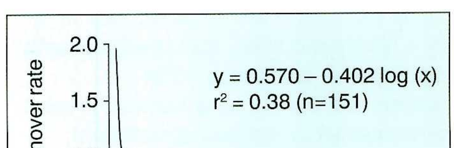

Figure 14. Relationship between relative turnover rate of breeding bird species and area of wood (1990–91)

woodpeckers (*Dendrocopos major*) readily cross gaps between woods and utilise groups of quite small fragments of woodland Marsh tits (*Parus palustris*) and long-tailed tits (*Aegithalos caudatus*) may be more restricted by their reluctance to cross open ground For the wren, the number of breeding pairs was found to increase linearly with woodland area, but no such relationship was apparent for the marsh tit, with its more specialised habitat requirements The effects of woodland area, isolation and other characteristics on individual species are currently being analysed

To investigate the role of dispersal in maintaining populations in very small woods, we are measuring the replacement rate of individuals In one breeding season, all the adult breeders of certain species in 16 small woods (mean area=1 51±0 27 ha) have been marked (colour ringed) and also, where possible, their young In the next breeding season, new emigrants can be identified (they are either unringed or have been marked with the colour code of a different wood), as can the local adults and young from the previous year Between 1990 and 1991, the replacement rate of adult breeders was high and local species extinctions occurred in many of the woods (Table 4) The large majority of replacements were immigrants Of 113 home-grown juveniles, only one (a wren) bred on its natal site in 1991 This indicates that immigration is essential for the persistence of bird populations in small woods However, without knowing the fate of the juveniles produced in these woods, we cannot say that they are acting as population sinks (ie sites which 'soak up' surplus individuals from elsewhere without contributing a surplus of their own) It may be that groups of small sites simply exchange juveniles To address this problem, birds have been marked in groups of small woods but, as yet, there is little evidence of substantial movements between these woods Juveniles may be dispersing further afield and only additional information will confirm this possibility

Although the study is still in progress, the results obtained so far have a number of implications for the management of small woodlands When creating new small woods (and when large woods are being reduced in size or broken into fragments), planting the largest possible area up to about 2 ha will give the greatest gains per additional unit of area in both breeding species numbers and population stability Planting such woods in groups will effectively create a larger woodland for those species willing and able to cross the gaps between them Movement of less mobile species can be facilitated using smaller woodland or scrub patches (which are also valuable bird habitat in their own right) as stepping stones between the larger woods Species/area relationships such as those discussed above provide information about bird species numbers but say nothing about which particular species may or may not be present Thus, individual species' requirements must also be taken into consideration in management decisions The high turnover of bird populations in small woods, especially those of less than 2 ha, means that a reservoir of larger woods must also be maintained in order to obtain stability and sustainability at a landscape scale Additional data will be required to determine the long-term viability of the populations of networks of small woods, and to establish the optimum ratio of large to small woods

Table 4 Replacement rates of adult breeders and local species extinctions in small woods (mean area=0 51± 0 27 ha, n=16) in East Anglia

Species	No of breeders ringed in 1990	% of 1990 breeders present in 1991	No of ringing sites at which species breeding in 1990	% of 1990 ringing sites at which species breeding in 1991
Wren (*Troglodytes troglodytes*)	52	4	16	50
Robin (*Erithacus rubecula*)	37	8	14	79
Chaffinch (*Fringilla coelebs*)	20	15	11	91
Dunnock (*Prunella modularis*)	57	23	16	75
Blackbird (*Turdus merula*)	31	26	15	73
Great tit (*Parus major*)	18	33	10	80
Blue tit (*Parus caeruleus*)	26	38	14	93

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Hedgerow changes in Great Britain

(This work was partly funded by the Department of the Environment and by the former Nature Conservancy Council)

Hedgerows are among the most important landscape features and wildlife habitats in Britain Their loss has been of concern to conservationists and countryside users for many years, but recent incentives and policies have resulted in changes in hedgerow management and in some planting of hedges, especially in the arable areas of East Anglia and the Midlands Has the balance been redressed, and what are the effects of current land use and management on hedgerow diversity?

In 1977–78 and in 1984, ITE carried out sample-based surveys of land use, landscape features and vegetation in Great Britain (Barr *et al* 1986) The sampling unit was a 1 km square and the survey approach was based on the ITE land classification, designed to ensure that a representative sample of sites was visited The surveys included the mapping of hedges as a field boundary type, and the 1977–78 survey recorded vegetation quadrats alongside linear features, including hedgerows.

Information collected on hedgerows in the 1977–78 and 1984 surveys allowed estimates of gains and losses to be derived for Great Britain and for major regions within it, as described by Barr *et al.* (1986) and summarised as follows:

	Hedgerow gain	Hedgerow loss
England	3 200 km	22 300 km
Scotland	<100 km	3 300 km
Wales	400 km	2 600 km
Great Britain	3 600 km	28 200 km

In 1990, as part of a wider research programme, Countryside Survey 1990 was completed, the third in the series of field surveys (Barr 1990). Over 500 1 km squares in Great Britain were visited by staff based at the six ITE research stations, and, as part of the field survey, hedgerows were mapped in the same way as in the 1984 survey. In addition, vegetation quadrats alongside hedgerows were recorded as in 1977–78. This field information will be integrated with the land cover map of Great Britain, being produced from satellite imagery by ITE's Environmental Information Centre (described earlier in this Report, pp15–19).

Changes in the lengths and characteristics of hedgerows

Comparisons of boundaries containing a hedge component show that the net change between 1984 and 1990 amounts to nearly one quarter of the length of 1984 boundaries which contained hedges (Table 5).

