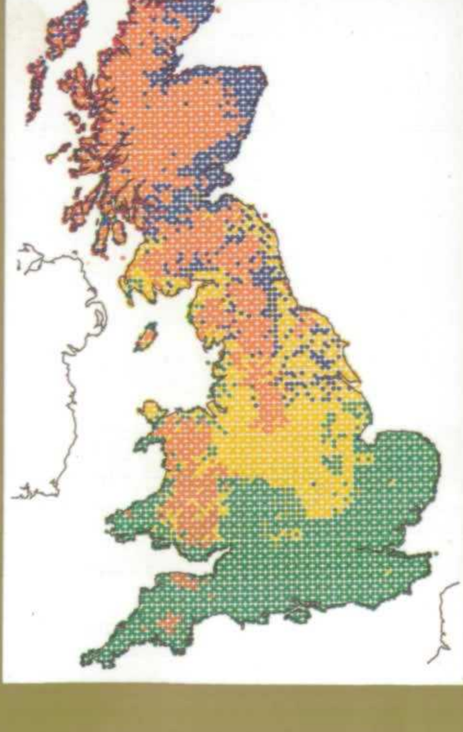
Institute of Terrestrial Ecology

Report for 1987/88



The Natural Environment Research Council

Foreword

The Natural Environment Research Council produces its Annual Report which contains selected information about the scientific activities of its component Institutes. However, it is a vital part of the activities of each Institute that it should produce its own Annual Report, in which the thrust of its research can be expressed fully.

The Institute of Terrestrial Ecology is part of the Terrestrial and Freshwater Sciences Directorate of the NERC. This Directorate's in-house capability comprises the Institutes of Hydrology and Virology, the Freshwater Biological Association and the Unit of Comparative Plant Ecology (Sheffield) and the Water Resource Systems Research Unit (Newcastle University). The increasing collaboration and integration in the Directorate has been advanced further in the year under report by the introduction of programmes, in which the Directorate's work is organised, cutting across Institute boundaries. The Institute of Terrestrial Ecology is an essential component of the total span of skills and disciplines within the Directorate and it is a pleasure to provide an introduction for its Annual Report.

The Institute of Terrestrial Ecology is now managed as two sections, with three stations in the north and three stations in the south. The organisational changes, taken together with the constant pressures of obtaining commissioned research, have made it a complex and challenging year. The two Directors and their staffs have made notable progress in science and in organisation, as shown in this Annual Report.

P B Tinker

Director of Terrestrial and Freshwater Sciences
Natural Environment Research Council

Cover Illustration

ITE has developed a land classification system which has derived 32 land classes, based on multivariate analyses of map-derived geological, topographical and climatological data. Field surveys were carried out in 1978 and 1984 in order to provide quantitative estimates of a range of ecological factors and to assess changes in composition that are taking place. The stratification system has been used in a series of contracts where a limited number of samples are required for modelling purposes, eg for the Department of Energy on the land potentially available for wood energy plantations, and for the Department of the Environment on countryside implications of possible changes in the Common Agricultural Policy. Currently, a major project is under way on the ecological consequence of land use change for DOE. The cover illustration presents a reduction of six classes to five groupings to show the principal regional patterns in Great Britain.

The Natural Environment Research Council

Report of the Institute of Terrestrial Ecology for 1987/88

Contents

Artwork for figures carried out by Jane Owens, on placement at ITE Merlewood Research Station from Blackpool and Fylde College.

Directors' statement

After the major changes in the organisation and structure of NERC which dominated last year, 1987–88 was, for ITE, a period of adaptation to the new programme structure within the Terrestrial and Freshwater Sciences Directorate. This NERC Directorate contains four institutes (Institute of Terrestrial Ecology, Institute of Hydrology, Freshwater Biological Association (FBA), and Institute of Virology), and two university units (Unit of Comparative Plant Ecology (UCPE) at Sheffield, and Water Resource Systems Research Unit at Newcastle), and aims to promote joint research programmes between institutes and universities.

The year saw several changes in the senior staff of the Institute, with Dr B W Staines, Dr M G R Cannell and Dr M Hornung replacing respectively Dr D Jenkins (Banchory), Dr (now Professor) M H Unsworth (Edinburgh), and Dr O W Heal (Merlewood) who became Director ITE (North) at the end of last year.

A Visiting Group, chaired by Professor R Cormack, visited all ITE stations between October 1987 and March 1988. At the time of writing, the Visiting Group's report has been received and accepted by Council. In May 1987, to our relief and satisfaction, NERC announced its decision to retain the stations at Furzebrook and Banchory. However, at the end of the reporting year, in March 1987, staff at Bangor were informed that Council was exploring the possibility of closing the station and transferring some staff to an ITE unit within the University. No firm decision has yet been taken.

The past few years have been characterised by a progressive shrinkage of the Science Budget allocated to all NERC Directorates, which has resulted from a reduction of funds coming to NERC and a gradual transfer of funds from institutes to the university sector. This loss of funds has been met by the energetic pursuit of research commissions and by general economies and loss of staff. By the end of March 1988, ITE had succeeded in increasing its contract income for the year to more than £3M, 45% of its total budget, despite a decline in staff numbers over the year from 273 to 251. Although staff numbers have declined, the vitality of the research stations is being sustained through Special Topic Awards, research students, visiting research workers and collaborative contracts. New contracts included a three-year extension of the Department of Environment (DOE) commission for work on 'acid rain', worth just over £1M for the three years. This programme of work includes projects being carried out at Edinburgh, Monks Wood and Merlewood, and at the Universities of Nottingham, Lancaster and Aberdeen. The research is concentrating on studies of the atmospheric cycle of the major gaseous pollutants (SO_2, O_3, NO_x); the processes of surface–atmosphere exchange of pollutants through a study of wet and dry deposition; the effects of these pollutants on vegetation; and the prediction of those areas of Britain where impacts on vegetation and freshwater ecosystems are likely to be greatest.

Another important commission from DOE was a series of desk studies on the likely effects of 'climatic change' resulting from increases in the atmospheric concentrations of the 'greenhouse' gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and tropospheric ozone). Staff at Monks Wood, Edinburgh, Furzebrook, FBA and UCPE were involved, in collaboration with the Universities of Edinburgh and Nottingham. The reports highlight the urgent need for research into this global problem.

Another DOE contract has funded work at Merlewood, where a team has been studying the ecological consequences of changes in land use in Britain. With land being taken out of agriculture, this research should provide valuable information for a more rational policy for the use of land in Britain.

At one time, the Nature Conservancy Council (NCC) was the main customer for the Institute's research. This is no longer true; our range of customers has increased dramatically. However, NCC continues to fund projects on topics ranging from the management of habitats for wildlife to the effects of agricultural pollutants on birds. One important new area of work funded by NCC has been an investigation into the possible effects of pesticide spray drift on native flora and fauna. Initially, the study is looking at 'high risk' herbicides and their effects on higher plants, ferns and lichens.

The Institute's receipts from the private sector increased substantially this year.

British Petroleum Development Ltd has commissioned staff at Furzebrook to undertake research and monitoring of the environmental impacts of oilfields in Dorset. Eurotunnel commissioned a similar environmental impact study on the construction of the Channel Tunnel and its ancillary onshore developments (at Monks Wood), whilst Shell Research Ltd has funded work on tree propagation (at Edinburgh).

ITE was successful in gaining several new contracts from the Commission of the European Communities (CEC) in 1987, for work on environmental pollution, the use of remote sensing to assess range conditions in the Sahel, and the effects of wind on trees. The Institute also secured further support from the Overseas Development Administration for its research on tropical forestry in Cameroon and Kenya. Staff at Bangor continue to earn contracts from CEC for the CORINE project, aimed at testing the feasibility of mapping from satellite imagery, and for management applications of remote sensing in CEC Less Favoured Areas.

A major new experimental facility was installed during the year at Edinburgh, with support from DOE, CEC and the US Department of Agriculture, namely a set of open top chambers for experimental studies on the effects of gaseous pollutants and acid mists on young trees. The chambers are sited close to the ITE laboratories surrounded by arable farmland, at an elevation of 180 m above sea level, where pollutants are present at very low concentrations. All chambers are supplied with irrigation water; 21 have filter units and three are supplied, at the same flow rates, with ambient air. Measured doses of pollutant gases, or of acid mists, can be administered to plants within the chambers. Solar domes and a misting facility have also been built at Bangor, where they will be used for studies of the impacts of ozone and NO_x on crops and natural vegetation, projects supported by the Welsh Office and NCC. These facilities should enable the Institute to stay in the forefront of pollution research in the years to come.

Major capital expenditure in this year was also needed to replace equipment in the analytical chemistry laboratories at Monks Wood, following a fire at that station. At Merlewood, the four existing germanium γ-detectors, which have been heavily used in analyses of post-Chernobyl radioactivity in soil, vegetation and animal tissues, have been supplemented by five additional counters. A new bird enclosure has been built at Banchory to provide facilities for work on fish-eating birds, partly funded by the Department of Agriculture and Fisheries for Scotland.

ITE has organised a number of symposia and scientific meetings during 1987–88, including two international meetings arranged on behalf of the CEC. These conferences were on 'Early diagnosis of forest decline', held in Edinburgh, and on 'Biological diversity', in Dublin, arranged by staff at Furzebrook. ITE was also responsible for organising seminars on 'Acid rain in British forests', held at the Royal Society in London in association with the European Year of the Environment, and on the 'Conservation of the Cairngorms', a joint venture with the Department of Scottish Studies at Aberdeen University. Exhibits were mounted at the Royal Show and at the Royal Highland Show, demonstrating aspects of the Institute's work, whilst an Open Day was held at Merlewood in July 1987, which attracted over 1500 visitors.

The Institute's staff continue to attract individual awards to mark their scientific standing. Dr H Kruuk (Banchory) obtained Individual Merit Promotion to Grade 6 in recognition of his work on the behavioural ecology of mammals. Dr A Watson (also at Banchory) received the Neill Prize of the Royal Society of Edinburgh, and Dr I Newton (Monks Wood) received the British Ornithological Union medal for eminent services to ornithology. Dr J D Goss-Custard (Furzebrook) was awarded the degree of DSc by Aberdeen University for work on wader ecology.

1987–88 has seen the Institute staff adapt successfully to organisational and financial changes. The continued success in the competitive field of contract research, combined with the increasing national and international awareness of environmental challenges, emphasises the important role of ITE as an ecological research organisation. The research reports which follow illustrate the broad lines of both basic and applied research which we believe will continue to develop.

J P Dempster
O W Heal

Assessing the effects of technological developments

One of the most important applications of ecology is in the assessment of the environmental impact of urban or industrial developments, or of changes in land use. Planning procedures at national, regional and county level in Britain involve consultation between planning authorities and environmental scientists, and for any major new development an environmental impact assessment is required. In some cases, it will also be necessary to undertake 'base-line' surveys of animal and plant communities in the area where developments are proposed, so that environmental effects can be monitored.

The reports which follow describe ITE's work on the impact of a variety of developments in southern England. The section also includes an account of the work of the Biological Records Centre (BRC) at Monks Wood. The BRC data base is an important source of information about the occurrence and distribution of animal and plant species which may be affected by future changes in the pattern of land use, or by industrial, urban and other developments.

Plate 1. View of Channel Tunnel platform from Shakespeare Cliff

The impact on the terrestrial environment of constructing the Channel Tunnel

The construction of the Channel Tunnel, together with all the ancillary developments such as the rail terminal, could have serious effects on the environment in the area. This part of south-east Kent, from Ashford to Folkestone and Dover, has a number of sites of major interest for wildlife conservation.

Notwithstanding previous assessments of the environmental impact and survey work by the Nature Conservancy Council, ITE has been commissioned by Eurotunnel to provide base-line data on plant and invertebrate communities, with a view to establishing a long-term programme to monitor the effects, not only of construction, but also of the operation of the Tunnel.

Because the effects of the Tunnel's construction must be distinguished from changes arising from other causes, it is necessary to record plants and animals in replicate samples 'on' and 'off' the construction sites.

The main tunnelling operations are toward the eastern end of the Folkestone Warren Site of Special Scientific Interest (SSSI). Here, at Abbots Cliff and Shakespeare Cliff (Plate 1), seven kinds of vegetation have been identified and permanent quadrats have been set up, both on and off the site, to record the changes in each plant community. Similarly, pitfall traps have been installed in representative areas of each of the seven plant communities, both on and off the site.

Apart from the main tunnelling, which will create dust and noise, an old colliery platform at the foot of the cliffs is to be extended to take the spoil from the borings. This extension will stabilise the cliff face and isolate it from salt spray. The old colliery platform has already, to some extent, isolated and stabilised one area of cliff, which is now well covered with shrubs, such as privet (*Ligustrum vulgare*) and brambles (*Rubus fruticosus* agg.) (rather than sparse wild cabbage (*Brassica oleracea* subsp. *oleracea*) and rock samphire (*Crithmum maritimum*)), and has a different range of beetles from neighbouring areas. Our study has shown that the invertebrate communities of such stabilised areas are quite different from those of unprotected cliffs.

Above the cliffs, still within the Folkestone Warren SSSI, is an isolated area of rich chalk grassland known as Round Down which supports the best population in Kent of the rare early spider orchid (*Ophrys sphegodes*). During tunnelling, this grassland will be almost surrounded by the upper construction site and its access roads, and is likely to be particularly affected by increased levels of dust. Here, the precise location of every plant of the early spider orchid is being mapped in an area 20 m x 50 m, and the annual changes will be monitored. In 1987, 177 plants were mapped. A transect has also been set up for recording butterfly numbers at monthly intervals.

On the Folkestone–Etchinghill Escarpment SSSI, similar chalk grassland is at risk from tunnelling and from construction of the vast Cheriton Rail Terminal. Although lack of grazing has encouraged the growth of grass and scrub, many sections still support a rich variety of plants and insects. On this escarpment, eight permanent transects have been established, and on each the plants in six permanent quadrats are being recorded. At four of the transects, on Sugar Loaf Hill, Round Hill, Castle Hill and Cheriton Hill, selected groups of invertebrates were also recorded to determine the natural variation in the communities before major engineering

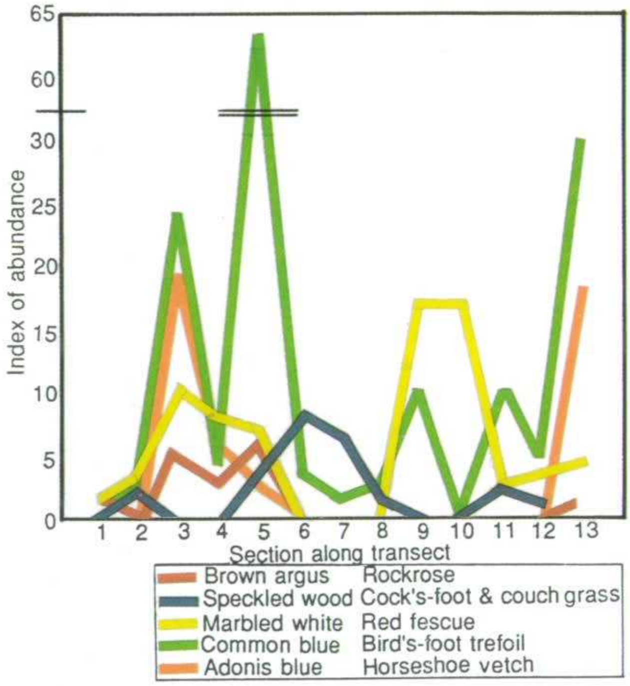


Figure 1. Annual index of abundance for five butterfly species on Castle Hill–Sugar Loaf transect on Folkestone Escarpment in 1987. The associated larval foodplant is shown in the key.

work began. So far, 38 000 individual specimens have been collected.

Two separate butterfly monitoring transects have been set up, one at Cheriton Hill, recorded monthly, and another between Castle Hill and Sugar Loaf Hill, recorded at weekly intervals. Records from the latter transect (see Figure 1) will allow comparisons to be made with other grassland sites, and with the national and regional trends observed in the national Butterfly Monitoring Scheme.

A number of rare and local flowering plants occurs on the Folkestone to Etchinghill Escarpment, and some have been selected for special study. The very rare late spider orchid (*Ophrys fuciflora*), only known in Britain from a few sites in Kent, has been recorded, in the past, from a number of sites on the escarpment. In 1987, only 13 flowering plants were found within an area of 35 m x 15 m on Cherry Garden Hill. Candytuft (*Iberis amara*) is known in Kent at only one locality, within the grounds of Cheriton waterworks. A flourishing population of 408 plants was mapped during 1987 in an area 20 m x 10 m. The distribution of some other species is being mapped less precisely.

A complementary study of water plants and invertebrates at 14 sites on five streams in the Folkestone and Ashford areas is being done by staff of the Freshwater Biological Association's River Laboratory, East Stoke, Dorset.

The difficulties in establishing sites for long-term monitoring of the environmental impact of developments like the Channel Tunnel were illustrated in 1987 by both changes in the developer's plans and the unpredictability of the British weather. Originally, it was planned to route the access road from the M20 to the Cheriton Terminal through Beachborough Park and along the southern edge of Asholt Wood SSSI. Trees in the park were known to support one of the best lichen floras in Kent. Permanent quadrats, set up on the trunks of trees in the park and in the centre of the wood, were recorded photographically, and the total lichen flora was assessed for each of the trees. Additional quadrats were placed over selected rare species. A total of 136 species of lichen was recorded in the area, 29 of which were found in the permanent quadrats and 21 within the rare species quadrats. Although the immediate threat to this site has lessened with the rerouting of the access road, data collected in 1987 will provide a means of assessing the effect of any increase in pollution from vehicular emissions from 1993 onwards. The unpredicted event was the 'hurricane' of 16 October, which blew down one of the sample trees (the only lime tree in the park) and severely damaged several others.