However, net change is a balance of gains and losses: hedges have been planted as well as removed. In addition, some boundaries have changed in their nature and appearance, leading to increases and decreases in boundaries that can be defined as hedgerows. For example, lines of immature trees that have been thinned out and then laid as hedges will lead to an increase in the estimate of hedgerow length. Conversely, where a former hedge has been unmanaged over a number of years, it will grow into a line of trees (a relict hedge) (Plate 4).

Plate 4. Many hedges have grown into lines of trees, through lack of management

Other examples of change in boundary type include where a hedge has become 'gappy' and has been recorded as a line of shrubs, and no longer as a hedge, and, conversely, where vegetation growing on the top of a bank has been cut in such a way that a hedge is formed. Such changes are given in Table 6, which also shows the lengths of hedgerow that have been lost to the countryside by the development of buildings (both urban and agricultural). Included are hedges that have become 'curtilage' boundaries and are no longer defined as hedges for the purpose of this study. In some cases, where there has been a change in land use, some boundaries have been redefined as part of the countryside and so have led to a hedgerow gain.

Table 5. Estimates of net change in hedgerow lengths in Great Britain, England, Scotland and Wales between 1984 and 1990 (lengths and standard errors (±) in '000 km)

	England	Scotland	Wales	Great Britain
Total hedge length in 1984	410.5 (±25.1)	67.6 (±8.8)	71.1 (±8.4)	549.0 (±32.7)
Total hedge length in 1990	325.2 (±21.5)	49.6 (±7.0)	53.3 (±6.8)	428.0 (±28.3)
Net change between 1984 and 1990	85.3 (±8.5)	18.0 (±3.0)	17.8 (±3.3)	121.0 (±11.6)

Boundaries that were recorded as hedges for the first time in 1990 (other than those resulting from change in boundary type) totalled 26 400 km. The complete removal of hedgerows between the two dates amounted to 52 200 km, or 9.5% of the total hedgerow length in 1984.

Close inspection of the results shows that most change is associated with the management of hedgerows. About 111 500 km, or 20% of the 1984 hedgerows in Great Britain, were coded in 1990 as a different type of boundary (eg lines of trees or shrubs, or as relict hedgerows). Conversely, only some 25 000 km of 'new' hedges in 1990 came from the redefinition of boundary types. This suggests that hedgerows were subject to less active management in 1990 than in 1984. In Great Britain as a whole, the distribution between height and management classes of the lengths of boundary containing hedges remained similar between the two dates. However, when considering 'gappiness', the lengths of incomplete hedges have increased between 1984 and 1990.

Lines of relict hedges (defined as 'a line of shrubs or trees showing where a hedge has once been') were estimated

Table 6 Estimates of hedgerow gains and losses in Great Britain, England, Scotland and Wales between 1984 and 1990 (lengths and standard errors (±) in '000 km)

	England	Scotland	Wales	Great Britain
1990 hedges gained				
New hedges	19.7 (±2.0)	3.3 (±0.5)	3.4 (±0.6)	26.4 (±2.5)
Change in boundary type	18.5 (±2.3)	3.2 (±0.7)	3.3 (±0.6)	25.0 (±2.9)
Buildings/curtilages	1.4 (±0.3)	0.2 (±0.1)	0.3 (±0.1)	1.9 (±0.4)
Total gain	39.6 (±3.3)	6.7 (±1.0)	7.0 (±1.1)	53.3 (±4.3)
1984 hedges lost				
Hedges removed	39.4 (±3.5)	6.1 (±0.9)	6.7 (±1.1)	52.2 (±4.5)
Change in boundary type	77.8 (±7.4)	17.2 (±2.7)	16.6 (±2.8)	111.5 (±10.1)
Buildings/curtilages	7.3 (±1.2)	1.4 (±0.4)	1.4 (±0.5)	10.1 (±1.7)
Total loss	124.8 (±8.6)	24.7 (±3.4)	24.8 (±3.5)	174.3 (±12.0)

independently from the hedgerow data, for 1984 and 1990. Many former hedgerows were redefined as lines of trees and shrubs in the 1990 survey. The figures in Table 7 support the contention that a relaxation of hedgerow management has led to a decrease in hedgerow length and a corresponding increase in lines of trees and shrubs.

An overall conclusion from the comparison of 1984 and 1990 data is that the rate of hedgerow removal between 1984 and 1990 is greater than in the period 1978–84. In addition, there has been a decline in the intensity of hedgerow management between 1984 and 1990, leading to an increase in the boundary type defined as relict hedgerow.

While the results of this analysis provide the most up-to-date figures available on

Table 7 Estimates of lengths of 'lines of relict hedgerow' in Great Britain, England, Scotland and Wales for 1984 and 1990 (lengths and standard errors)

	England	Scotland	Wales	Great Britain
1984	36.0 (±4.3)	7.3 (±1.5)	10.3 (±2.6)	53.5 (±6.3)
1990	63.1 (±6.3)	12.1 (±2.5)	15.2 (±3.6)	90.3 (±9.5)

recent hedgerow changes, caution should be used in their interpretation. These results are based on a sample-based survey and due regard should be paid to statistical errors associated with extrapolation from a sample to national estimates. ITE is analysing the results from a quality assurance exercise which will give a measure of the confidence that can be placed in the results from the survey, and which will comment on observer consistency and problems of definition.

Diversity in British hedgerows

As an integral part of the ITE field surveys in 1977–78 and 1990, vegetation was recorded in a variety of habitats and land cover types, in order to provide information on the quality of hedgerow habitats, as well as quantitative measures. A stratified sample of 322 1 m x 10 m plots was surveyed adjacent to hedgerows in 1978, these were from 256 squares stratified according to the 32 ITE land classes. These plots were surveyed again in 1990, but some were misplaced and 63 no longer had hedgerows present. As a result of sampling in other 1 km squares, additional plots were recorded for the first time in 1990, leading to a total of 1176 plots.

Data from all 1176 hedgerow plots were analysed using TWINSPAN to produce two classifications of hedges – one by woody species and the other by herbaceous (ground flora) species. In each case, simple keys were produced which require only limited botanical expertise to allocate further hedge plots to the TWINSPAN classes.

Resulting from the classification by woody species, 11 classes were identified.

Description	% frequency
1 Hawthorn (*Crataegus* spp.) dominant	46.9
2 Blackthorn (*Prunus spinosa*) predominant	23.0
3 Hazel (*Corylus avellana*) predominant	13.3
4 Mixed hawthorn	5.2
5 Elm (*Ulmus* spp.) dominant	4.2
6 Elder (*Sambucus nigra*)/ hawthorn	3.4
7 Beech (*Fagus sylvatica*) dominant	1.6
8 Non-native species dominant	0.8
9 Gorse (*Ulex europaeus*) dominant	0.7
10 Wild privet (*Ligustrum vulgare*) present	0.4
11 Other species dominant	0.5

An examination of the frequency of these classes in 1977–78 and 1990 showed that the overall proportions of the 11 groups had remained constant, although there was considerable movement of individual plots between classes.

The hazel dominant and mixed hawthorn classes were richer in woody species, averaging 4.4 and 3.6 woody species per 10 m plot respectively. The hazel dominant class was also richest in associated ground flora species (15.3 species per plot). In contrast, the commonest class of hedge, hawthorn dominant, had only 2.0 woody species per 10 m plot, with the associated herbaceous species count averaging 12.8 per plot.

Of the hedge classes which were richest in woody species, mixed hawthorn hedges were particularly abundant in the Midlands and East Anglia (having ground flora characteristic of cultivated fields), whereas hazel hedges were centred on south-west England (having a ground flora of meadow and woodland species). Of the plots that were not recorded in

Plate 5. Composition of hedgerow ground flora may be determined by adjacent land use rather than hedgerow management

1990 because the associated hedge had been removed since 1977–78, 31% had been classified in the species-rich mixed hawthorn type and 27% were in the elm dominant class. These data suggest that hedgerows removed between 1977–78 and 1990 included many which were species rich, and therefore of high ecological value.

The herbaceous flora was also analysed and aggregated into four principal groups, representing arable, lowland grassland, marginal upland, and upland situations. These groups showed strong geographical patterns in species diversity. The most diverse types were in lowland grasslands and marginal uplands, in contrast to those of the eastern lowlands where the vegetation was dominated by species typical of disturbed and arable situations.

The hedge flora would seem, therefore, to be highly affected by the management of the surrounding fields (Plate 5). A preliminary examination of the data has shown a correlation between intensity of land use and overall species diversity (woody plus herbaceous species), with managed grasslands being associated with the greatest hedgerow diversity and agricultural crops with species-poor hedges.

Contrary to expectation, it was found that current hedgerow management (measured in terms of cutting regimes, height and gappiness) had little correlation with the diversity of either the herbaceous or woody vegetation in the hedges. Likewise, there was limited correlation between the overall number of woody species and the diversity of the ground flora.

In addition, between 1978 and 1990, there was an overall loss of species throughout the sample, and more species declined in cover than increased, with a trend towards species typical of more highly mangaged land use. There was also a trend in the overall vegetation composition towards species which are characteristic of higher nutrient levels, associated with agricultural intensification, and an increase in the number of species groups containing ruderal plants, characteristic of disturbed and highly managed land use.

Examination of survey data, therefore, indicates that diversity in the ground flora of hedgerows is generally associated with the characteristics of neighbouring land use, rather than with hedgerow management. This association may be due to the relatively transient nature of stages within the hedgerow management cycle (measured in the survey at only one point in time), as compared with the relative longevity of plant communities. In contrast, a fundamental change in the management of surrounding land use (eg with associated changes in fertilizer application, or herbicide rates) may have a rapid effect.

The mapped survey information suggests that hedgerow management has declined. Even though detailed analysis of hedgerow diversity shows no obvious relationship between management and diversity at any point in time, it seems likely that continued reduction in hedgerow management over a long period would lead to changes in the ground flora. Certainly it is well known that hedgerow management is important to more mobile species, such as insects and birds. We expect to follow up these aspects using more intensive, and experimental, studies.

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Insect diversity and farm woodland pattern

(This work was funded by the Forestry Research Coordination Committee (FRCC) as part of the NERC Special Topic programme in farm forestry)

Fragmented woodland

Fragmentation was a feature of forests before man became a predominant influence. Semi-permanent open spaces were created by the dynamic interaction of treefall gaps, beaver (*Castor fiber*) meadows and grazing areas with the processes of regeneration. Permanent open spaces in the woodland cover were provided along river valleys, lakes, wetlands, cliffs and areas of poor soil (Warren & Key 1991). Insect species evolved to utilise one or more of these mosaics. For instance, saproxylic larvae exploited dead wood in woodlands, whilst adults gained energy and protein for dispersal and reproduction from nectar and pollen sources in the open areas. Towards the industrial revolution, man's influence grew and total forest cover declined. However, coppicing and pollarding of native tree species partly replicated the natural balance of tree cover and open space in the fragmented woodlands, although numbers of insects which had adapted to middle and old growth declined because of the reduction in the volume of dead wood. From 200 years ago, the shift towards high forest, in which alien species replaced native species, reduced the habitats available to insects that required early and late successional stages. Major losses of insect species occurred during that period, most intensely in the last 50 years (Warren & Key 1991). Furthermore, threatened woodland insects showed limited powers of dispersal within fragmented patterns of woodlands, and evidence suggests that isolated races evolve reduced powers of dispersal (Dempster 1991).