Tidal barrages, estuaries and wading birds

In biological terms, the intertidal flats of estuaries are often extremely productive and may support enormous numbers of animals, each of which may have a very fast rate of growth. Amongst the larger invertebrates, for example, it is not uncommon to find, in one metre square of mud, several tens of thousands of a small snail called *Hydrobia* (which has a maximum shell height of 6–7 mm), several thousands of the burrowing shrimp *Corophium* (maximum length 10 mm), a thousand or so ragworms *Nereis* (maximum length 10–20 cm), a similar density of the burrowing bivalve mollusc *Macoma balthica* (maximum length 20–30 mm), and a few hundreds of the bivalve *Scrobicularia plana* (maximum length 30–40 mm). This characteristically high density of animals indicates that intertidal flats are amongst the most productive of natural habitats. In fact, their biological productivity can match even that of good arable land.

Because of their high productivity, intertidal estuarine flats attract large numbers of predatory birds (Plate 2). Several species of wildfowl and gulls occur on estuaries and feed either on the invertebrates or on mats of vegetation which also occur there. Many species use the wide open spaces as safe

Plate 2. Curlew, oystercatcher and redshank feeding on intertidal estuarine flats

roosting areas. Yet, with the exception of the Brent goose (*Branta bernicla*) and the shelduck (*Tadorna tadorna*), most of these birds are not heavily dependent on intertidal flats for a limited resource.

This is not the case with the wading birds, a specialised group containing many species for which estuaries provide essential sources of food. They feed on the larger invertebrates living in, and on, the substrate and use a variety of feeding methods to catch their food. Because birds have a high metabolic rate, they must consume a great deal of food, especially when the ambient temperature is low, so that their demands for food energy are high. When converted to the numbers of individual prey items required each day, the food consumption of wading birds produces some impressive figures. A single redshank (*Tringa totanus*) eats up to 40 000 shrimps or 1000 ragworms during each 24 hours in winter; a single oystercatcher (*Haematopus ostralegus*) eats 50–100 mussels or several hundred cockles over the same period. Also, because wading birds may feed at the very high average densities of several tens of thousands of birds per hectare, they can consume, in total, enormous numbers of their prey. The population of 1500–2000 oystercatchers on the Exe estuary, south Devon, eats between 15–30 million mussels between September and March. Intertidal flats can be high-productivity, high-turnover systems with large densities of wading birds consuming huge numbers of their prey.

Most of the wading birds that occur in Britain breed in spring and summer over an area which stretches northwards as far as north-west Canada to the west and Siberia to the east. The waders return from the breeding areas from late summer onwards. Some spend a short period on British estuaries, accumulating energy reserves to fuel further migration to wintering areas along the coasts of continental Europe and Africa. Many remain in Britain, although movements around the country may occur depending on the species. The numbers of many wader species in Britain reach a peak during the winter, when their main goal is simply to survive. As the time of spring migration approaches, they accumulate fat reserves for the flight back to the breeding areas. This emigration starts as early as February in species that breed in the more southerly regions of north-west Europe, but does not occur until as late as May in the birds breeding in the Arctic.

The large concentration of specialised, interesting and attractive birds on estuaries means that the habitat has become the focus of much public concern, both nationally and internationally. So, when plans are put forward to develop all or part of an estuary in Britain, its significance for waders is usually well known and the protection of the birds can become a major issue. In the case of barrages, the main concern is that, by permanently inundating with water some or all of the intertidal flats, the food supply of the birds will be seriously reduced, and their numbers depleted.

The extent of the inundation varies between different schemes. In some, such as the proposed barrage on the estuary of the Taff/Ely rivers in Cardiff, the purpose is to create a lagoon of standing water, which would submerge all the intertidal flats, so the birds feeding there at the moment would have to find somewhere else. Barrages constructed to generate electricity have a different effect. These barrages work by letting the tide drive turbines, which can be driven either on the flood or ebb tides, or both. The only functioning barrage at present is situated on the estuary of La Rance in Brittany, and it generates electricity on the ebb tide, as would the proposed barrage on the River Severn. This method of generating power means that the flood tide is allowed into the basin upstream of the barrage and, after the tide has receded some way downstream of the barrage on the ebb, the water in the basin is allowed to flow through the turbines. The basin is not completely emptied during this period because of the returning flood tide. Compared with the area available to birds before a barrage is built, the area of intertidal flats upstream of a barrage is reduced because the intertidal zone becomes narrower.

The concern is that the reduction in intertidal area upstream of the barrage will make it more difficult for the birds to obtain their food. As a result of less feeding space being available, the birds' density would increase and so would the competition between them. Competition in these birds occurs either directly because of interference between foraging individuals, or indirectly because the food supplies are depleted when bird density is high. Furthermore, by holding back the high tide, the barrage would also reduce the amount of time available for the birds to feed during each tidal cycle.

Increased competition would undoubtedly heighten any difficulty the birds already have in collecting enough food. However, other changes in the system could occur which would offset the effects of increased competition. In high-energy estuaries, such as the Severn, the water is turbid, little light penetrates the water column, and primary productivity is relatively poor. By reducing the strength of the currents, the water would clarify somewhat and productivity would increase; the invertebrates on which the birds feed would themselves have more food, grow more, and so provide a better food supply for the birds. The reduced currents might also allow more stable mudflats to develop, which would further benefit the invertebrates. In the Severn estuary, the conditions are such that few common bivalves, such as the mussel and *Macoma*, can thrive; the high concentration of sediment in the water blocks their siphons so that they cannot function. Birds that feed on bivalves, such as the oystercatcher, are therefore scarce on this estuary. A barrage could enable more of these invertebrates to prosper, so that some waders would benefit.

For the wading birds, therefore, there can be both losses and gains when a barrage is built, especially in a high-energy estuary. The problem for the research worker is to predict the net effects on the birds of increased competition and reduced foraging time on the one hand, and increased production of the food supplies on the other. Studies attempting this prediction for the Severn barrage are now in progress under a contract placed by the Energy Technology Support Unit at Harwell.

Monitoring for the oil industry

Western Europe's largest onshore oilfield, and the pipeline route associated with it, both lie within environmentally sensitive areas of southern England (Figure 2). Drilling is being carried out by British Petroleum Development Ltd (BP) to tap the Bridport and Sherwood reservoirs, which lie beneath Poole Harbour, on land bordering its southern shore and in parts of Poole Bay. The 90 km pipeline, connecting the oilfield to the refinery on Southampton Water, crosses the Isle of Purbeck, passes to the north of the Poole/Bournemouth conurbation, and skirts the western and southern edges of the New Forest.

Integrating the exploitation of the resource with sound environmental management was a challenge for the developer, and one which required detailed and informed knowledge of ecological interrelationships so that the implications of particular proposals could be fully assessed. Staff from ITE Furzebrook have been involved for a number of years in providing advice to ensure that operations are carried out in such a way that adverse ecological impacts are minimised. In the early stages, the implications of different pipeline routes and other constructions associated with the oilfield development were examined in a series of preliminary desk studies and field surveys. A detailed analysis was also made to assess the sensitivity of different parts of the

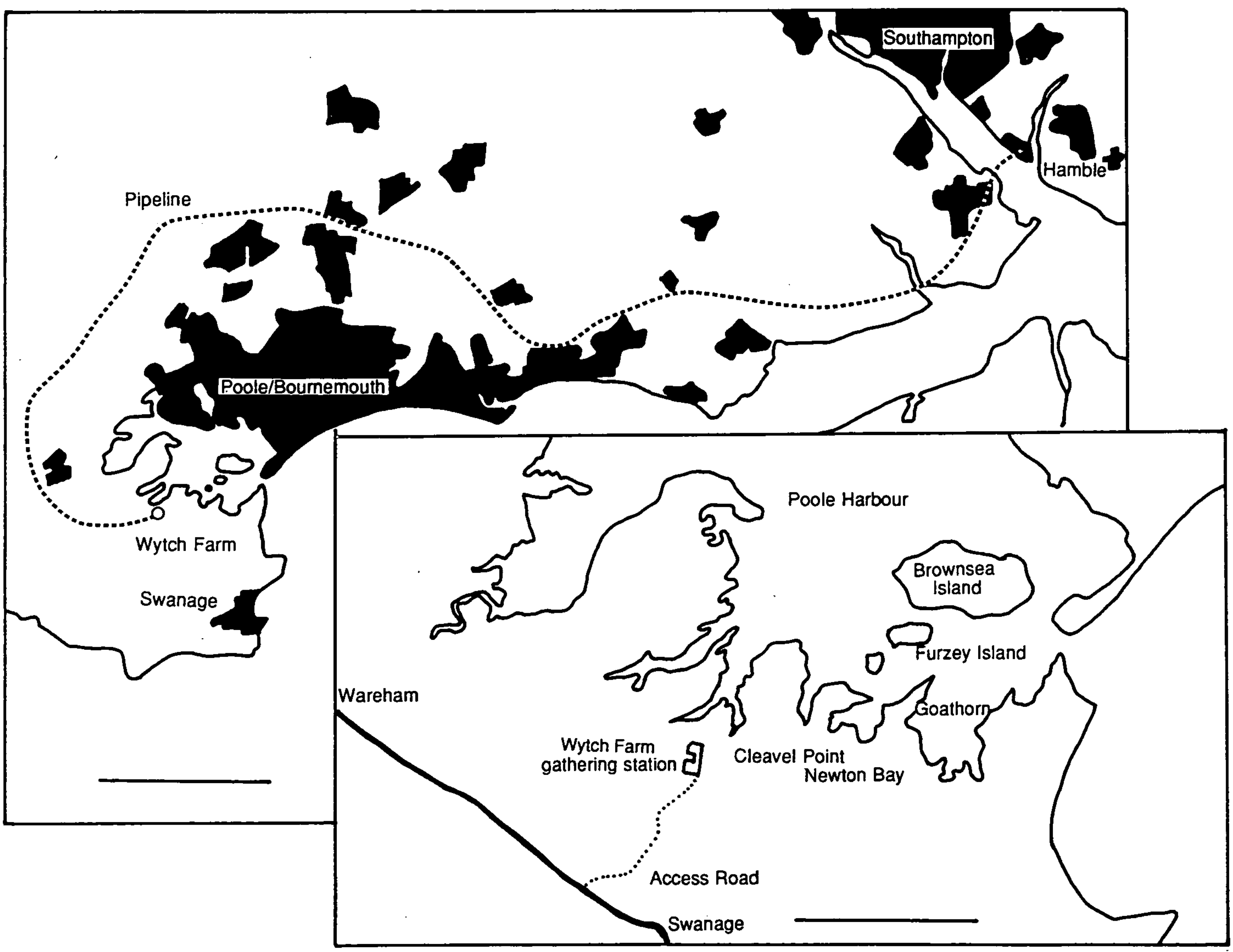


Figure 2 Map of the route of oil pipeline from Wytch Farm to Southampton Water, with inset showing part of Poole Harbour and locations mentioned in text.

Poole Harbour shoreline to possible oil spill pollution.

In order to ensure both minimum damage to areas of particular conservation interest and effective restoration following construction work, a biological monitoring programme has been established and funded by BP. The programme consists of a number of separate studies devoted to specific groups of plant and animal communities, individual species, or potential pollution effects.

There are two well sites on Furzey Island in Poole Harbour. The island also supports an unusually dense population of red squirrels (*Sciurus vulgaris*). A census carried out in 1987 indicated that at least 48 individuals were present. Maintenance of high numbers of animals depends upon retaining large enough areas of appropriate habitat conditions and a continuous production of adequate numbers of pine cones. Continued monitoring of the squirrels and the pine cone crop is being carried out during the course of the development.

The pine trees on Furzey are also being used as part of a monitoring programme to assess likely effects of pollution from construction and drilling activities. The lifespan of conifer needles varies according to a number of factors, including exposure, soil water conditions and atmospheric pollution. Needle retention times are being measured on trees in a range of locations on Furzey Island, on the neighbouring Brownsea Island, and at sites on the southern side of Poole Harbour.

Lichens have been used extensively in pollution studies because they make particularly sensitive indicators. The lichen communities on pine bark at the same sample locations as those used for needle retention measurements are being recorded photographically at regular intervals in order to assess any effects of pollutants or increased exposure.

Poole Harbour provides a winter refuge for a number of intertidal birds (waders and wildfowl). The numbers and patterns of distribution, and the behaviour of these birds are being recorded for comparable areas at different distances from construction/operational activities, in order to reveal any effects of these operations. The winter of 1987–88 was particularly mild and bird numbers in the Harbour were generally low, possibly because larger numbers remained on estuaries further north.

The birds are dependent for food on the richness of the intertidal invertebrate fauna. Some construction activities have a direct effect on the intertidal mudflats and saltmarshes. Where this work takes place within the intertidal zone, patterns of sediment deposition or erosion may be changed. The construction of a new water intake facility at Cleavel Point necessitated the excavation and replacement of areas of the intertidal mudflats, and the crossing of an area of saltmarsh. In order to assess the effects of this work, a series of samples was taken prior to the beginning of construction, and a base-line was established showing the distribution of sediment types and their associated fauna. The data indicate that coarser deposits, with small numbers of large animals, are found close to one of the deeper channels in the Harbour near the intake pipe, whilst large numbers of small species are found in the finer sediments around the sheltered shores of Newton Bay and Ower Bay.

Within the saltmarshes of Furzey Island, accretion and erosion rates are being measured using Kestner cores. These cores indicate that there has been accretion within the sheltered marsh on the north-east side of the island, but that along the southern shore there has been a gradual steepening of the marsh as a result of increased deposition on the landward side, coupled with more extensive erosion of the seaward side. Casual observations in other parts of Poole Harbour suggest that this phenomenon may be more widespread.

In addition to these basic studies, specific advice has been provided on methods to be used in laying pipelines through saltmarshes. Careful monitoring of the after-effects will be carried out as part of the advisory programme, to determine the effectiveness of the original methodology and to identify any secondary problems which may need action. Similar method statements, defining techniques, have been provided for freshwater marshes.

Much of the wildlife interest of Purbeck is associated with the heathlands, which provide the habitats of a number of nationally rare species, including Dorset heath (*Erica ciliaris*), the sand lizard (*Lacerta agilis*), and the smooth snake (*Coronella austriaca*). The distribution of these species, together with the other four British reptile species, have been surveyed along construction routes, and, where possible, these routes have been modified to avoid the reptile habitats. ITE has advised on the rehabilitation of areas of heathland, especially those containing Dorset heath (Plate 3).

Plate 3. Stoborough Heath. Multiple pipelines being assembled in trench deepened to pass under a road

Plate 4. Chale Wood. Restored pipeline route with first stages of recolonisation taking place

As part of the development, a new road to the gathering station (the collecting point for oil from the scattered individual wells) has been built. Preconstruction surveys of the wet meadows and of the woodland and scrub communities along the route have been made, and provide a base-line for assessing the effects of the road on the parts of these communities adjacent to it. Of particular interest in this area are the species-rich hay meadows, which are also crossed by the export pipeline, and the reinstatement of these areas will be monitored carefully following the completion of construction work.

The export pipeline passes through agricultural land for the most part. Where semi-natural communities are affected, the same techniques of establishing base-line surveys, providing advice on restoration, and monitoring the progress of that restoration have been employed. Studies along the pipeline have concentrated on: three heathland sites, one heathland/scrub transition site, one woodland, five areas of wet grassland and marsh, three sites of potential ornithological interest, and an area within which the rare nit-grass (*Gastridium ventricosum*) was known to occur in the past. For all the sites with botanical interest, detailed vegetation maps of the affected areas have been drawn up and quantitative floristic data have been collected. Following completion of the pipeline, progress in restoring these communities will be followed by a series of repeat surveys. Interest in the ornithological sites was directed towards identifying nesting areas, so that precautions could be taken to avoid disturbance, as far as possible (Plate 4).

This study provides a good example of the integrated approach to assessment and monitoring which ITE is able to provide. Similar studies are also being undertaken on a more restricted scale at a number of other areas in south-east England, in association with other oilfield developments.

The Biological Records Centre

The national data bank of information on the occurrence of plants and animals in the British Isles is operated by the Biological Records Centre (BRC) at ITE Monks Wood. The data bank consists of 3.5 million records of nearly 9000 species, and is held on VAX computers within the NERC Computing Services network. An archive of over 600 000 original documents, supporting the data bank, is housed at Monks Wood.

The data are contributed voluntarily to BRC by specialists throughout the British Isles. Most data are obtained through the 60 national biological recording schemes, which cover a wide variety of taxonomic groups. Schemes are organised by scientists at universities, colleges, museums and other institutions, by national societies and study groups, and, in some cases, by private individuals. BRC also receives data from other sources, eg survey, monitoring and research projects in NERC and at universities and colleges.

The greater part of the costs of BRC is borne by NERC, but BRC has received support from the Nature Conservancy Council (NCC) since 1973 in several ways. An annually renewed contract from NCC provides funds for the general work of BRC and supports specific areas of work in the rolling programme to input new data. Supplementary contracts have funded staff to work on data for particular groups in which NCC has an interest. In addition to these contracts, NCC is providing staff to work on two botanical projects which are described below. Other external sources of funding are the World Wide Fund for Nature (review of butterfly recording in the UK), Department of the Environment for Northern Ireland (survey of specialist biological groups), and various publishers and environmental consultants.

New computer hardware installed at Monks Wood since 1987 and the transfer of the main BRC data bank to the ORACLE data base management system on a VAX 8600 at BGS Keyworth have resulted in greater efficiency in data handling and in the retrieval of data for users. Output from the data bank is available via the Joint Academic Network (JANET) as hard copy (both as listings and as distribution maps) or as 5¼' IBM PC disks (for small quantities of data). On-line access to data is available at BRC or by arrangement via JANET.

The programme to input new data and to update existing data held on computer is benefitting from the enthusiasm for recording generated among the volunteers in earlier years by BRC. Several large data sets have been processed in recent years, and the following publications have resulted or are in press or preparation: Characeae (stoneworts); Chilopoda (centipedes); Diplopoda (millipedes); Diptera — Sepsidae; Ixodoidea (ticks); Lepidoptera — Zygaenidae, etc (burnet moths, etc); marine algae (seaweeds); Opiliones (harvestmen); terrestrial Isopoda (woodlice). Forthcoming publications include works on *Potamogeton* (pondweeds), Coleoptera — Staphylinidae (rove-beetles), Coleoptera — Coccinellidae (ladybirds), Diptera — Brachycera (horseflies, soldierflies, etc), Diptera — Tipulinae and Ptychopteridae (craneflies), Odonata (dragonflies), and mammals. A complete list of atlases is contained in the ITE leaflet *Current atlases of the plants and animals of the British Isles.*

The updating of existing data for flowering plants and ferns has been continuous since 1981. Nearly 1000 species have been covered, often in response to requests for data or maps

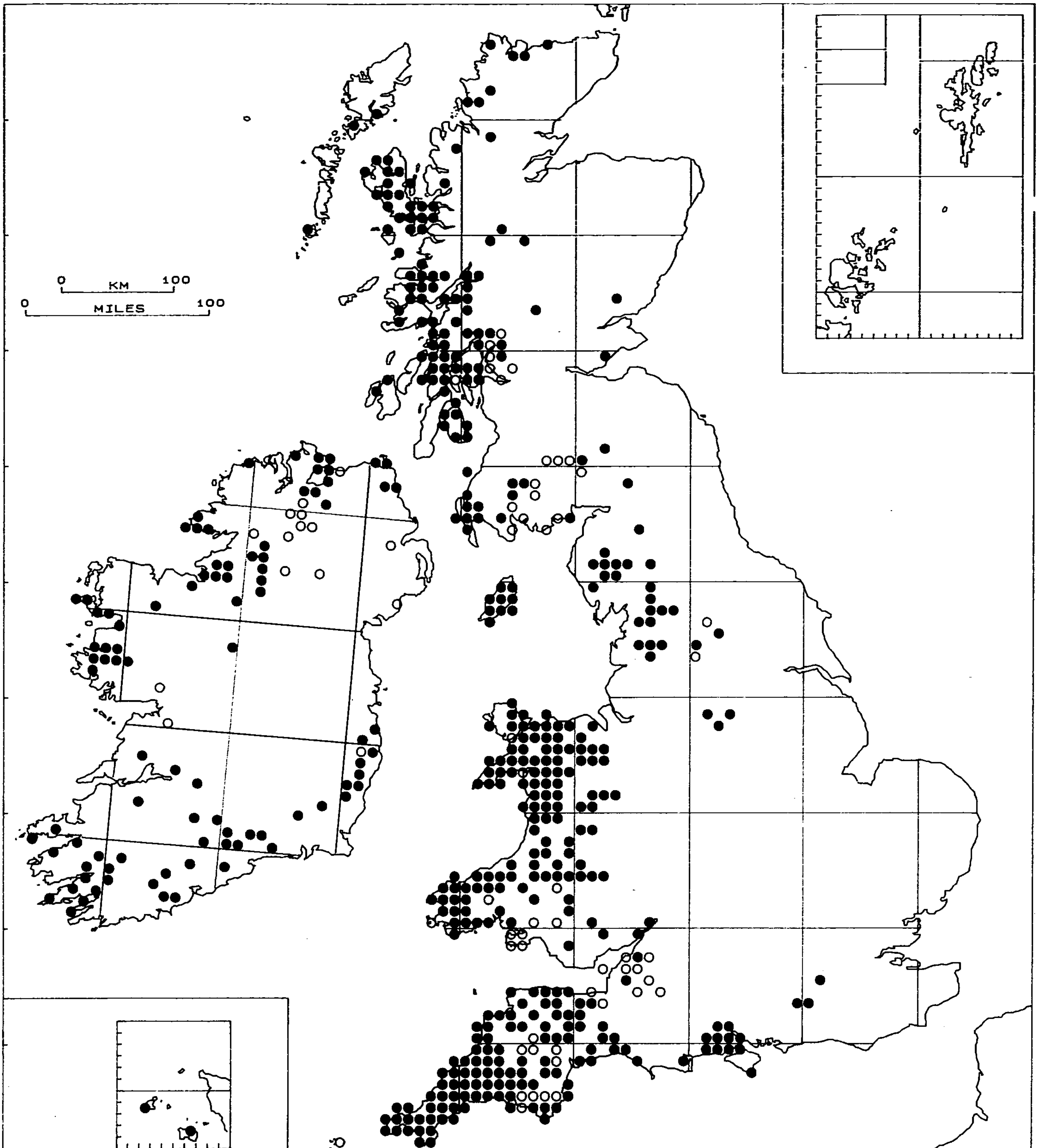


Figure 3. Example of a distribution map produced from the Biological Records Centre's data base. The map shows the recorded distribution of the liverwort *Lejeunea lamacerina* in 10 km squares of the British and Irish National Grids. This species of liverwort grows on rocks and trees in moist, shaded localities, often mixed with other bryophytes.

from researchers, scientific publishers and the Nature Conservancy Council, and many maps (Figure 3) have been published in research publications or used in post-graduate theses.

Two botanical projects, based at BRC, are staffed with NCC employees working within the BRC project group. The Botanical Society of the British Isles (BSBI) set up a new recording scheme in 1986 to assess the current status of the British and Irish flora, and to provide a means of monitoring future changes. During 1987 and 1988, the flora of an 11% sample of 10 km squares throughout the country is being surveyed to give an objective assessment of which species have changed in distribution and/or abundance since the *Atlas of the British Isles* was published in 1962. Within each of these selected 10 km squares, three tetrads (2 km x 2 km squares) are being surveyed in detail to establish a base-line for monitoring future changes. Over 5000 completed record cards have been received for the 1987 field season.

The other botanical project staffed by NCC employees at BRC is the preparation of a bryophyte atlas. Data on mosses and liverworts, collected by the British Bryological Society over the last 25 years, are being processed at BRC. Input of data was completed in the early summer of 1988. The data will be validated and restructured, and distribution maps will be prepared in 1989.

BRC works closely with the many local records centres which are operated throughout the country, mainly by local authorities. All local centres are run independently of BRC. County wildlife trusts and local natural history societies also collect and store biological records independently of BRC. Greater collaboration and standardisation in biological recording are seen by BRC as essential for the more efficient use of available resources, in particular the large and expert workforce of volunteers. BRC has taken a leading role in discussions on the co-ordination and standardisation of biological recording in working groups set up by the Linnean Society, Wildlife Link, and the National Federation for Biological Recording. Several conferences have been organised under the auspices of the National Federation.

The World Wide Fund for Nature has helped fund BRC to conduct a 'survey or surveys' to help plan the future of national butterfly recording in Britain. This survey has drawn in information on local recording schemes throughout the country.

Public relations are an important part of BRC's work. The production of recording scheme newsletters, organising or attending scheme meetings, lecturing to special interest and student groups, and providing general information to the media and the public all help to promote the work of this national data centre.

The UK or British Isles contribution to European species mapping projects is co-ordinated by BRC. These projects include the *Atlas Florae Europaeae, the Atlas des reptiles et amphibiens d'Europe*, and the European Invertebrate Survey. BRC has been represented at several meetings of the Council of Europe on the use of data banks in nature conservation.

Environmental pollutants

ITE has a large programme of work on environmental pollution, covering a wide range of topics. Almost all of the work receives outside funding. The first report in this section is a summary of one of four desk studies which ITE has undertaken for the Department of the Environment (DOE), describing ways in which the climate change associated with increasing levels of the 'greenhouse' gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and tropospheric ozone) might affect different ecosystems in the UK.

Climate change, sea level rise and coastal ecosystems

Carbon dioxide is produced in massive quantities from burning fossil fuels, like coal, oil and petrol. Some of this CO_2 is taken up by green plants in photosynthesis, but much of it is accumulating in the atmosphere, where the CO_2 acts like the glass of a greenhouse, letting sunlight in but reducing the loss of heat on radiation. Like the air in a greenhouse, the atmosphere warms up.

The expansion of the existing water in the oceans as they get warmer could, in itself, raise the sea level; if ice caps and glaciers melt, very large rises in sea level may occur. There have been several forecasts of sea level rises of at least one metre in the next hundred years, and some forecasts are of rises in excess of four metres. A desk study by ITE, commissioned by DOE as part of a wider study of the biological effects of climate change, considered the biological implications of sea level rises of up to 1.65 m in a hundred years. It has been estimated that the improvement of existing sea defences to withstand such a rise would cost in the order of £5,000 million. Various different options for sea defence and coast protection, therefore, have to be considered, including raising the existing sea walls, building new walls further inland, building major estuarine barrages, and even abandoning whole sections of coast to natural processes.

The greatest impact of such a rise in sea level would be in the south and east of Britain, where soft coasts, protected by sea walls, predominate. As the sea level rises, erosive processes would become dominant, and there would be considerable losses of marshes and intertidal flats, especially of the fine sediments, although there would be a partial redeposition of these in sheltered areas. The slope of the shore would become steeper and each of the zones narrower. If the sea walls were raised in height at their present positions, they would have to withstand greatly increased erosional forces, as the saltmarshes and mudflats to seawards were progressively lost.

Even with a sea level rise of only 0.8 m, it is estimated that virtually all of the upper saltmarsh community would be lost and replaced by pioneer and lower marsh communities. A rise of 1.65 m would result in the loss of virtually all the upper and lower marsh, and the mudflats would be reduced in area by at least 50%. Some of the eroded sediments would build into new marshes in the most sheltered areas.

With a lowering and a narrowing of the flats and an increase in coarse sediments, the invertebrate fauna of the intertidal flats would become poorer and less diverse, except locally where fine sediments had been deposited. The productivity of the surviving species would be reduced because high loads of suspended sediments interfere with their filter feeding. The turbidity would also reduce the growth of phytoplankton and the general productivity of the inshore waters.

These changes would greatly reduce the present large numbers of birds, of many species, that roost, feed or breed in the intertidal areas and on the saltmarshes. The loss of the upper saltmarsh would eliminate much of the breeding territory of several species of waders; half the British population of redshank (*Tringa totanus*) would have to find alternative breeding sites. The loss of marsh would also affect the wildfowl that feed there during the winter, particularly the Brent goose (*Branta bernicla*) and wigeon (*Anas penelope*). There are many species of wading birds that feed on intertidal flats, as well as wildfowl, like the shelduck (*Tadorna tadorna*). These would all find less food available, and many would die of hunger or as a result of increased predation.

If new sea walls were to be rebuilt further inland, there should be some regeneration of existing habitats, but it would involve the loss of considerable areas of improved agricultural land, as well as some areas of rough marsh land used for grazing, in itself a habitat of considerable conservation interest. The sea walls would have to be moved a long way landwards for there to be substantial regeneration of lost habitats.

A partial (storm surge) barrage, like the present Thames barrier, cuts off extreme high tides and prolongs the period of slack water at high tide. Sedimentation inside the barrier would increase, especially at high levels where there is vegetation. The resulting growth of saltmarsh would lead to a narrowing of the width of the intertidal flats, but intertidal invertebrates would remain productive for a while, before the area was lost to saltmarsh or by the drying out of the surface. The number of wading birds able to use the area would be reduced, as food resources decline.

An impermeable barrier excluding the sea completely would cause the total loss of the flora and fauna of the existing intertidal area, which would be replaced by a range of new freshwater habitats, open water, marshes and grassland that would only partly compensate for the losses of saline habitats.

There would be other changes in coastal areas affecting sand dunes, shingle banks and earth cliffs. Increased erosion of the seaward dune ridges would release sand to build new dunes further inland. While some of the larger dune sites could accommodate these changes with little overall impact on the flora and fauna, many of our dune sites are too small for this natural readjustment to take place, without loss of productive agricultural land. Enhanced erosion of earth cliffs might be unacceptable on social grounds, but the extra sediment input could play a vital role in natural coast-building processes elsewhere.

A predicted combination of higher sea levels with increased rainfall would cause changes inland, including increased flooding both by the sea and by freshwater. Present 'wash lands' that are flooded by the storage of excess water in the winter, but by breeding birds in the summer, could become near permanent lakes. In addition to the increased threat of flooding, East Anglian rivers would experience more frequently, and to a greater extent, the salt penetration that has caused major fish kills, eg in Broadland. An event that previously only occurred once or twice in a hundred years might become a regular occurrence, and large areas might become brackish, with consequent changes in plants and animals.

Plate 5. Spraying a rice paddy field (copyright International Programme on Chemical Safety)

Toxic chemicals

It is estimated that, in the developing world, 10 000 people a year die from poisoning with agricultural or industrial chemicals. Environmental damage from the misuse of chemicals and unsound agricultural practice is extensive in some areas, but is difficult to quantify. Many developing countries are still using chemicals which have been banned in developed countries because they are damaging to the environment or to human health (Plate 5). The reasons for their continued use are partly economic (protection of the environment may be of low priority in countries with severe economic difficulties) and partly the lack of available information.

At ITE Monks Wood, information is readily available from an extensive and efficient library system and via computer data bases on the toxicity and potential hazard of chemicals. There is often limited information on the environmental behaviour and toxicity of chemicals in tropical countries, and most of the tests done on chemicals are biased towards conditions in the largely temperate, developed countries.

Various programmes have been set up under the auspices of United Nations (UN) agencies, such as the World Health Organisation (WHO), and the United Nations Environment Programme (UNEP). ITE is involved with two of these activities: the International Register of Potentially Toxic Chemicals (IRPTC) and the International Programme on Chemical Safety (IPCS), both based in Geneva. The funding for this work is now provided by the Department of the Environment, as part of the British contribution towards the work of these UN agencies; in the past, funding has come direct from the various agencies.

The IRPTC is a computer data base held on the UN computer in Geneva. The data base includes files on 500 chemicals which have been identified as potentially the most hazardous. It contains information on chemical structure, physico-chemical properties, hazard to human health, toxicity to various other species, details of environmental fate and of residues in the environment, together with information on the safe disposal of waste, and legal controls on use in countries throughout the world. The staff of the Register operate a free enquiry service, answering specific queries on the safe use and disposal of chemicals. The system has recently been made directly accessible and is being modified for use on mini-computers within developing countries; the computers will be provided from a fund set up by the developed world.

Information for the data base is collected by IRPTC staff and by collaborating institutes with different expertise, in various countries. ITE is one of the collaborating institutes, and has provided information to the Register on the environmental fate and toxicity of about 150 chemicals.

Information is collected by searching the scientific literature. The papers are assessed for their scientific merit, and the information they contain is reduced to a standard format on data coding sheets. This simplified and standardised information is entered into the various sub-files of the Register, where it is available, on request, from Geneva. The Register is updated regularly.

Courses on the interpretation of the data files are organised, on a worldwide basis, for people likely to make use of the Register. IRPTC seeks simply to present information and does not produce its own assessment of the particular hazards of chemicals, but the Register does contain *verbatim* reports of assessments by national governments and by international agencies. All information is fully referenced, so that those interested can obtain copies of the original source material, if they need to do so.

The International Programme on Chemical Safety (IPCS) is jointly sponsored by WHO, UNEP, and the International Labour Organisation. Its activities are varied, but include the production of documents evaluating the hazard (or potential hazard) of chemicals, with particular reference to the developing world. The documents are produced on three different levels: an *Environmental health criteria document* (EHC), which is a detailed scientific document aimed at government officials and decision-makers, containing all information available on the behaviour of a chemical and its toxicity to man, domestic animals and the environment; a

Health and safety guide (HSG), which is aimed at supervisors, local medical teams and environmental officers; and a *Safety card*, with pictorial information for the illiterate, for use in the work place. ITE is involved in drafting both EHC and HSG documents, particularly the environmental aspects, and has helped to produce 21 of the 75 documents published so far.

The draft documents are circulated widely for comments, which are incorporated in a second draft for consideration by a group of international experts who produce an agreed 'evaluation' of the hazards to man and the environment. This final draft is edited and published by WHO in Geneva and circulated, largely free of charge, throughout the world. A recent survey conducted amongst users of the documents testified to the success of the Programme.

Production of these documents is lengthy and time-consuming, because all information has to be checked repeatedly. The volume of material for well-studied chemicals is enormous — there are 35 000 scientific papers on DDT and its metabolites — and selection is often difficult, but the work is satisfying because it is both varied and useful. ITE has been involved in all stages of production of the documents, has hosted two meetings of experts at Monks Wood, and has participated in meetings elsewhere. The chemicals covered have ranged from insecticides and herbicides to metals and detergents, for all of which the lessons learnt by the developed world are being passed on to the developing countries.

Radionuclides in birds and their food in west Cumbria

Since 1983, concern has been expressed in the media about the apparent decline in numbers of waterfowl, waders and gulls in the Ravenglass estuary, particularly the black-headed gulls (*Larus ridibunda*) nesting on the Drigg dunes; it was suggested that the decline might be caused by radionuclides in the effluent from the nuclear reprocessing plant at Sellafield.