Farm woodland

The area of broadleaf woodland in lowland Britain could increase into the 21st century and reverse the fragmentation of woodland observed over the last 200 years (Watkins 1991). This project focused on arboreal insect populations, and studies at ITE Monks Wood have investigated other wildlife (Hooper & Hill 1991) which could benefit from an expansion of farm woodlands if they comprise mixtures of native broadleaf tree species, managed to promote the particular habitat features of natural woodlands. However, the viability of these insect populations may depend on changes to the pattern of woodland fragments, in addition to the overall change in woodland density. The aim of the current investigation was to identify the factors that limited the activity of arboreal insect populations in an established pattern of farm woodlands. The findings will provide insight into the effects of changes to the fragmented pattern of woodlands on the viability of insect populations, essential components of natural biodiversity in the landscape.

The field investigation

Excluding the effects of geographical range, tree species and age on arboreal insect species, an observational study was made of populations on a single tree species of similar age in a system of farm woodlands in Midlothian, Scotland. Measures of insect species and abundance were compared with the structure and situation of the individual trees (sample unit) within each woodland and the structure and situation of the woodland in the farm landscape. Questions were focused on the mechanisms that limit the distribution of arboreal insects by restricting the study to the insect fauna of beech (*Fagus sylvatica*). The introduction of beech into the region as policy woodlands and shelterbelts between 1650 and 1840 (Brown 1953) removed the confounding influence of historical abundance and distribution of insect species before extensive woodland fragmentation.

Methodology

To date, trees have been sampled by insecticide fogging, physical 'knockdown' linked with leaf search, and leaf collection in late summer. Knockdown samples have been sorted, and the abundance of 12 insect species specific to beech have been compared between 45 trees in 15 woodlands and beech in nine hedgerows.

Classification of the woodlands

Cluster analysis was used to classify samples taken by knockdown in 1991 into groups ranging from high to low insect species number and abundance. The resemblance functions of the analysis were used to define three clusters, and measurements for each habitat factor were grouped according to the clusters. Differences for each factor were tested with analysis of variance combined with a multiple range test to separate categories when the result was significant. All three trees in eight out of 15 woods and all nine hedge samples were undivided within specific clusters. Hedgerow samples were clustered in the medium category, along with 18 trees. Eight factors varied significantly ($P<0.01$) between the good, medium and poor sites for insect species richness and abundance (Figure 15).

Leaf-dwelling species

Leaf-mining and gall-forming insects were counted on collected leaves. The relative densities of the micromoths, *Stigmella tityrella*, *S. hemargyrella* (Nepticulidae), *Phyllonorycter messaniella*

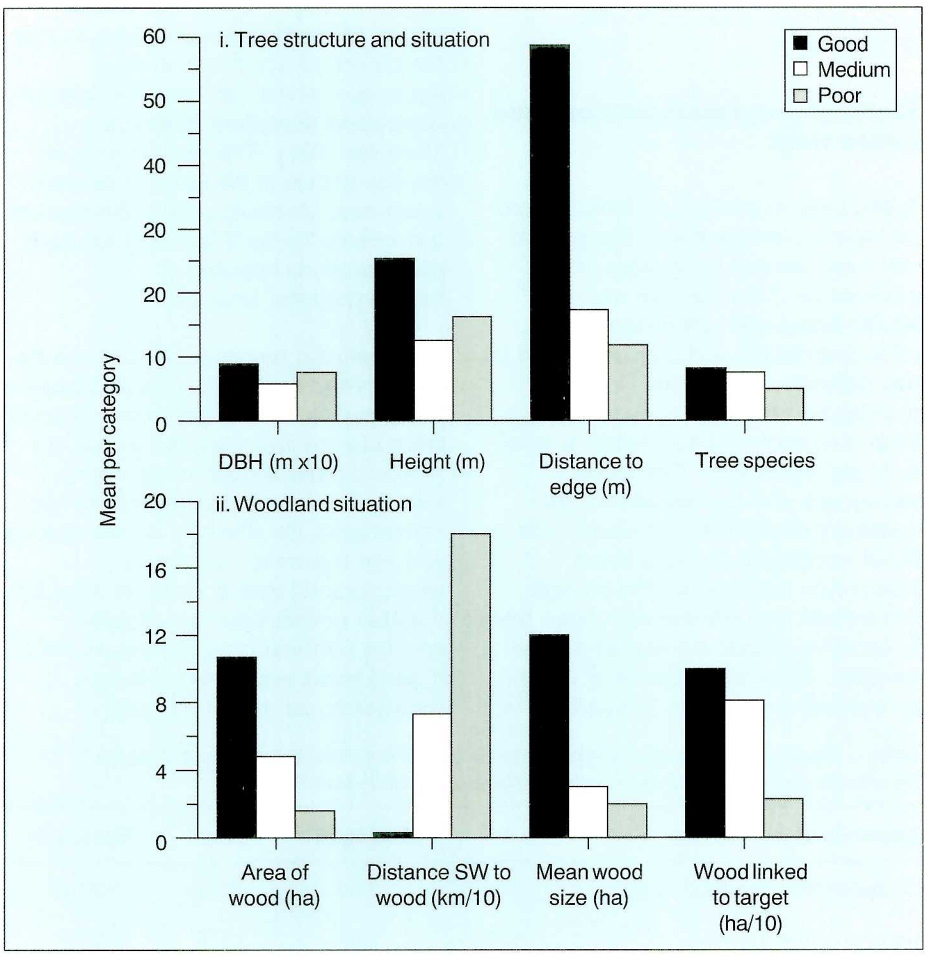

Figure 15. A comparison of measurements of (i) tree structure and situation, and (ii) woodland situation, clustered according to the abundance of 12 species of insect specific to beech on each tree. There were significant differences (P<0.01) between the clusters for all the parameters indicated