In 1985, Durham University and ITE obtained a two-year contract from the Department of Environment to investigate the situation. Durham University undertook to establish the facts about the changes in bird populations, and to study their feeding and breeding behaviour, while ITE investigated the concentrations and effects of radionuclides in the birds and their food.

The results were complicated by the Chernobyl disaster, which enhanced the concentrations of ^{134}Cs and ^{137}Cs in the tissues of most of the animals sampled for radionuclide analysis. Fortunately most of the birds were collected before 2 May 1986, the date of the Chernobyl incident, so that the material for analysis was representative of the conditions before that event. Four species of marine invertebrates had been sampled in 1984 prior to the Chernobyl incident, and this analysis allowed some comparisons to be made. In all, twelve species of invertebrates were sampled: the lugworm *Arenicola marina* and ragworm *Nereis diversicolor*, seven species of mollusc, namely the spire shell (*Hydrobia ulvae*), winkle (*Littorina littorea*), cockle (*Cerastoderma edule*), mussel (*Mytilus edulis*), peppery furrow shell (*Scrobicularia plana*), and two species of tellin (*Macoma balthica* and *Tellina tenuis*); three species of crustacean, namely the shore crab (*Carcinus maenas*), the shrimp (*Crangon crangon*) and the burrowing shrimp (*Corophium volutator*).

With few exceptions, ^{103}Ru and ^{106}Ru reached higher concentrations in all these invertebrates than any other radionuclide, but, being relatively inactive biologically, ruthenium was detected only once in a bird, in the liver of a shelduck (*Tadorna tadorna*).

The most contaminated species of those sampled in 1984 was the ragworm (^{106}Ru = 3718, ^{137}Cs = 358 Bq kg^{-1} fresh wt). By 1986, the only species with a ^{106}Ru concentration over 1000 Bq kg^{-1} was the peppery furrow shell (1648 Bq kg^{-1} fresh wt). The least contaminated species of invertebrate was the mussel, both in 1984 and 1986. ^{137}Cs concentration in this species in 1984 was only 27 Bq kg^{-1} (fresh wt) compared with 321 for the lugworm, 358 for the ragworm, and 133 for the shrimp. Only the tellins had concentrations similar to the mussels (35 Bq kg^{-1} fresh wt).

Similarly, the plutonium concentrations all appeared to have decreased since 1984. The only species still concentrating significant quantities of plutonium in 1986 was the spire shell ($^{239/240}$Pu = 107 Bq kg^{-1} fresh wt and ^{238}Pu = 28 Bq kg^{-1}). Again, the mussel was one of the least contaminated of all the species sampled ($^{239/240}$Pu = 16 Bq kg^{-1} fresh wt and ^{238}Pu = 4 Bq kg^{-1}).

Samples of lugworms and tellins were also collected from other sites on the Cumbrian coast, and from Southerness Point in the Solway Firth and Fleetwood in Lancashire. Concentrations of caesium and plutonium in invertebrates from both the latter areas were similar to those found at Ravenglass, with rather lower concentrations in Morecambe Bay and the coast of Cumbria north of Nethertown. Samples of lugworms and mussels were collected once a month from Ravenglass to measure any seasonal variation in radionuclide concentrations, but no fluctuations of this nature were detected.

All these invertebrates were analysed with normal amounts of sediment in their guts, ie as birds would have eaten them, but none contained particularly high concentrations of any radionuclides, as shown by these figures.

Of the ten species of birds from Ravenglass sampled for analysis, those which fed regularly in the estuary had the higher concentrations of caesium and plutonium in their tissues, as expected. Shelduck and oystercatchers (*Haematopus ostralegus*) had some of the highest concentrations of ^{137}Cs in their muscle tissue (295 and 613 Bq kg^{-1} fresh wt), yet both have bred successfully or increased in numbers since 1984. The least contaminated species from Ravenglass was the black-headed gull, in which the highest concentration of ^{137}Cs in pectoral muscles from eight birds was only 46 Bq kg^{-1} (fresh wt), yet their numbers in the colony breeding on the Drigg dunes declined from over 10 000 pairs in 1976 to about 1500 pairs in 1984, the last year they bred at this site. Fluctuations of a similar magnitude had occurred before, but 1984 was the first time the gullery had been abandoned, leading to the suspicion that enhanced concentrations of radioactivity in the birds' food and environment might be responsible.

Plate 6. Black-headed gulls following the plough in spring

Black-headed gulls normally feed inland during the breeding season (Plate 6) and feed their chicks on earthworms and beetles, but they do feed in the estuary to some extent both before and after nesting, taking ragworms, burrowing shrimps and spire shells. Concentrations of caesium and plutonium in adult and nestling black-headed gulls (killed by foxes (*Vulpes vulpes*) at Ravenglass in 1981 and 1984) were considerably lower than concentrations in their estuarine prey.

Assuming a background dose rate level of one m over silt, road and saltmarsh, comparable to data collected by the Ministry of Agriculture, Fisheries and Food in 1981 from Ravenglass, and modifying it by a factor of 1.5 to approximate to the exposure dose received by a bird standing on the source, it was calculated that the background exposure would be in the order of 8.3×10^{-7} grays (Gy) per hour. The birds started to arrive in February, and most had completed their clutches of eggs by the end of May, so that the total maximum background radiation dose received by the gulls could have been in the order of 2.4 m Gy over the four-month period. The total maximum dose equivalent rate to the whole body was 9.8×10^{-7} SV h^{-1} ($\simeq 8.4 \times 10^{-7}$ Gy h^{-1} whole body absorbed dose rate) and to the gut lining was $\simeq 1.8 \times 10^{-3}$ Gy h^{-1} during the same period.

Previous research workers found that nestling tree swallows (*Tachycinera bicolor*) exposed to gamma radiation at levels of up to 4500 mGy immediately after hatching suffered no ill effects, although their subsequent growth could be retarded with chronic doses of 1000 mGy per day.

Research on embryo mortality at St Bartholomew's Hospital showed that a chronic dose of 10 Gy over 20 days was necessary to reduce full-term development and cause the death of 50% of the eggs of black-headed gulls (collected from Scolt Head National Nature Reserve (NNR) in Norfolk). As the absorbed radiation dose to the gulls' eggs on the Drigg dunes at Ravenglass was no more than 0.18 mGy over the same 20-day incubation period, mortality among egg embryos or chicks could not be ascribed to external radiation.

Likewise, the total radiation received by the gulls, from their food, their tissues and their background, could not have produced any observable effects over a lifetime, being more than three orders of magnitude too low. What has emerged clearly from these studies is that the presence of foxes on both NNRs on either side of the estuary acts as a major disturbance factor when the gulls first arrive in the spring, and was almost certainly responsible for the recent extinction of the colony. The situation was exacerbated by an unusually severe outbreak of myxomatosis in 1984, from which the rabbits (*Oryctolagus cuniculus*) on the dunes did not recover for three years.

Before 1958, the gullery was managed for the gulls' eggs, which were marketed in London, and the whole area was keepered; there were, therefore, no resident foxes on the dunes, and the colony was by all accounts generally stable.

The effects of gaseous pollutants on soil decomposition

There is evidence from field observations that the distributions of certain fungi are correlated with levels of sulphur dioxide pollution. Some fungi found on leaf surfaces, fungal pathogens and lichens seem unable to survive in the presence of only moderate concentrations of this gas.

Air pollutants may similarly affect fungal and bacterial populations in soil and litter, although there is little direct experimental evidence of the impact of air pollutants on soil micro-organisms. The lack of research reflects the practical difficulties of fumigating leaf litter and soil with low concentrations of pollutant gases. Until now, studies have been mainly indirect in their approach, using the solution products of the air pollutants in place of the gases themselves, based on the assumption that many gaseous air pollutants (such as sulphur dioxide and nitrogen dioxide) become anti-microbial only in solution. There is very little information about the concentrations of pollutant solution products which occur in soils, and the results of these studies are therefore difficult to relate to field conditions.

The impact of air pollutants on litter decomposition is considered to be particularly important because the litter layer lies at the interface between the atmosphere and the soil on which forests and woodland plants depend for the nutrients necessary for their growth. Often, these nutrients become available through the process of decomposition, mediated by fungi, bacteria and animals present in the soil and litter. The suggestion that air pollutants may impair forest soil biological activity is, therefore, a serious one, and has resulted in a recent increase in research into the effects of wet deposition of air pollutants. In contrast, there have been few studies of the effects on soils of the dry deposition of air pollutants, despite the fact that dry deposition is often the most significant deposition mechanism in regions close to pollutant emission. Several research groups have reported the major importance of dry deposition of sulphur dioxide in the acidification of areas in central Europe, and a recent report suggests that the dry deposition of sulphur dioxide contributes more than acid precipitation to the acidification of large areas of the UK.

Scientists from ITE Merlewood conducted an experiment in which Scots pine (*Pinus sylvestris*) needles were exposed to a range of sulphur dioxide concentrations in a field fumigation system designed and operated by the Central Electricity Research Laboratories. The system consists of four replicate plots constructed in a 2.6 ha field at the Glasshouse Crops Research Institute, Littlehampton, and is designed to expose large sample areas to spatially homogeneous sulphur dioxide concentrations, at a range of concentrations from ambient to about 50 ppb (parts per billion).

Scots pine needles, collected from the litter layer of a pure stand growing at an unpolluted site, were air-dried and put into litter bags, each containing 5 g of dried needles. The litter bags were placed in four field fumigation plots for a period of seven months. The daily mean sulphur dioxide concentrations for the four plots were: control, 7 ppb; low, 14 ppb; medium, 30 ppb; high, 48 ppb. After fumigation, microbial respiration of the needles was determined by infra-red gas analysis, nutrient release was assessed by washing the litter bags with distilled water and analysing the resulting leachates, and samples of the needles were analysed for major elements, including calcium and magnesium.

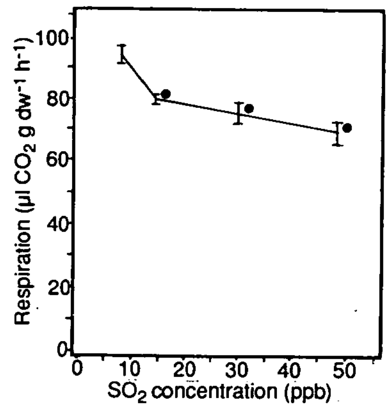


Figure 4. Microbial respiration of Scots pine litter fumigated at the Littlehampton field fumigation plots (n=6). Error bars are standard errors, ● denotes significant difference from control at P<0.05.

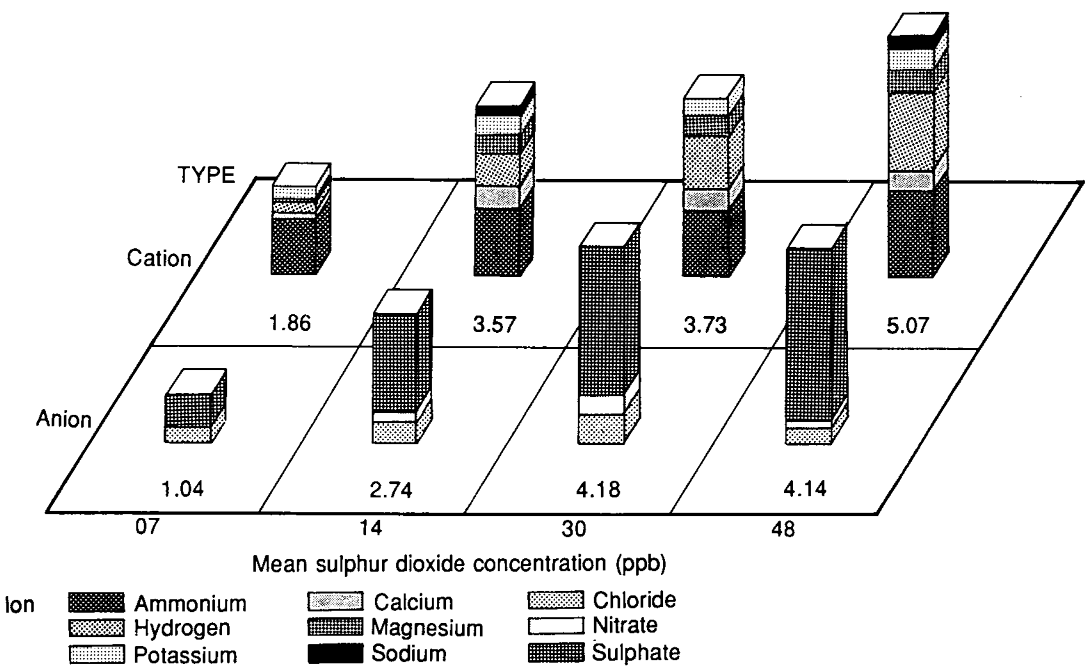


Figure 5. Chemistry of leachates from the litters exposed in the field fumigation facility. Cation and anion totals expressed in micro-equivalents per gram of needles.

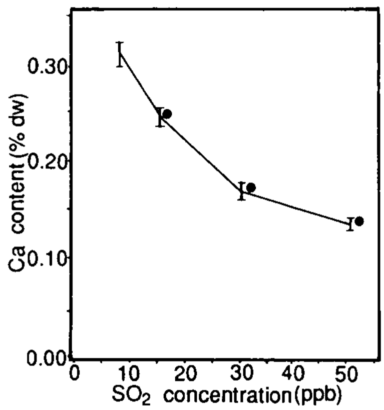


Figure 6. Effect of sulphur dioxide fumigation on the calcium content of decomposing Scots pine needles. Error bars are standard errors, ●0 denotes significant difference from control at $P<0.05$.

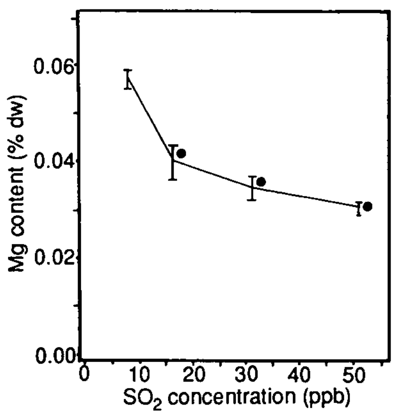


Figure 7. Effect of sulphur dioxide fumigation on the magnesium content of decomposing Scots pine needles. Error bars are standard errors, ● denotes significant difference from control at $P<0.05$.

The results show a marked reduction in microbial activity with increasing concentration of pollutant (Figure 4). The chemistry of needle leachates in relation to sulphur dioxide exposure is summarised in Figure 5; there was a marked increase in sulphate and hydrogen ion concentration with increasing exposure, and a drop in leachate pH from 5.1 in the control plot (7 ppb) to 4.2 in the most highly polluted plot (48 ppb). A significant loss of calcium and magnesium occurred, six times more magnesium being found in leachates from the 14 ppb plot than from the 7 ppb control plot. Figures 6 and 7 show clearly the effect of fumigation on the loss of calcium and magnesium from the needles. Sulphur dioxide appears to be deposited on the litter and subsequently oxidised to form sulphate and sulphuric acid, leading to litter acidification. The intermediate oxidation states (sulphite, bisulphite and undissociated sulphurous acid) are believed to be the toxic agents causing the observed reductions in litter respiration rates.

All these effects were noted after only seven months of fumigation; the longer-term effects of sulphur dioxide pollution have still to be evaluated.

In the European environment, soil acidification and the leaching of important, and often scarce, nutrient cations as a result of dry-deposited acid gases remain a cause for concern. A reduction in microbial activity could, in the longer term, result in reduced rates of nutrient mineralisation in forest soils, with a progressive impoverishment of soil fertility. The work reported here demonstrates that sulphur dioxide may be causing significant effects at less than 7 ppb, the kind of levels not uncommon in large areas of England. Similar, if not more severe, effects have been observed when deciduous leaf litters are exposed to dry deposition. There appears to be a relationship between the base status of a litter, the rates of sulphur dioxide deposition and the resultant pH reductions, and effects on biological activity.

The work is being extended to determine which types of litter, soil and micro-organisms are most affected by sulphur dioxide, and to investigate the effects of ozone and oxides of nitrogen on the chemistry and biology of soils.

A study of the frost hardiness of red spruce growing in the Appalachians

Visible signs of forest decline that could be attributed to atmospheric pollution are found in two areas of North America: San Bernardino National Forest near Los Angeles and the high-elevation forests of the Appalachians in the eastern United States. It has been suggested that atmospheric pollutants and photochemical oxidants, in these mountainous areas, have so altered the physiology of the trees that they have become susceptible to frost and drought, and other extremes of weather which may be associated with climatic change.

Since the summer of 1986, ITE Edinburgh has been participating in the US National Acid Precipitation Assessment Program (NAPAP), a major research programme involving several research projects on various problems relating to atmospheric pollution. The ITE project, the first work outside the United States to be funded under the Program, is concerned with the decline of red spruce (*Picea rubens*) in the Appalachians, and seeks to establish whether the decline is associated with a reduction in winter hardiness, and whether such a reduction could be caused by exposure to pollutants.

Most tree species growing in their native habitats start to harden well before the onset of severe autumn frosts and can withstand sub-zero temperatures below those normally experienced during winter. Red spruce growing in the northern Appalachians, therefore, could be expected to start hardening in August and to be able to withstand temperatures down to at least –40°C, while in the southern Appalachians red spruce trees

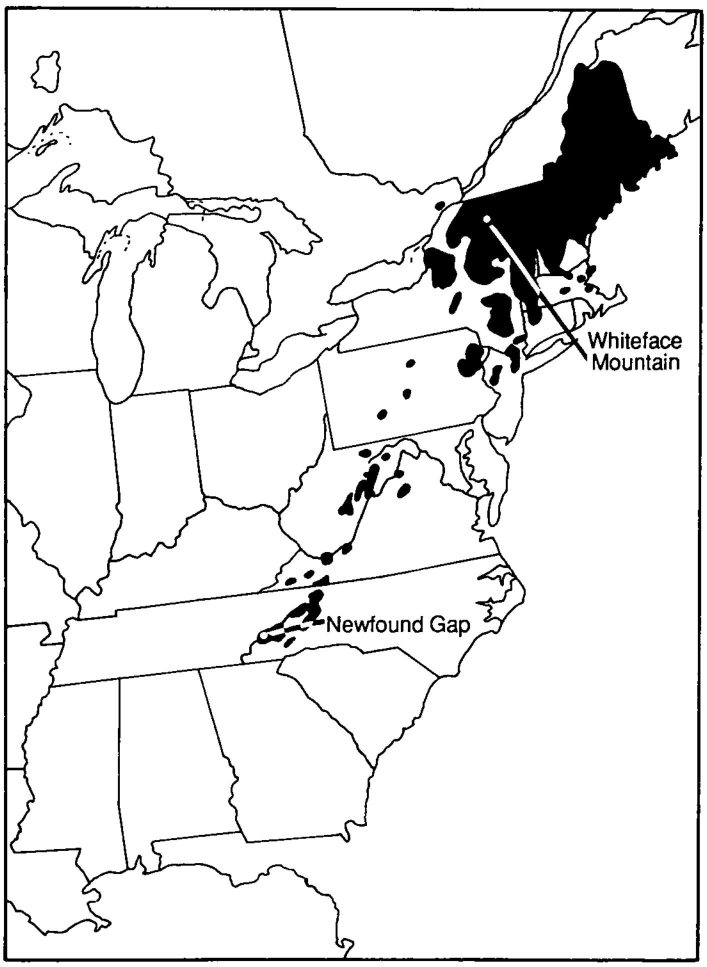


Figure 8 Natural range of red spruce, showing the location of the two main sites at which shoots were collected for frost hardiness assessments.

should start to harden in September and be able to withstand at least –30°C. The ITE study compared material from healthy trees growing on Whiteface Mountain (New York State), Newfound Gap (North Carolina) (Figure 8) and Kilmun (Scotland), with shoots taken from trees showing signs of dieback in Clingman's Dome (Tennessee). The shoots were taken from the trees in the United States at regular intervals between the months of August and February and freighted to Edinburgh for testing. (In the first year, 1986–87, when samples were taken between September and December, the results indicated that a longer sampling period was necessary.) The material was subjected to temperatures between –3°C and –39°C in a controlled-temperature freezing cabinet, programmed to ensure gradual cooling to the selected temperature, at which the shoots were held for three hours, followed by gradual warming. After freezing, the shoots were stored at 3°C for 14 days and then visually assessed for damage.

The pattern of frost hardening was related to the current maximum and minimum daily temperatures and to the past records of temperatures at the collecting sites. Shoots from Whiteface Mountain, where there are often cool nights in August with minimum temperatures below 10°C, began to harden in August; those from Newfound Gap, where minimum temperatures are higher than 10°C during August and early September, did not begin rapid hardening until the end of September (Figure 9). Maximum frost hardiness was similar at the two sites, although winter temperatures are much lower at Whiteface Mountain. Shoots from trees at Clingman's Dome were, surprisingly, at least as hardy as those from Newfound Gap, despite the symptoms of forest decline; at the end of January, none of the shoots was damaged by temperatures of –39°C. Trees of red spruce (of New York State origin) growing in Scotland were found to be hardy to between –33°C and –39°C, even though the lowest temperature recorded that winter at Kilmun was –7°C. Individual trees at all sites differed significantly in their frost hardiness. The least hardy trees may have suffered slight frost damage in severe winters over the last 22 years (1968, 1976, 1980 and 1981 at Whiteface Mountain; 1974, 1983 and 1985 at Newfound Gap).

These findings and the evidence of past records do not lend much support to the view that trees suffering from decline in the Appalachians are predisposed to frost damage. The timing, rate and extent of frost hardening were adequate to protect trees from injury at all sites in the period to the end of November, and only in very severe winters were the more susceptible trees likely to be damaged. If pollutants do predispose red spruce to frost injury, the effect is slight, and certainly not sufficient on its own to account for forest decline in the high Appalachians. However, the study did not examine the susceptibility of trees to winter desiccation or the tendency to deharden prematurely. These and other factors require further research.

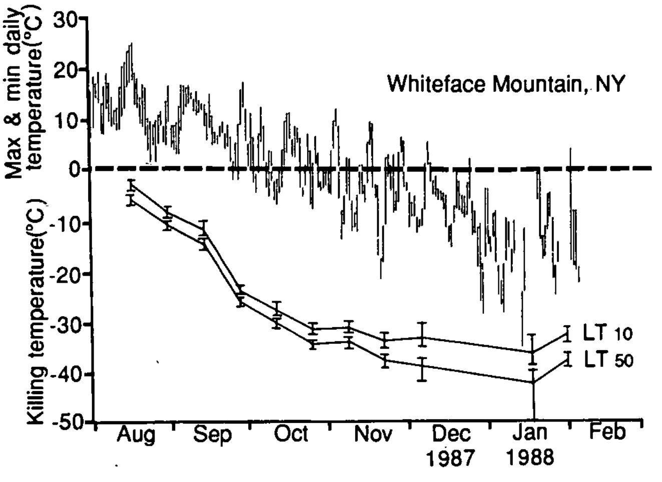
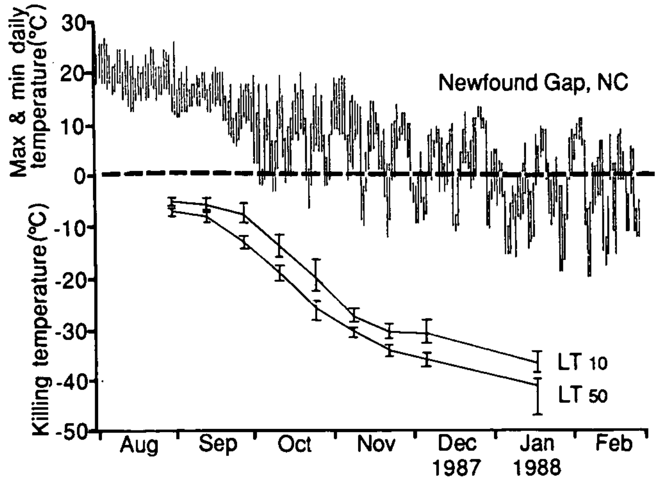


Figure 9. Change in the frost hardiness of current year's shoots of red spruce on trees growing at Whiteface Mountain, NY, and Newfound Gap, NC, in 1987–88, shown in relation to maximum and minimum daily air temperatures. LT50 is the temperature killing 50% of the shoots; LT10 is the temperature killing 10% of the shoots. Vertical bars are the 95% confidence limits.



Some problems associated with commercial forestry

ITE's programme of forestry research has widened and developed from its original focus on tree growth and physiology to encompass work on many of the agents that threaten or damage commercial forest plantations. Work on three such agents is described here.

Bark stripping by red deer in a Sitka spruce plantation

Extensive afforestation has occurred in upland Britain in recent decades, with Sitka spruce (*Picea sitchensis*) the tree planted most frequently. Red deer (*Cervus elaphus*) (Plate 7) have colonised many of these forests and have sometimes damaged the trees by scraping the bark off the trunks for food (Plate 8). It is feared that the value of the timber crop is being seriously reduced in some areas.

ITE Banchory has been studying the impact of deer in Glenbranter Forest, Argyll, since 1978, and has previously reported on browsing damage to young trees. This report describes when and where bark stripping occurs, how many trees are damaged, and the nature of the wounds.

Some 6000 trees were monitored, at 42 afforested sites, each roughly 1.5 ha in extent. Checks for damage were made every three months or, since 1984, every six months.

Plate 7. A red deer stag in winter, the season when most bark stripping occurs

Bark stripping occurred most frequently in winter and least frequently in summer, with more trees being wounded in the December–March period than in the whole of the rest of the year. This seasonal pattern was consistent throughout the study.

The incidence of bark stripping was very patchy. Over one-year periods, most sites suffered no damage, but at four sites 5–10% of the trees were bark stripped (Table 1). At the worst affected thicket site, 18 of 176 trees were damaged. Overall, rather less than 1% of the trees were bark stripped per year, with negligible rates of damage in stands nine- and 44-years-old. Much heavier rates of damage were experienced by Norway spruce (*Picea abies*) than Sitka spruce, both in pole and high-canopy forest.

Often the trees bark stripped were found to be near-neighbours, as shown in Figure 10. Trees were bark stripped a second or third time significantly more often than expected by chance, so small patches of forest showed heavy rates of damage over the years. In Figure 10, two trees were bark stripped three times between 1981 and 1986 and another tree

Plate 8. A bark stripping wound of typical size, with tooth marks resulting from the scraping action of the deer

Table 1. The occurrence of different intensities of bark stripping on Sitka spruce in Glenbranter Forest, at study sites and on study plots (sites comprised six plots randomly positioned within *c* 1.5 ha; plot size ranged from 75 m² at pre-thicket sites to 480 m² in high-canopy forest).

Forest stage	Age (yrs)	Number of sites with trees bark stripped (%) during a 12-month period: 0	1	2	3-4	5-6	7-8	≥9	Average no. trees per site	Initial no. of sites
Establishment-restock	0-8	67	3	1	1				140	14
Pre-thicket	9-14	22	14	1	1		1		162	4
Thicket	15-28	29	20	10	2	2		1	170	8
Pole	29-44	20	6	2	1				275	4
High-canopy	44-	48	4	1					129	9

Forest stage	Age (yrs)	Number of sites with trees bark stripped (%) during a 12-month period: 0	1-4	5-8	9-12	13-16	17-20	≥20	Average no. trees per plot	Average size of plot (m²)
Establishment-restock	0-8	419	4	2	1				23	180
Pre-thicket	9-14	210	11	11				2	27	143
Thicket	15-28	323	24	22	9	3	3		28	91
Pole	29-44	144	14	3	1			1	46	177
High-canopy forest	44-	235		3		2			22	468

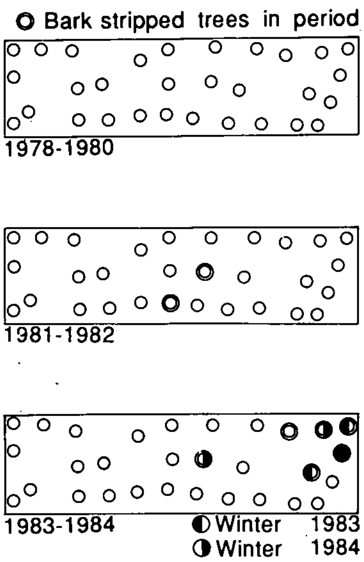


Figure 10. Clustering in the incidence of bark stripping over nine years amongst 30 trees initially 19-years-old. Damage is shown for two-year periods and selected three-month seasons.

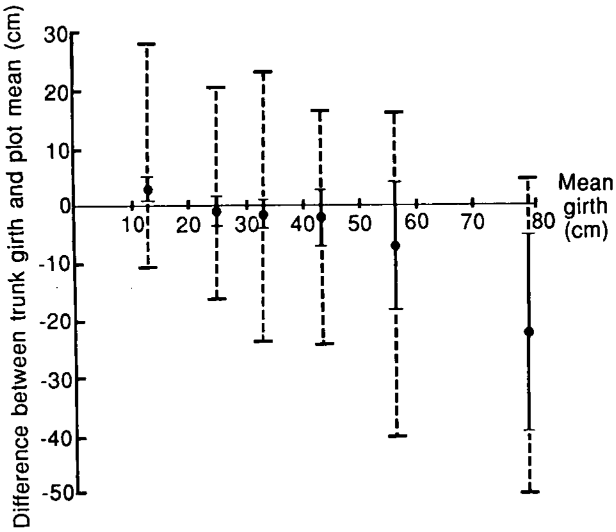


Figure 11. Selectivity in bark stripping on Sitka spruce, as shown by comparing the girth of damaged trunks and the girth of all trunks on plots with damage, in size classes of mean girth. 95% confidence limits and ranges (dotted lines) are given.

was damaged twice in 1985–86, but the chances of a tree being bark stripped again declined steadily with time. None of the damage 'hot-spots' encountered in Glenbranter persisted throughout the nine years of the study.

Selectivity in bark stripping was examined by comparing the girth of damaged trees or trunks with plot means (Figure 11). On plots where the mean tree girth was less than 20 cm, the trunks damaged were significantly larger; on plots with means between 20 cm and 40 cm, the damaged trunks were of average girth; on plots where the mean girth was above 60 cm, damaged trunks were significantly smaller than the girth average. The trunks bark stripped varied quite widely in size at all mean girths, possibly because neighbouring trees often have different girths.

Some of the trees that are bark stripped will ultimately die, especially in the older forest stages where small trees are often suppressed by taller neighbours or may be thinned. The impact of bark stripping on the tree crop is thus somewhat diminished. Accumulating the observed rates of damage over the 36-year vulnerable period (Table 1) suggests that 27% of the trees are likely to be affected. However, for the trees in the top quartile, the accumulated rate of damage is only 14%; these trees will ultimately provide most of the timber yield.

The great majority of bark stripping wounds were small, especially in young stands and high-canopy forest (Table 2). In Norway spruce the wounds were somewhat larger, the biggest found during the study being 2030 cm², compared to 1330 cm² for Sitka spruce. Pathologists believe that small wounds often heal before rot-causing fungi can colonise, and that only wounds greater than 300 cm² in size are highly susceptible to rot. These predictions will be tested by following the fate of the damaged trunks. However, defects in the timber near the wounds may result from the production of resin and distortions to growth, and the extent of spread of small wounds along the trunks may have important effects on timber quality.

The losses in timber value caused by bark stripping in Glenbranter are appreciable, but not very serious. From the number of wounds and the estimated deer density, individual red deer rarely appear to feed on bark, an assessment confirmed by the total absence of Sitka spruce bark in the stomachs of 300 red deer shot in the area. Nevertheless, if the habit of eating bark became more widespread, damage could increase dramatically.

Table 2. Size of bark stripping wounds on Sitka spruce trees in Glenbranter Forest.

Forest stage	Number of wounds in size class (cm)			
	<60	60-99	100-299	300
Establishment-restock	11	1	1	0
Pre-thicket	40	9	5	2
Thicket	148	25	30	5
Pole	53	11	24	6
High-canopy forest	7	4	1	0

Towards an ecological basis for predicting insect pest outbreaks

The farmer or forester always wants to know when and where pest outbreaks will occur. As well as the current problems facing the grower, there are threats from new pests entering the country, pests switching host plants, pests on new crop species, cultivars or provenances, and new pests which arise as side-effects of control measures.

For example, in recent years, new insect pest problems have emerged in UK forestry. Most of these pests are native insects which have hitherto caused no problem on native trees, but have become pests since they colonised the exotic conifers which form the basis of the UK forest industry. The most serious of these pests is the pine beauty moth (*Panolis flammea*) (Plate 9), a noctuid whose larvae consume pine needles. Prior to 1976, this insect was only found on Scots pine (*Pinus sylvestris*), to which it caused no appreciable damage. However, following the establishment of lodgepole pine (*Pinus contorta*) plantations in Scotland in the late 1950s and early 1960s, there have been over 50 outbreaks at more than 30 different forest locations, over 2.5 million trees have been killed, and many more have been saved only by insecticide application by the Forestry Commission (FC).

Plate 9. Pine beauty moth

The grower's response to a pest problem can be to allow damage to occur or to spray prophylactically. The dangers inherent in these alternatives are either financial loss (because crops are damaged), or both financial loss (if insecticides are applied unnecessarily) and harmful side-effects. An accurate predictive system would enable more precise control and reduce both financial loss and adverse environmental effects. In marginal cases, eg in agricultural systems where pests cause a small loss in yield, predictive systems must attain a certain degree of accuracy to be a better strategy than prophylactic control. In other cases, such as that of the pine beauty moth, failure to control could be economically disastrous, but to apply insecticides prophylactically would be extremely expensive, logistically almost impossible, and environmentally unacceptable.

This report considers two aspects of the prediction of outbreaks of a forest pest: where in the forest can an outbreak be expected, and when?

The identification of areas of forest which are particularly at risk from attack by insect pests has been the preoccupation of forest managers for many years. Forest areas are large, and difficult and costly to survey. However, pest outbreaks typically start in relatively small parts of the forest, and then spread out to threaten larger areas. It is widely acknowledged that, if the location of outbreak epicentres could be predicted, pest management would be made much easier. The most reliable way to establish a site risk assessment system is to categorise areas which appear to be particularly vulnerable to pest outbreaks, and then to try to establish an ecological basis for the site/outbreak relationship.

In Scotland, outbreaks of the pine beauty moth usually centre on areas of lodgepole pine growing in deep unflushed peat where trees grow poorly. The pattern of outbreaks is similar to that of many other insect pests, whose outbreaks centre on areas where trees are growing in stressful conditions, such as ridge tops, poorly drained soils or very shallow sandy soils. The main current theory to explain the association between insect outbreaks and poor tree-growing sites is that the foliage of trees grown under stress improves in quality as a food source for pests because of an increase in foliar nitrogen or a decrease in the level of anti-herbivore chemicals such as tannins, or both. Many pest management problems could follow from accepting this theory too readily. For example, if tree stress is important, efforts to alleviate it (by thinning and fertilizer application) may succeed in reducing pest numbers. However, if stress is not involved in stimulating pest outbreaks, then practical measures to alleviate it would be worthless.