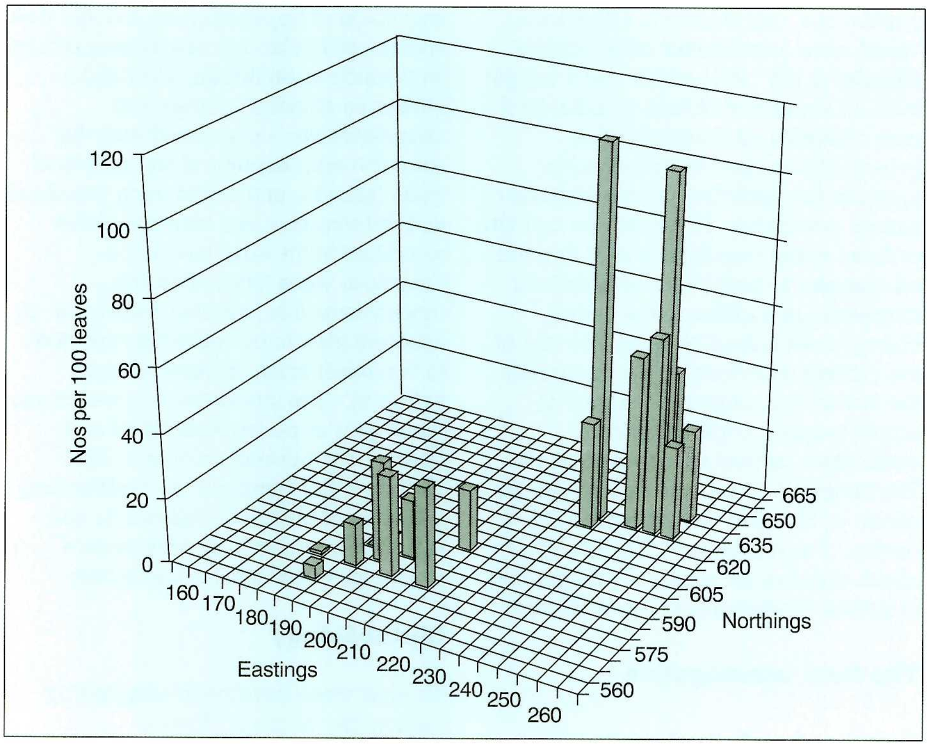

Figure 16. Spatial distribution of the combined densities of gall midges of Cecidomyiidae and micromoths of Nepticulidae and Gracillariidae on beech leaves in woodlands in Midlothian, Scotland

and *P. maestingella* (Gracillariidae), and the gall midge, *Hartigiola annulipes* (Cecidomyiidae), were generally lower in the south-west compared with the north-east parts of the study area (Figure 16). Three woodland factors accounted for 68% of the variation in the combined abundance of those species in a stepwise multiple regression (Table 8). The similar pattern of abundance shown by those species could be a product of their intimate association with beech leaves. However, no pattern was detected in the abundance of mines of the beech weevil (*Rhynchaenus fagi*) in the same woodlands.

The role of beech hedges

The abundance of leaf-dwelling species was similar on beech leaves collected from hedges and the average from trees in all the woodlands sampled (Table 9). The successful development of larvae in leaf mines and galls suggests the use of hedgerows as linear habitats as opposed to movement corridors. Therefore, the hedgerow network must be considered an integral part of the woodland pattern. The field boundaries associated with the woods in the south-west which supported fewer micromoth and gall midge populations were typically dry stone walls, compared with beech/ hawthorn (*Crataegus monogyna*) hedges characteristic of the better sites in the north-east part of the study area (Figure 16).

Findings, recommendations and future work

Beech trees in smaller, secluded woods had fewer insect species. The pattern was most marked for species of micromoths (Gracillariidae and Nepticulidae) and gall midges (Cecidomyiidae), and may be caused by two different mechanisms. Insect populations on beech in woodlands <2 ha in area may not be as viable as those in larger woodlands. Therefore, immigrants may be essential for the continuity of populations through time. Small woodlands, far from larger woodlands, may not receive enough immigrants, but, alternatively, more trees in small woodlands are exposed to the weather. Work in the final year of the project will test whether immigration or constraints imposed by the woodland structure on feeding, reproduction and winter survival restrict the distribution of insect species of particular life history strategies.

Tree structure and the composition of the ground flora may interact to influence the distribution of leaf litter, particularly in exposed farm woodlands. The loss of leaf litter from the wood could affect the survival of larvae in gall midges or micromoths during winter, or could reduce successful host location by emerging adults in spring. This hypothesis would account for the differences observed in the distribution of the beech weevil, which overwinters as an adult, and the other species (Figure 16), which overwinter as larvae associated with the leaf litter. A poor ground flora is supported under the shade of beech, which could create the conditions for leaf and, therefore, insect species loss. However, the same guilds of insects on other tree species could be affected in woods that were grazed to create a similar draughty woodland structure (Capel 1988). The overall impact of the wind could be reduced by the pattern of woodlands in the landscape, which can lower the surface windspeed (Saunders, Hobbs & Margules 1991). This may account for the importance of the factor of distance south-west (prevailing wind direction) to a woodland >2 ha (Table 8), a measure of exposure as opposed to biogeographical isolation.