This theory had not been adequately tested before, but the pine beauty moth system appeared to be an ideal case for examination. Therefore, in 1983, a study was initiated to see whether outbreaks of the pine beauty moth started in areas of deep peat because the trees growing there were nutritionally better for pine beauty moth larvae. Various methods were employed: the nitrogen and tannin content of pine foliage was analysed; the survival, growth and development of larvae were assessed in predator exclusion cages; and populations were monitored on trees growing in different soils. The results were surprising. No evidence could be found to support the theory that lodgepole pine growing in deep peat provided a better food source for pine beauty moth larvae: the nitrogen level of pine foliage was higher for trees growing in deep peat and the tannin level was unaffected by soil type; larvae survived and grew less well on trees growing in deep peat; and the growth of pine beauty moth populations during the spring and summer seasons was unaffected by soil type.

A different basis is required for predicting where pine beauty moth outbreaks will occur. Moreover, there is now a general need to question the widely accepted view that pest outbreaks occur where trees are subjected to stress, because it not only appears to be untrue for the pine beauty moth on lodgepole pine, but recent research in USA and Scandinavia strongly suggests that it is not true for a range of defoliating insects.

The pine beauty moth is a typical univoltine forest pest; its populations take several years to reach levels which threaten serious defoliation to lodgepole pine plantations. However, the number of years between outbreaks is not constant (Figure 12). If control measures are to be rationally applied against this insect, its populations must be closely monitored or its fluctuations must be accurately predicted.

In Scotland, the pest control strategy currently adopted against the pine beauty moth is based on close monitoring of the overwintering soil-dwelling pupae. If their numbers exceed a certain threshold level (in an autumn survey),

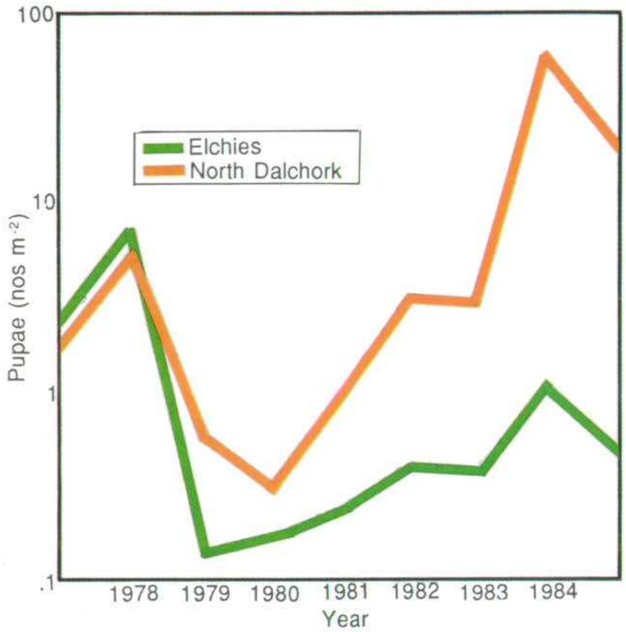


Figure 12 Changes in the numbers of pine beauty moth in two forests. Population numbers reached pest outbreak levels in both forests in 1978. Although a second outbreak occurred six years later in North Dalchork, Elchies Forest remained free from further outbreaks.

then a check on the population is made again by assessing egg numbers the following spring. If serious defoliation is considered likely, then insecticide control measures are applied when egg hatch is nearly complete.

The current system is, therefore, one of short-term prediction. The main advantage is its accuracy; the main disadvantage is that the egg survey has to be done very rapidly in the short period between the end of egg laying and the start of egg hatch. The best hope for an improvement in short-term prediction lies in replacing the egg survey by a predictive population model. The main obstacle to such a model is the large degree of variability in adult fecundity which occurs in Scotland. However, a joint ITE/FC project on adult emergence, egg laying and egg hatch has shown that much of this variability can be explained by the temperature between March and early May. The eventual aim of this project is not just to reduce dependency on the egg survey, but also to predict when control measures should be applied.

Medium-term outbreak prediction by a population model may also replace, to some extent, the need for monitoring pupal numbers. However, the model requires an accurate knowledge of the important factors influencing the survival of every stage of the pine beauty moth life cycle. Recent research in ITE and FC has begun to provide this information. Among the important relationships which have been revealed and which will have to be incorporated in an accurate population model are the close dependency between egg hatch and bud burst which is necessary for good larval survival, and the influence of one year's damage on the ability of lodgepole pine to protect itself from attack in the following year.

Trees and windthrow

The hurricane-force storm in southern England during October 1987 highlighted the high cost to forests and woodlands that such 'catastrophic' events can cause. However, normal winter gales each year cause millions of pounds of damage to commercial conifer forests.

Staff at ITE Edinburgh are working in collaboration with the Forestry Commission Research Branch and the University of Oxford to quantify the effects of wind on commercial plantations of Sitka spruce (*Picea sitchensis*). Of particular interest is the question of inter-tree spacing. Trees planted widely apart tend to be more wind stable, apparently because they develop thick stems and widely spread roots, but such trees may produce many large branches and low-density wood, making them less valuable to the timber industry. If the effect of tree form on wind stability can be quantified, it should be possible to choose a 'compromise' tree spacing which provides increased stability without causing too great a loss in timber production and value.

Four aspects are currently being investigated.

1. *Peak windspeeds over forests*

Windspeed will vary during any storm, gusting to peaks which might be damaging to trees. In order to predict the risk of damage, it is necessary to know not only the commonly available mean hourly windspeed, but also likely peak windspeeds. None of the Meteorological Office weather stations record windspeed over a forest. To compare extreme (ie peak) windspeeds over the particularly rough surface of a forest with results from coastal and open-country sites, ITE has installed an anemometer and wind vane at Rivox, Moffat Forest, in south-west Scotland. The readings from these instruments are monitored by a battery-operated data logger programmed to record hourly mean and peak windspeeds and mean directions, as well as the frequency of occurrence of different windspeeds in steps of 5 m per second up to $50\,m\,s^{-1}$.

2. *Bending of tree stems due to constant forces*

Although a tree bending in the wind is subjected to varying forces from the wind and the weight of its own displaced canopy, it is useful to start investigations by considering steady forces. The easiest way to apply a steady force to a tree is to attach a cable at, say, 70% of total height and apply tension with a winch. Using this method, the shape of the bent stem can be recorded by tape measures and the force applied measured with a loadcell in the cable. A bent position before any damage has occurred to soil or roots is then a good representation of the situation when the tree is swaying in non-destructive winds. The problem of relating the bending of the stem for a given force lies in: (i) the limited knowledge of the elastic modulus of wood in living conifers; (ii) the need to cut up the tree and weigh each part; and (iii) the fact that simple engineering theory does not apply, because the amount of bending in a tree is much greater than would be experienced by any normal engineering structure. However, a method has recently been described in which the tree is divided vertically into 'elements' of, say, one metre; the bending of each element of stem will be small enough for the engineering theory to apply. This approach has been used with eight mature (9.6–13.2 m height), 22-year-old Sitka spruce trees for which mass distribution and the variation in diameter along the stem were known. By matching the theoretical stem bending curve with field measurements (shown for four trees in Figure 13), an estimate of Young's modulus of elasticity of the stemwood and the distribution of stress along the stem were obtained. Young's modulus for these trees fell in the range 2.0–6.4 GPa (gigapascals), generally lower than that reported for sawn green timber but similar to that reported for intact stem sections. The distribution of stress (longitudinal force per unit area) along the stem was not uniform, but reached a maximum (Figure 14) at a height which depended on the taper, as measured by the ratio of tree height to stem diameter 2 m from the ground. Maximum stress occurred higher up in the more tapered stems (Figure 15). Although the bending force was applied at a single point in this investigation, calculations showed that a maximum in the stress distribution, albeit less pronounced, would still occur from the wind drag forces which are distributed up through the canopy. This non-uniformity has also been found in Japanese red cedar (*Cryptomeria japonica*) and is to be preferred to the assumption of uniform stress distribution.

3. *Bending of tree stems by varying forces*

When a gust of wind hits a tree, it bends, storing elastic energy which is released as kinetic energy on the back swing. From the principle of energy conservation, the maximum kinetic energy must equal the maximum stored

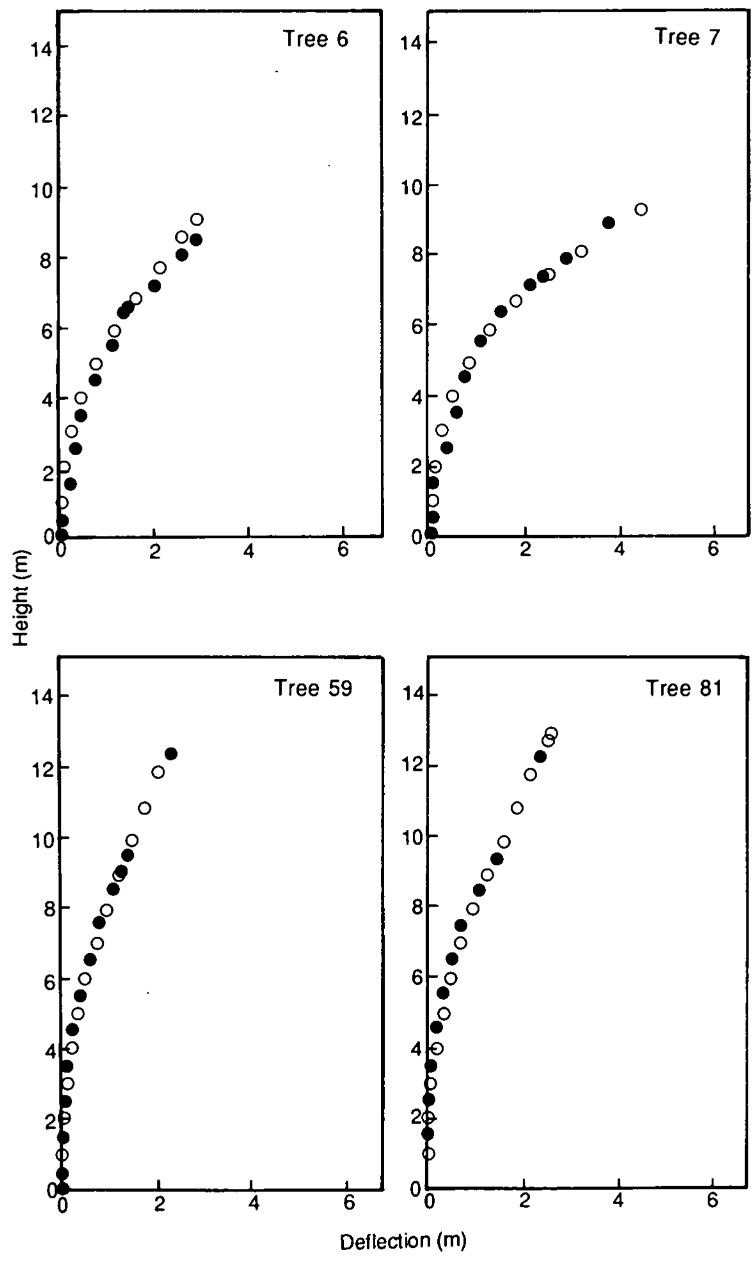


Figure 13 The shapes of bending stems of 22-year-old Sitka spruce trees growing at Moffat Forest in south-west Scotland. The trees were bent using a winch and cable attached at 70% of tree height. Measured deflected positions (●) are compared with those calculated from a structural mechanics model of the tree treated as a multi-element tapered cantilever beam (O).

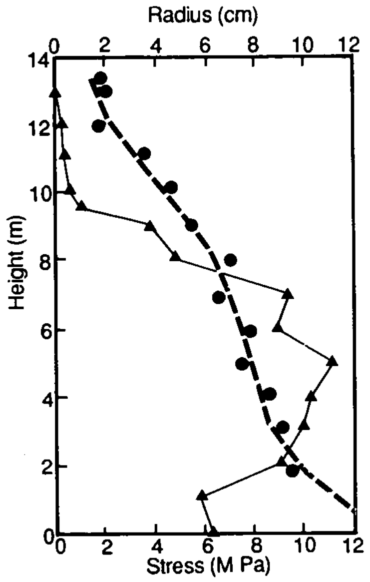


Figure 14. Variation of estimated stress (▲-▲) with height within a single stem of Sitka spruce, compared with the variation of stem radius with height. Radii are shown as measured values (●) and as a fourth order polynomial fitted to these measurements (----).

elastic energy. Maximum elastic energy is stored at the maximum deflection, and can be calculated using the multi-element mechanical theory mentioned above. The maximum kinetic energy of the tree during the same oscillation occurs as the tree passes through the mid-point, and depends primarily on the mass of material and the frequency at which the tree sways naturally. The natural frequency of sway can be estimated because all the other variables are measured or calculated from the mechanics. This approach has been tested against data obtained by the Forestry Commission Research Branch for five 13 m high Sitka spruce. The estimated natural sway frequency compared well with that observed in the field during manual swaying, and fell in the range 0.3–0.5 Hz.

The sway of a tree is damped so that it dies out if only one gust passes. Damping is caused by the resistance of the air, by structural damping in the stem and, in forests, by the branches of neighbouring trees rubbing together. These components of damping can be separated in manual sway tests by observing the decay of the oscillation in three situations: (i) with neighbouring branch interference, (ii) with neighbouring trees tied back to remove inter-branch contact; and (iii) with branches removed to eliminate air damping. Damping in the above sway tests was recorded in this way, and coefficients based on the simplest case of viscous drag (damping force proportional to velocity) were calculated from the decay of the oscillation. More detailed consideration of the air damping of branches suggests, however, that the damping is due to drag forces, which are proportional to velocity to the power 1.8, and therefore different from viscous drag. It is possible, however, to calculate an equivalent viscous drag damping coefficient which will be dependent on sway amplitude. Such coefficients were calculated for the spruce in the sway tests, and an encouraging agreement was reached with the results from the decay of oscillation. Inter-branch (based on the concept of drag in the 'mixed' medium of branches plus air) and structural damping are now being considered, and more field data are being collected.

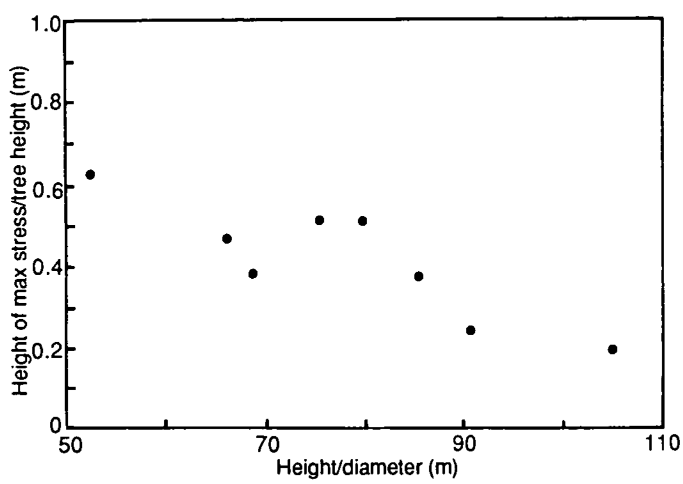


Figure 15. The height at which maximum stress occurred in stems of Sitka spruce when bent by cable and winch, shown as a function of the ratio of tree height (m) to diameter (m) at 2 m from ground. Height of maximum stress is expressed as a fraction of tree height.

4. *The effect of spacing on tree form*

The description of the statics and dynamics of tree sway requires the mass distribution and other mensurational data for the individual tree. To apply the mechanical theory to management practice, it is necessary to know how tree form varies in typical plantations due to natural and imposed factors, like inter-tree spacing. In 1980, ITE established a spacing trial at Eskdalemuir, south-west Scotland, in collaboration with the Economic Forestry Group. The trial consists of plots of Sitka spruce at four spacings (500, 1000, 1500 and 2000 stems ha^{-1}) at each of three elevations, and is designed primarily to study variation in growth rate with spacing. It will also provide valuable data on variation in tree form.

This research is partially supported by the CEC materials programme, and links are maintained with similarly supported research on wind tunnel modelling at Oxford University and with field studies of tree canopy manipulation at the Danish Forest Experiment Station.

Land use and resource management

Wind is a potential source of power for the generation of electricity. ITE has been commissioned by the Department of Energy to undertake a study of this potential in the UK, a project which is outlined below. The other work reported in this section is concerned either with aspects of resource assessment for planning purposes (one study based in Wales and the other in China), or with ways in which the use of land for agriculture and other purposes affects the vegetation of natural habitats.

Wind energy

Research by the Department of Energy (DEn) has shown that wind power is one of the most promising renewable energy sources for generating electricity. The case has been made that up to 20% of our electricity needs in the UK could be supplied by wind energy. In November 1986, the world's first variable geometry vertical axis wind turbine was inaugurated at Carmarthen Bay in Wales, and one year later the UK's largest wind turbine was inaugurated in Orkney; this three megawatt turbine provides sufficient power for 2000 homes.