Some general recommendations can be made based on these results and those of other studies. If a variety of tree species were planted and managed so that old standard trees already present were tolerated and natural regeneration was encouraged, the diversity of tree species and age classes in a particular geographical location would account for a higher potential number of insect species (derived from Southwood 1961). If dead wood was tolerated in the woodlands, the saproxylic guild of

Table 8. Woodland parameters which relate to the distribution of micromoth and gall midge abundance ($\log_{10}(n+1)$) on beech in farm woodlands of Midlothian, Scotland

Stepwise variable selection	*b*	Mean square	*F* ratio	Significance
Distance SW to woodland >2 ha	–0.36	5.92	57.02	<0.001
Number of tree species	0.08	1.62	15.59	<0.001
Mean distance to nearest ten beech	0.01	0.42	4.02	=0.05

Analysis of variance to test the fit of the data to the model: b=0.58; F_{35}=25.54; P<0.001; R^2=0.68

Table 9 Comparison of abundance of arboreal insect species between beech in woodlands and hedges (significant difference between means derived from a t-test (P<0.05)). Chalcidoidea are parasitoid wasps associated with the indicated host*

Characteristic species	Mean mines/galls/100 leaves Woodlands	Hedges
Rhynchaenus fagi	36.5	14.7*
Rhynchaenus–Chalcidoidea	0.2	0.2
Phyllonorycter maestingella	6.3	10.0
Phyllonorycter–Chalcidoidea	0.1	1.7
Stigmella tityrella	0.9	3.3
Hartigiola annulipes	0.5	0.7

insects could contribute to the potential list. The actual number of insect populations in a woodland will depend, at the woodland scale, on the quality of the habitat structure and microclimate. The large-scale pattern of the woodlands could determine the likelihood of new woodlands being colonised by the potential range of insect species capable of dispersal from existing woodlands. The proximity of a new woodland to an established woodland comprising the same tree species could encourage immigration or reduce the exposure of the woodland to the weather. For the latter reason, a diverse ground flora should be encouraged and grazing avoided, factors which would encourage wider natural biodiversity in farm woodlands (Capel 1988).

P Dennis

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Ecological impact assessment of a novel water abstraction scheme

(This work was funded by Grampian Regional Council)

The demand for water in Grampian Region is expected to increase steadily over the next few decades. However, some of the existing supplies will soon not be able to meet new European Commission standards for quality without substantial further treatment. In the case of smaller water schemes, such treatment is unlikely to be cost effective. One possible solution would be to tap a relatively high-quality source that would need little further treatment: water from the river Spey. The method of abstraction proposed would be to pump water from a series of wells sunk in the gravel floodplain of the lower Spey, south of Forres. A large-scale scheme of this type has not previously been attempted in Britain, but would have a number of advantages, including relatively small and inconspicuous headworks, and pre-abstraction filtering of the water by the gravel. The preparation of an ecological assessment of the impacts of the scheme concluded a series of technical and feasibility studies by Grampian Regional Council, undertaken in order obtain a Water Abstraction Order. It was also necessary to ensure that the ecological implications of the scheme had been adequately considered. The study was undertaken by a team from ITE Banchory, and the Institute of Freshwater Ecology (IFE) at Edinburgh and Barnard Castle.

Approach

First, the development proposals were listed (Figure 17). In some developments it is feasible to consider alternatives to the development proposals, but there were no obvious alternatives (apart from no development) in the present case. The next stage was the identification of issues and concerns about the development. This involved consultation with statutory and voluntary agencies, private individuals and objectors to the scheme.

Before an analysis of possible impacts could be undertaken, it was necessary to inventory the ecological resources of the proposed site, and adjacent ground. In order to include adequate control areas, a corridor of land was assessed extending both upstream and downstream of the development: 12 km in length and 1–3 km wide. Existing

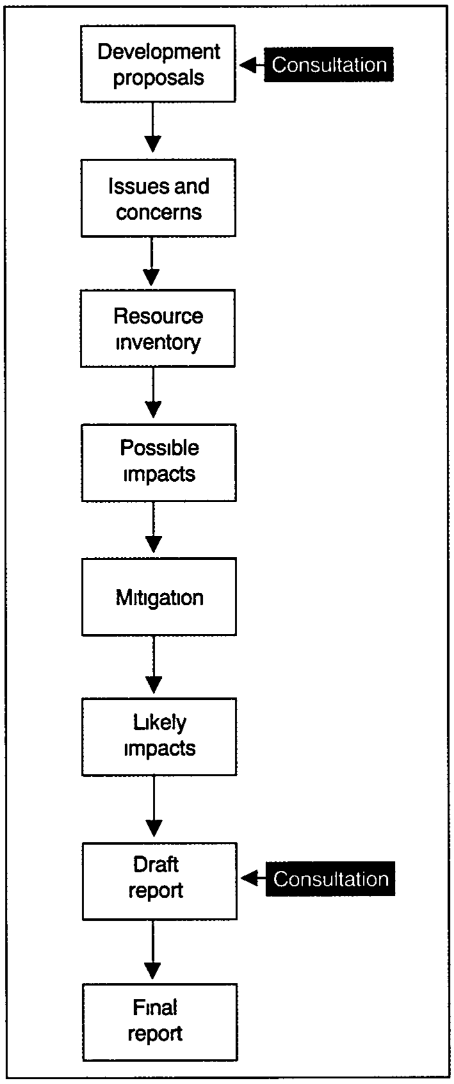

Figure 17 Stages in the preparation of the ecological assessment of the Spey water abstraction scheme

information was obtained from several sources

- published studies and previous reports relating to the proposal wellfield,
- unpublished reports and local records held by the Nature Conservancy Council (NCC) and others,
- data base information held by ITE, including the Biological Records Centre, IFE and the British Trust for Ornithology