Its commitment to wind energy has led the Department of Energy to investigate its potential for use nation-wide. A numerical modelling project has been established to assess the UK wind resource and to quantify windflow over the complicated terrain which prevails over much of the land surface. The model will provide a relatively simple and inexpensive method of resource evaluation for the whole of the United Kingdom. However, not all of the land area can be exploited, either for technical reasons, eg features like forests distort windflow, or because of constraints on the use of land, such as the planning controls in National Parks which are likely to prohibit the construction of windmills. DEn's Energy and Technology Support Unit, based at Harwell, has commissioned ITE to identify and quantify these constraints. The first phase of the project covers factors pertaining over large areas and which are capable of being recorded for the whole country. A second phase, to identify the most suitable areas without physical or environmental constraint, will incorporate wind energy data. This phase may involve sampling, based on the principle of land classification, similar to that used successfully by ITE in a variety of other studies, eg to identify areas of land available for planting trees for energy purposes. Finally, detailed site constraints, such as the distance to individual houses, will be determined before tackling the ultimate objective, namely the identification of those sites fulfilling all of the necessary requirements which would make them suitable for the erection of a windmill.

The wind resource model is based on the National Grid. Because resolution is possible down to a single one km grid square, it has been necessary to ensure that the physical and environmental constraint information collected is available in the same format. The aim is to prepare an inventory of all one km squares in the UK (and Northern Ireland) which will enable assessment of whether or not any square is constrained by physical or environmental factors and which of the many types of constraint applies. A one km square could be totally within, for example, an urban area, lake, forest, National Nature Reserve, Area of Outstanding Natural Beauty, Environmentally Sensitive Area or a green belt. Because the constraints vary between the absolute (an urban area) and the less immutable (a green belt), it is important that such a distinction is retained within the data base for each square.

Further definition within the square is also necessary as it may be possible and desirable to site a windmill close to a feature which occupies the square without filling it, eg a road or part of a Site of Special Scientific Interest. To that end, an automated procedure has been devised, based on a digitising package; it enables not only the quick identification and recording of a totally constrained one km square but also recording of partially constrained squares, by calculating the percentage of the square so constrained.

The digitising computer package uses a Tandon Personal Computer and involves the operator in digitising the four corners of the map containing the required information, thus fixing the map in the context of the National Grid. Closed areas within these four parts can then be digitised to allow different characterisation of each area. The string of connected digitised parts, or arc, delimits an area which can be 'seeded' according to its characterisation, the process being observed on a VDU screen, as it happens. Appropriate software translates this arc into lists of the one km grid squares, designated by National Grid co-ordinates, contained therein.

At the outset of the project, it was clear that the time taken to digitise data on a national scale would be substantial, but the scale at which it was undertaken could not compromise the objective of within-square resolution for some factors. One of the most time-consuming tasks was to digitise urban areas, roads, rivers and forest blocks. Fortunately, data in a suitable format were already available through Mapdata, a commercial organisation involved in UK map production. The digitising burden, therefore, has been restricted to areas where there are institutional environmental constraints.

As no single environmental agency has, as part of its remit, the task of collating the various constraints on development at a national level, it has been necessary to approach all of the appropriate agencies for information on the land areas for which they are responsible. The Nature Conservancy Council (Sites of Special Scientific Interest, National Nature Reserves), Ministry of Agriculture, Fisheries and Food and the Department of Agriculture and Fisheries for Scotland (Environmentally Sensitive Areas), the Countryside Commission of England/ Wales and Scotland (Areas of Outstanding Natural Beauty, National Parks, National Scenic Areas) are three of several such agencies. Separate government departments have responsibilities for Northern Ireland. The availability and quality of suitable mapped data to cover the UK have been found to be extremely variable both within and between agencies. The task of assembling suitable data is, therefore, considerable, but the information base currently being compiled will be extremely useful in helping to answer strategic questions about land use and land availability, as they arise in the future.

Following the sieving process to remove areas of constraint, the remaining areas will be assessed in relation to the wind resource, and land which is suitable will be identified. At that stage, detailed constraints will need to be determined, including roughness of terrain, distance to village, houses, roads, etc, local windflow patterns, and transmission costs. It will be necessary to survey, by sampling, the suitable one km squares to obtain an estimate of the areas with highest wind potential and with no environmental constraints. Sensitivity analysis will also be possible, as some of the constraints, eg green belts, are concerned with a presumption against development.

A series of key areas will be identified for detailed site surveys. The factors incorporated at this stage will include geological and soil conditions, visual assessment, ownership, patterns of small woodlands, and hedgerows. Finally, individual site assessments will be produced, defining the environmental characteristics. Among the detailed characteristics to be ascertained at this stage is the local movement of bird populations. Bird mortality is probably not a matter of concern, but disturbance of evening flight patterns, for example, may cause population displacement.

Resource management in the Less Favoured Areas: integrating digital elevation data with remotely sensed data

In 1985, the Joint Research Centre (JRC) of the EEC instituted a collaborative programme of research into the use of remote sensing for management applications in the agriculturally Less Favoured Areas (LFA) of the EEC. The main aim of the programme is the establishment of practical management models within which remotely sensed data can be used to supply part or all of the information needed for operational decision-making related to land management activities in these regions.

The study described here forms part of the collaborative programme and is being undertaken by ITE Bangor within the Snowdonia National Park. A National Park was chosen for the study because the statutory requirements for integrated land use planning within the Park make it a suitable place to test the application of remotely sensed data and systems for land use modelling. Of particular interest are models for the systematic appraisal of landscape and environmental quality, for the detection and measurement of change, and for assessment of possible effects.

Remote sensing in upland regions of Britain is fraught with a number of problems, including the high incidence of cloud cover, the effects of terrain on imagery, and the complex nature of the land cover mosaic. Some of the interpretation problems can be overcome by the use of remotely sensed imagery in combination with co-registered data sets (particularly digital terrain data), and the following paragraphs describe some of the techniques being developed.

The study will ultimately cover the whole of the Snowdonia National Park, but, initially, a small subsite was selected to develop and test some of the basic methods. This subsite is situated in the southern part of Snowdonia and covers a 10 km x 10 km region of varied topography with deep valleys and grassy mountain slopes. Local relief is in the order of 900 m, with extensive areas of steeply sloping ground. Land cover is diverse and includes coniferous and deciduous woodlands, wetlands, acid mountain grasslands, and large areas of moorland and bracken.

A digital elevation model (DEM) of the area has been generated by automatically scanning contours from an Ordnance Survey (OS) map and rasterising the resultant digital contours using terrain modelling software. The DEM produced a raster elevation image by linear interpolation of the height values, and slope and aspect were derived by computing partial derivatives of the local surface of the terrain model.

Simple enhancement techniques applied to remotely sensed imagery of upland areas can be effective in identifying and mapping broad cover types, such as coniferous forest, felled areas, moorland, and agricultural grassland. However, it is apparent (Plate 10 left) that the intensity of reflected radiation from areas of uniform cover varies as a consequence of changes in slope gradient and aspect, due primarily to changing levels of illumination resulting from differences in the orientation of the ground surface. If classification techniques are to be reliable in areas of extreme topography, methods of radiometric correction must be developed to suppress this topographic interference. Various methods have been proposed, including the use of band ratios and the separation of training sets into aspect subclasses. In this study, a reflectance model was used to correct multispectral imagery prior to classification.

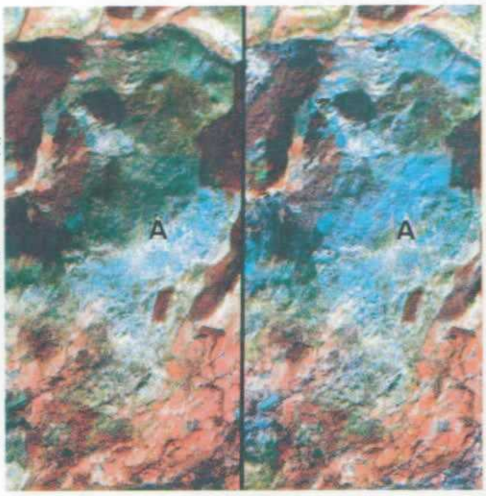


Plate 10. The effect of topography on satellite imagery. 'A' marks the summit and the ridge line between north- and south-facing slopes in a uniform area of mat-grass grassland; (left) raw data, (right) corrected data (image copyright CNES 1986)

The simplest reflectance model assumes perfectly diffuse reflection at the surface, and correction is necessary only for differences in illumination caused by the orientation of the surface. However, natural vegetation canopies are not perfectly diffuse reflectors. It is, therefore, necessary to modify the simple model by including both incidence and exitance parameters. Solar azimuth and elevation were derived from navigation data associated with the satellite imagery, and the local angle of solar irradiance was derived by computing partial derivatives of the surface of the elevation model. Applying this reflectance model significantly reduced the problem of differential illumination (Plate 10 right) and improved the accuracy of the land cover classification.

Traditional automated classification of digital satellite imagery has tended to rely solely on spectral information. In areas of low or no relief, where there are large homogeneous fields of arable crops, this approach has worked well, but the technique is not so accurate in upland regions. However, it is well known that vegetation zones in upland areas correlate well with elevation, a simple example being the tree-line. A

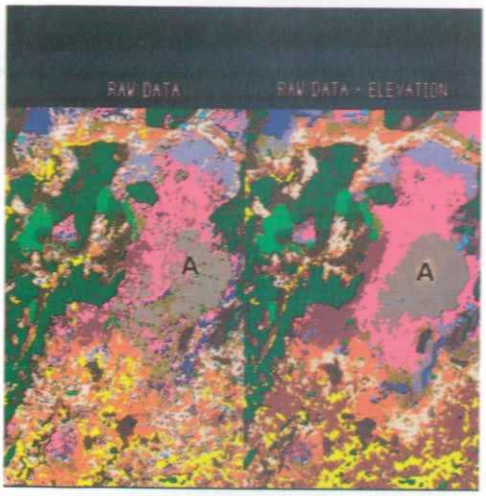


Plate 11. The effect of using elevation data with multispectral data on the classification of upland vegetation units. 'A' marks summit of mountain

Table 3. Some examples of decision rules for British upland vegetation.

Bent-grass (*Agrostis*)	Not above 1500'; slopes 0–40° (>10, then rare on south aspects); prefers better drained, less acid land.
Moor-grass	Usually 2100'; gentle slopes; slight northern preference; prefers damper soils.
Bracken:	<1800'; rare on wet lands (and flat); aspect not tolerant of exposure or deep shade, higher altitude on south-facing slopes.
Bilberry (*Vaccinium*)	<4100'; slopes 0–40° (maximum abundance on gentle slopes).
Heather (*Calluna*)	<2500'; only on well-drained land (steeper slopes), usually rocky.

digital elevation model has, therefore, been used to supplement multispectral data in maximum likelihood image classification (Plate 11). The dispersed nature of vegetation units in the spectral classification around the summit (A) has been transformed into a distinct concentric pattern by the addition of elevation data. The resulting classification clearly separates the mat-grass (*Nardus*)-dominated grassland on the summit from the moor-grass (*Molinia*) at lower altitude, and bracken (*Pteridium aquilinum*) and improved grasslands on the lower valley-sides.

The enhancement of spectral information can be taken much further. There is a wealth of existing ecological knowledge about the distribution of vegetation in relation to environmental factors, and ITE has sought to develop procedures to formalise this knowledge. For example, relationships between topographic variables and the spatial distribution of upland vegetation communities can be expressed as rules which can be used to influence the multispectral classification, perhaps by computing prior probabilities for different vegetation types.

A simple example of such a rule relates to the tree-line (species X does not grow above Y metres). This information can be placed in a spatial context by using a digital elevation model. Digital elevation data can be used to compute other landform parameters, such as slope, gradient and aspect. Figure 16 illustrates how the shape of the local surface might be used to resolve confusion between moorland and wetland (moorlands prefer the dry conditions found on convex slopes, whilst wetlands tend to be found in hollows or concave surfaces). Table 3 lists more complex rules relating vegetation distribution to altitude, slope and aspect.

This knowledge has been built into a series of 'decision rule' classifiers which compute prior probabilities for different land cover units from their topographic environment, as described above. The effect of these procedures on

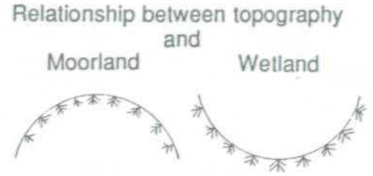


Figure 16. Simple example of a decision rule relating vegetation distribution to topography.

classification performance is currently being assessed.

An interesting and useful consequence of the existence of co-registered multispectral satellite imagery and digital elevation data is the possibility of generating three-dimensional perspective views (Plate 12). Outputs of this type have potential applications for landscape assessment and land use planning. For example, proposed changes such as afforestation or major construction developments can be mapped as a digital overlay and presented as a perspective plot in order to assess their likely visual impact. One application currently being considered for this type of product is the ecological consequences of reservoir expansion.

Plate 12 shows part of a perspective plot of the study area viewed from the south-east at an angle of 30 degrees. This viewpoint was chosen to highlight trends in vegetation patterns with altitude, by means of a cross-section of an area of varied relief. The false-colour composite used in this illustration depicts coniferous forest in dark red, moorland in green, montane grassland and clearfelling in blue, and improved land in pink.

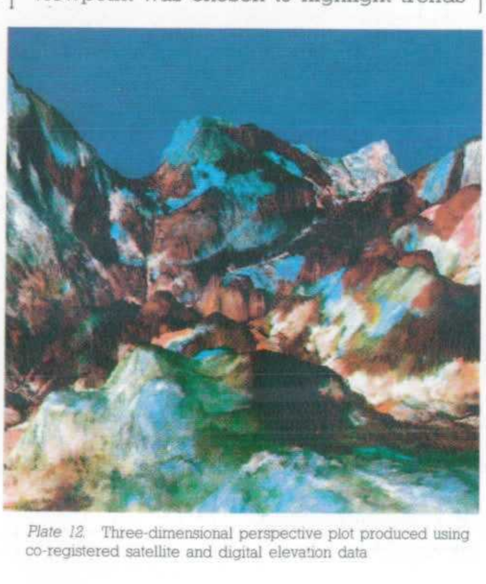


Plate 12. Three-dimensional perspective plot produced using co-registered satellite and digital elevation data

The management of renewable natural resources in China

With support from the British Council and the Overseas Development Administration, ITE has developed working links with two environmental organisations in China, the Institute of Applied Ecology (IAE) in Shenyang (formerly the Institute of Forestry and Soil Science), and the Commission for Integrated Survey of Natural Resources (CISNAR) in Beijing.

Collaboration with IAE began in 1980, with the aims of working with Chinese ecologists to improve the management of mixed species forests in China, for both conservation and sustainable production.

The project is focused on the Changbai Mountain Reserve, designated an international Biosphere Reserve by UNESCO in 1958, and situated in north-east China along the border with Korea (41°42' N, 127°38' E). It has a total area of 210 000 ha, made up of a core area of 80 000 ha with absolute protection and a surrounding buffer zone of 130 000 ha, at altitudes from 700 m to 2691 m above sea level (asl). There are four well-defined vertical vegetation zones (Figure 17): coniferous/broadleaved mixed forest, boreal conifer forest, birch (*Betula ermanii*) wood, and alpine tundra, representing a unique series of vegetation zones on the east coast of the Eurasian continent.

IAE and ITE jointly organised an international symposium at Changbai in the summer of 1986. The symposium volume, entitled *The temperate forest ecosystem*, was published by ITE in 1988. It contains papers on recent research in

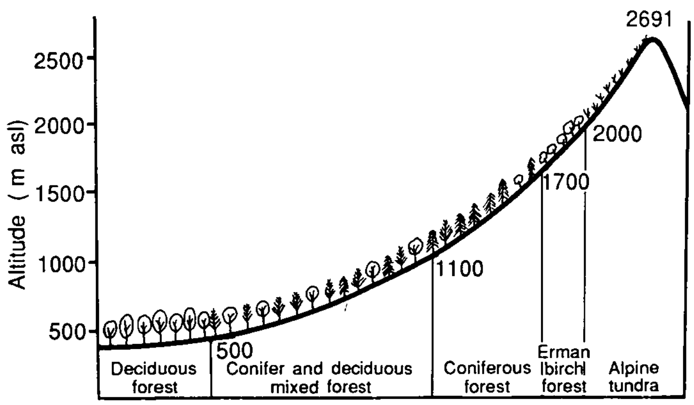


Figure 17. Altitudinal zonations of vegetation on the north slope of Changbai Mountain Biosphere Reserve.

temperate forests in different countries, and provides detailed descriptions of the Changbai sites and research recently carried out there.

A computer simulation model of forest growth and nutrient dynamics, FORTNITE, originally developed in the USA but modified and developed by staff at ITE Merlewood, is now being used for the integration of the Changbai data.

IAE has compiled a data base consisting of four classes of data obtained from continuous field work since 1979:

i. environmental factors
ii. tree growth parameters
iii. tree nitrogen response data
iv. forest floor decomposition rates and nitrogen levels.

Data on eight major dominant species have so far been included to date: Korean pine (*Pinus koraiensis*), Amur linden (*Tilia amurensis*), Manchurian ash (*Fraxinus mandshurica*), painted mono maple (*Acer mono*), Mongolian oak (*Quercus mongolica*), Japanese elm (*Ulmus propinqua*), yellow birch (*Betula costata*), and poplar (*Populus*) species. The final data base will include information on 26 key species growing at Changbai.

The FORTNITE model will enable the Chinese scientists to assess the impact of alternative management scenarios on nutrient cycling, soil fertility and species composition. The most important topics being investigated are:

i. the development of the forest in terms of biomass production and species composition;
ii. the possible effects of selected management practices.

The collaborative work with IAE has highlighted several important points.

1. Although much high-quality research has been carried out at Changbai since 1979, many of the benefits of the results have not been fully utilised.
2. The modelling approach has helped to identify omissions in the data.
3. Limited access to Western literature has meant that, although the project leaders understood the value of systems analysis, they lacked practice in applying it.
4. The FORTNITE model was written as a series of Fortran modules; it was fortuitous that the original version transferred easily to the PDP 11/24 computer at IAE (ecological models should not only be based on good ecological principles and sound data, but should also have a high degree of portability and good-quality documentation).