Where necessary, field observations were made to supplement the available information Data on fish stocks, hydrology and terrestrial invertebrates were considered adequate, but additional field recording was undertaken on the vegetation, aquatic invertebrates, badgers (*Meles meles*), otters (*Lutra lutra*) and birds This recording was structured so as to provide a baseline for possible future monitoring

Conclusions

Much of the ground in the corridor proved of high scientific interest There were two Sites of Special Scientific Interest (SSSIs) and a denotified SSSI, as well as a number of areas of interesting shingle and woodland recorded in NCC surveys (Figure 18) The lower Spey is considered the best example of a braided river channel in Britain This was a major reason for the notification of an SSSI to the north of the proposed wellfield, and braided channel features were also present to the south Moderate levels of otter activity were noted, and parts of the corridor were valuable habitat for birds In both cases, the least valuable part of the corridor was the area selected for the wellfield

Impacts of the wellfield were assessed both by individual members of the study team, and in joint discussions The largest number of possible impacts would be during the construction phase They would all be detrimental, and included disturbance of wildlife by noise, visual intrusions, and pollution of the river by accidental diesel or silt discharges All these impacts were judged to be minor in character, and many could be mitigated (mainly by good working practice)

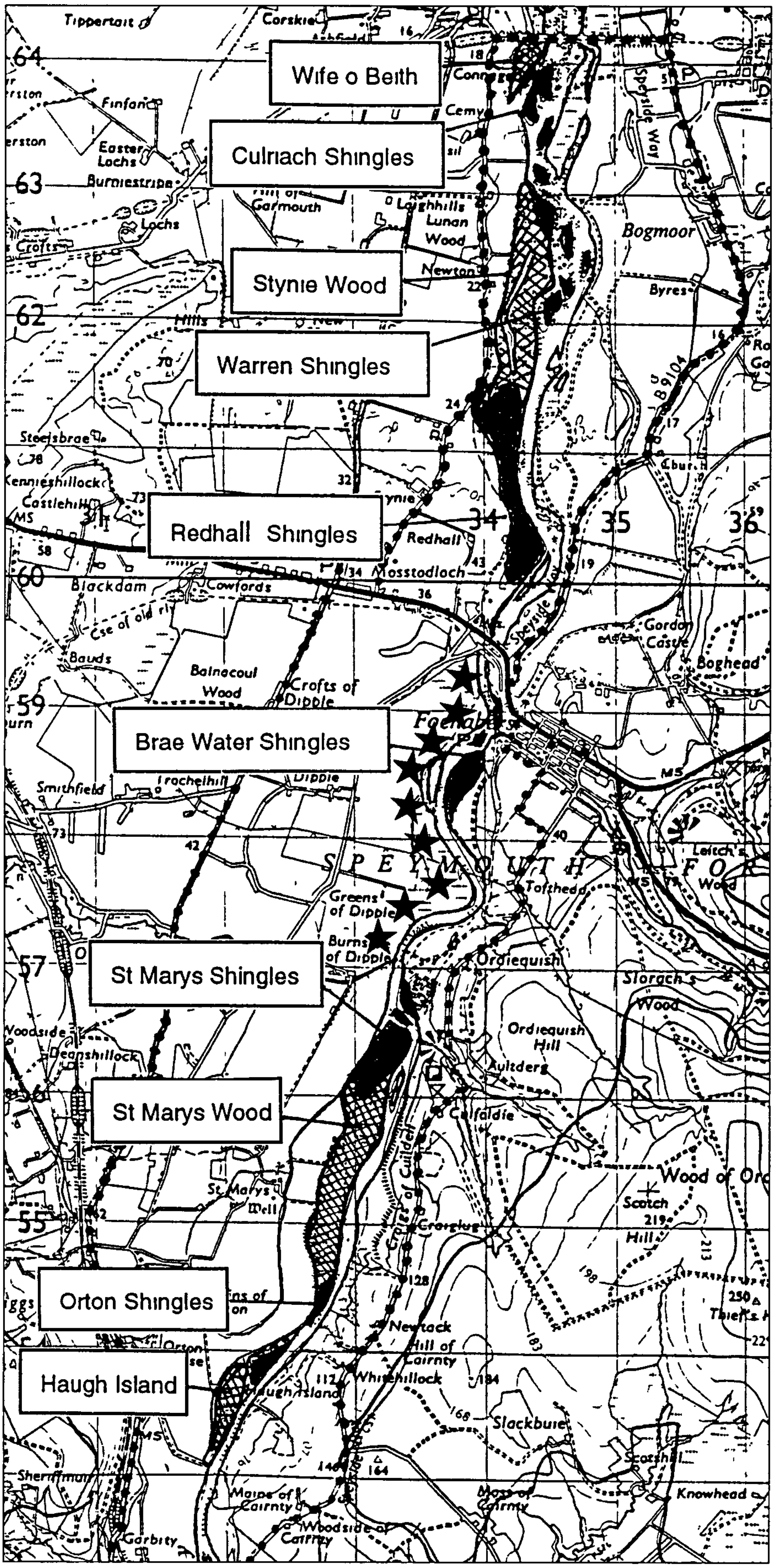

Figure 18 The Spey water abstraction study corridor (dotted line) The wellfield is shown by stars, and also indicated are woods (hatched) and shingles (solid) of nature conservation importance

During the operational phase, the abstraction process would reduce the levels of the water table in the vicinity of the wellfield (Figure 19) This was considered a major impact on soils and soil water The effects of cropping would vary in different parts of the area, with yields in some cases increasing and in other cases decreasing There could be some checking of tree growth at certain times of year, but dieback was considered unlikely Other impacts included possible small reductions in river flow, but, as abstraction would account for less than 3 5% of the lowest flow ever recorded, any effect would be difficult to detect with confidence A mitigation procedure to be adopted would release compensatory water from an upstream loch when flow rates fell below a rate of 21 5 $m^3 s^{-1}$ in the vicinity of the wellfield

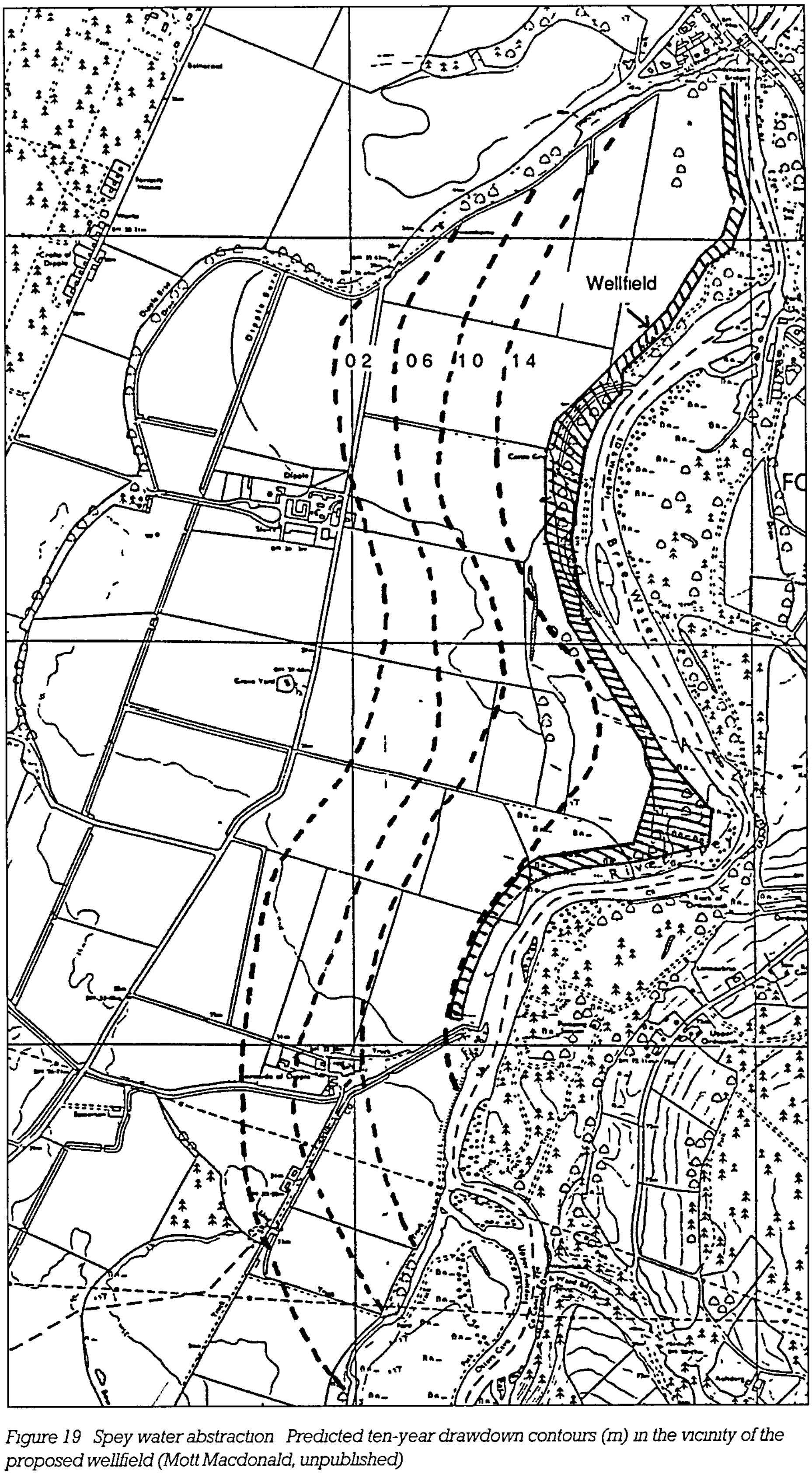

Figure 19 Spey water abstraction Predicted ten-year drawdown contours (m) in the vicinity of the proposed wellfield (Mott Macdonald, unpublished)

There would be a number of benefits from the proposed scheme during the operational phase These benefits would result mainly from changes in land use round the wellfield and from landscaping work which would improve the visual amenity of the area, as well as providing additional habitat for wildlife

An important recommendation of the study was that an independent group should be set up to monitor the development, and that this group should identify trigger points for key environmental attributes that would initiate more detailed monitoring and alert the Regional Council to a potentially severe impact (such as a pollution event or unanticipated effects on groundwater table levels)

The study was successfully completed on time, in spite of some disruption caused by the fire at Banchory Research Station On completion of the report, all the objections to the scheme were withdrawn and the monitoring group has since been set up and started to function Construction of the wellfield is expected to begin in spring 1992

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