CISNAR co-ordinates and organises integrated surveys and expeditions to collect information for evaluating the natural resources in China. This information is then processed into proposals for the rational exploitation, utilisation and conservation of those resources. ITE collaboration with CISNAR originally concentrated on methods of data handling, soil survey and interpretation, but the work has recently been expanded to include methods for evaluating soil erosion and land use planning at a provincial and county level.

In 1983, the south China expedition team from CISNAR completed a detailed survey of natural resources in Jiangxi Province in the heart of the red earth region. This subtropical region is located 23°10'–30°2' N and 108°10'–122°8' E, occupies an area of 616 000 km^2, 12% of which is cultivated land, and has 126 million inhabitants, most of them peasants. The density of population is 205 km^2, twice the average for China.

Topographically, the land falls into three main regions: low land, represented by river valleys and other low-lying areas, low hills up to 300 m asl and high hills above 800 m. Before the Cultural Revolution, the low lands were extensively cultivated for agriculture, and the lower and upper hills were forested. During the Cultural Revolution, there was massive deforestation, followed by widespread severe soil erosion. Today, many parts of the lower and upper hills, which can potentially support very productive forests and high-yielding agricultural and horticultural crops, are bare or covered with scrub and poor-quality grassland.

The region is capable of considerable agricultural expansion, having a favourable climate, with average temperatures of 12–15°C, an annual accumulative temperature of 4500–6500°C, a growing season of 230–335 days, few days of frost on the lower ground, and an annual precipitation of 1200–2000 mm, mainly falling in ten months of the year.

At present only about one-third of the region is used to its full potential, for a number of reasons:

i. the debilitating effects of soil erosion;
ii. the lack of high-quality pastures;
iii. industrial pollution, including acid rain, which is starting to affect the environment;
iv. the intensive use of fertilisers, especially in the paddy fields, which is beginning to cause excess nitrogen in the groundwater.

After a multi-institute visit to Jiangxi Province in October 1987, CISNAR, ITE, and the UK Soil Survey and Land Resource Centre (SSLRC) produced a collaborative research programme for the area, including the following main topics:

i. the calculation of precise estimates, based on stratified random sampling procedures, of the extent and degree of severity of the soil erosion;

ii. detailed studies of physical, chemical and biological properties of the main soil groups so that models can be developed for the major types of land use;
iii. the improvement of experimental design, statistical treatment of results, and analytical techniques for experimental farms and research stations;

Both the Chinese environmental scientists and the local staff are aware of the major environmental problems in the region, and feel that the development of a sounder scientific approach will help them to find a solution more rapidly. As in many other parts of the world, a lack of funds is impeding progress, but in 1986 the World Bank, through the International Development Association (IDA), provided credit of 40 million dollars for the Red Soils Area Development Project, which aims to improve the production of cash crops and livestock, and to create about 41 000 jobs in the red earth area of Jiangxi and Fujian Provinces.

Agricultural extensification: is the answer in the soil?

Since the 1940s, agricultural production has been rising steadily. This increase has been brought about by two main factors: (i) economic policies which have favoured both the increased cultivation of marginal land and the increased use of nitrogen fertilisers; (ii) scientific advances in plant breeding and crop husbandry. However, as we approach the 1990s, forecasts of agricultural economics within the EEC suggest that there must be a reduction in agricultural output. Two policies have been put forward: a reduction in the area of land farmed ('set aside'), or a reduction in production per unit area ('extensification'). Whilst this major reversal in agricultural policy has received a great deal of publicity over the last year, it is worth noting that such reversals have occurred in the past; there are, for example, many areas of semi-natural vegetation of Grade 1 National Nature Reserve status which show evidence of former cultivation. What is perhaps unique to the present situation is the potential scale of the reduction in productivity, and the implication that there may be the opportunity and resources to make a positive decision about the new land use objectives. One potential alternative land use might be the creation of new habitats with a high conservation interest in regions, such as the south of England, where the area of land available for conservation purposes is relatively small. Work at ITE Monks Wood is examining some of the problems in re-establishing floristically rich communities on abandoned agricultural land.

There are two main strategies that resource managers could use to create a diverse flora on agricultural land. The first option is to rely on natural succession to produce an acceptable result, perhaps with some manipulation such as controlled grazing. This approach has been successful on an abandoned old field overlying limestone at Wytham Woods in Oxfordshire, but the assumption must be made that propagules of the desired species will arrive at the site, either from buried seed sources or as seed rain, and that residual fertility is low enough to prevent the invasion and eventual dominance of aggressive species. It is well known that, when soil fertility is raised, species typical of floristically rich semi-natural habitats tend to disappear, leaving the more competitive species as dominants. A second approach is to be more ruthless about the required objective, and to manage specifically towards those ends. Seed mixtures containing the range of required species can be obtained and steps taken to manipulate soil fertility. ITE work is concerned with soil fertility and aims to discover whether it is a problem, and, if so, to decide what can be done about it.

The initial task was to compare the fertilities of soils from agricultural sites with soils under successional vegetation sequences on similar parent materials. Six sites were selected, two each on clay, sand and limestone, and three successional stages (species-rich grassland, scrub and woodland) at each site were compared with a soil currently being farmed nearby. Succession theory predicts that soil fertility (especially nitrogen supply) increases during succession. If this is the case, where do agricultural soils lie in the sequence? If agricultural soils have a high ranking, the objective should perhaps be to establish a later, rather than an early, successional stage. There is a great deal of experimental information on the problems of re-establishing early-successional, floristically rich vegetation after late-successional stages have been cleared. Some of these experiments might be used to glean predictive information for the establishment of species-rich vegetation on abandoned agricultural land.

Plate 13. Experimental sets of plant growth bioassays

Table 4. A comparison of (i) extractable phosphorus and (ii) mineralisable nitrogen concentrations in soils on agricultural land and from semi-natural communities on three parent materials.

	Parent material					
	Clay		Sand		Limestone	
Site	Hatfield Forest	Coombe Hill/ Northchurch Common	Clumber Park	Sherwood Forest	Lathkill Dale	Monks Dale
i. Extractable phosphorus (mg 100 g^{-1})						
Agricultural land	6.8	1.9	29.1	1.2	3.1	1.6
Grassland	0.9	0.7	0.5	1.3	0.6	0.3
Scrub	2.4	2.0	0.4	1.2	0.3	0.4
Woodland	0.3	1.2	0.8	0.5	4.1	1.2
ii. Mineralisable nitrogen (mg 100 g^{-1} 14 d^{-1})						
Agricultural land	8.3	4.0	2.4	6.6	14.3	13.2
Grassland	14.2	6.3	2.8	3.4	9.7	16.2
Scrub	15.4	6.6	4.8	2.7	14.9	14.9
Woodland	2.2	3.4	1.8	3.0	19.3	16.0

The fertility of soils on the selected sites was measured by standard chemical analysis and by comparative plant growth studies (Plate 13). Initial results showed that: (i) the main factor determining residual fertility in the agricultural soils was the level of extractable phosphorus, and nitrogen supply appeared, at least initially, less important; (ii) there was a great deal of variation in the factors affecting soil fertility between the successional stages.

Agricultural soils had extractable soil phosphorus levels ranging from 3 to 58 times higher than those of comparable semi-natural grasslands (Table 4), with the exception of an agricultural area at the Sherwood Forest overlying sand. This particular area is, in fact, an old field, abandoned in 1975, which now supports a rich grassland flora. The results suggest that, in sandy soils, extractable phosphorus can fall from agricultural levels to those of semi-natural grassland within about 12 years. The nitrogen supply was also greater in the Sherwood Forest agricultural (old field) soil than in the comparable semi-natural grassland soil. This may be the result of the old field soil having been limed in the past, increasing the pH over that of the semi-natural grassland soil (pH 6.0 compared to pH 3.5) and improving conditions for the microbial populations involved in N-mineralisation. In addition, there will undoubtedly have been increases in organic matter accumulation since the field was abandoned, providing additional substrate for microbial populations.

The data on soil fertility from the different successional stages emphasise the variability between the different successions on the different parent materials. On two scrub soils phosphorus supply was greater than on grassland soils, on another two scrub soils nitrogen supply was greater, but on the remainder there was no difference (Table 5). Woodland soils were found to be more fertile than grasslands only on the limestone sites, with phosphorus supply greater at one site and both nitrogen and phosphorus greater at the other (Table 5). These results suggest that increased soil fertility during succession may not be a general phenomenon, and, where it does occur, either nitrogen or phosphorus, or both, can be responsible.

Table 5. A summary of sites where phosphorus (P) and nitrogen (N) supplies were greater in scrub and woodland soils relative to unimproved species-rich grassland.

	Successional stage	
Site	Scrub	Woodland
Hatfield Forest	P	—
Coombe Hill/Northchurch Common	P	—
Clumber Park	N	—
Sherwood Forest	—	—
Lathkill Dale	N	PN
Monks Dale	—	P

The next phase of the study will focus on experiments where reductions in soil fertility have been observed after certain species have been sown. The aim is to devise methods for the creation of floristically rich vegetation on fertile agricultural soil, and to predict the timescales required for successful treatment.

The importance of linear features in agricultural landscapes

During 1974, staff based at ITE Merlewood carried out an ecological survey of Cumbria, which included recording vegetation from representative sample quadrats. In the course of the survey, it was observed that much of the botanical variation was not present in the open fields, because of intensive management involving fertilisers, herbicides and other agricultural practices, but occurred in linear features such as hedgerows and streamsides. Accordingly, during ITE's ecological survey of Great Britain in 1978, a method was developed to incorporate these linear features, by placing random quadrats along streamsides, hedgerows and roadside verges within each sample one km square. The data collected were used to estimate the extent to which linear features contributed towards the botanical variation in the landscape. These data are now being re-analysed, as part of a project funded by the Department of Environment (DOE), which aims to assess the ecological significance of changes taking place in land use. As part of this study, it is important to establish the vegetation composition of hedgerows, verges and streamsides, not only because of their inherent conservation interest, as seed sources and as habitats for insects, birds and mammals, but also because they are particularly susceptible to change.

Figures 18–20 present the mean number of species recorded per 10 m x 1 m plot within each ITE land class (ordered on a lowland–upland gradient), for each type of linear feature. The streamsides show a similar pattern of variability, with upland streams (eg in land classes 29 and 30) containing many species. Within the lowlands, classes 26 and 6 have a wide degree of variability, the former because eutrophication is not so great a problem in the Scottish lowlands and the latter because of generally less intensive management in the south-west of Britain. Roadside verges (Plate 14) show a rather different pattern because of the dominance of management, especially in the lowlands. Those in classes 28, 6 and 29 have most species. For hedgerows, some land classes stand out as having an exceptionally high number of species; in particular, land class 6, typical of much

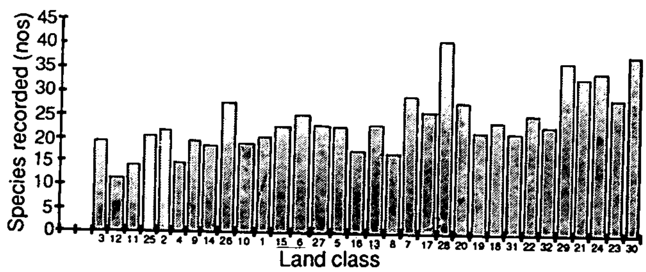


Figure 18. Mean number of species recorded in two 10 m x 1 m quadrats, situated at random locations on streamsides, where present, within eight one km squares taken at random from each of 32 land classes.

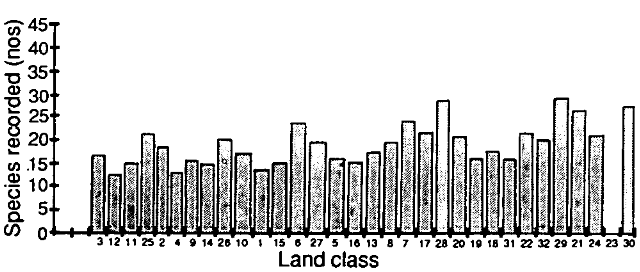


Figure 19. Mean number of species recorded in two 10 m x 1 m quadrats, situated at random locations on roadside verges, where present, within eight one km squares taken at random from each of 32 land classes.

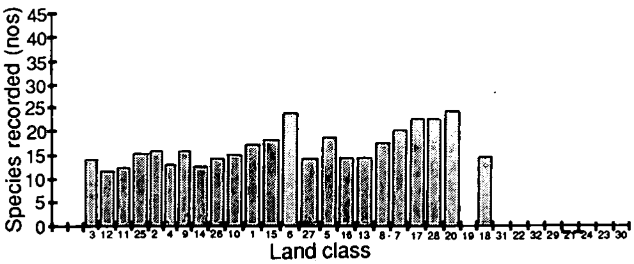


Figure 20. Mean number of species recorded in two 10 m x 1 m quadrats, situated at random locations on hedgerows, where present, within eight one km squares taken at random from each of 32 land classes.

of the west country, has a wide variety of species in the complex hedgerow banks. Other land classes, particularly those in the intensively farmed agricultural lowlands, have few species left in the hedgerows because of spraying and eutrophication along field margins.

In another analysis (Table 6), the numbers of species unique to the three linear features were compared with the numbers unique to other sample quadrats. Even though the data correspond to an area of only 20 m^2 along the linear features, as opposed to 1000 m^2 elsewhere, the figures show that the streamsides have a comparable number of unique species with the other (non-linear) sample quadrats; in other words, streams have a relatively high number of unique species. Hedgerows have comparable numbers with other areas in the lowlands, but the numbers of unique species fall off rapidly in the uplands, where grazing suppresses variability. Managed verges have relatively low numbers of species.

The linear features contain species not present in general agricultural land. An examination of the actual composition of the unique species shows the influence of the type of habitat involved. Streamsides contain species typical of water habitats, such as great hairy willow-herb (*Epilobium hirsutum*) and yellow flag (*Iris pseudacorus*), whereas the hedgerows contain more woody species, such as dog rose (*Rosa canina*), honeysuckle (*Lonicera periclymenum*) (Plate 15) and bramble (*Rubus fruticosus*). In the roadside verges and streamsides, there are meadow species, such as meadow-sweet (*Filipendula ulmaria*), wild angelica (*Angelica sylvestris*) (Plate 16) and meadow cranesbill (*Geranium pratense*). There is thus considerable potential for the management of linear features to develop and maintain a varied composition of species in areas that are otherwise intensively managed for agriculture.

A third analysis examined the most common species within different sample quadrats from linear features in the land classes. The strong diagonal arrangement of Table 7 shows that a wide range of species occurring in streamside habitats have a distinct upland–lowland gradient. The upland streamsides are dominated by species from the surrounding vegetation, with the more interesting

Plate 14. A roadside verge showing typical low vegetation maintained by a regime of spraying and cutting

Table 6. Species unique to two 10 m x 1 m quadrats placed at random along linear features, where present, in each of 32 land classes, compared with those from five 200 m² quadrats placed at random within the squares.

Land class	Verges		Hedges		Streams		Quadrats	
	Total	Unique	Total	Unique	Total	Unique	Total	Unique
3	84	11	102	17	123	26	179	42
12	100	18	92	17	39	23	229	35
11	89	11	84	11	62	23	110	61
25	78	8	67	9	67	45	106	47
2	102	11	118	8	127	8	211	120
4	119	13	130	20	125	22	205	39
9	131	14	119	11	158	39	238	54
14	107	7	77	16	110	41	145	51
26	92	10	90	11	117	38	148	72
10	85	8	91	11	110	28	150	49
1	68	8	62	18	70	32	123	67
15	72	12	67	8	68	24	96	84
6	84	11	73	20	117	21	173	75
27	65	7	64	9	113	43	132	77
5	97	10	103	15	141	22	221	73
16	88	12	71	8	143	53	147	53
13	108	10	102	8	154	36	164	68
8	79	15	47	14	136	25	193	50
7	54	10	119	16	120	35	155	87
17	89	13	61	12	168	40	181	35
28	65	8	58	2	139	44	161	53
20	49	11	61	3	116	44	170	58
19	54	5	0	0	90	31	111	63
18	54	14	47	3	158	23	162	57
31	87	4	0	0	115	6	129	84
22	103	7	0	0	164	22	212	71
32	111	10	0	0	142	15	210	46
29	103	9	0	0	197	28	212	54
21	98	6	0	0	183	22	208	43
24	66	11	0	0	172	32	150	37
23	0	0	0	0	87	31	184	52
30	81	12	0	0	96	49	138	33

localised species being less common, while the lowland streams have species such as oat-grass (*Arrhenatherum elatius*) and cock's-foot (*Dactylis glomerata*), characteristic of habitats with a low level of management.

The recent decline in management of verges is reflected in the abundance of coarse-growing species from a very restricted range (Table 8). As with the streamsides, there is a marked difference in the species composition of upland and lowland habitats, but with a sharp distinction between land classes 7 and 17 — the transition to upland conditions. The pattern of distribution within the hedgerows (Table 9) is one of relatively few dominant species, with a similar distinction between land classes 7 and 17. However, the importance of hedgerows in conservation terms relates particularly to the rarer species rather than to the dominant elements, because, at least in East Anglia, hedgerows are reservoirs for rare woodland species that are otherwise absent from the countryside.

Plate 15. Honeysuckle — a climbing plant found in hedgerows

Plate 16. Wild angelica — a common plant in verges and streamsides

Table 7. Occurrence of the most common species from the streamside quadrats in each land class.

Streamside species	Lowland															Land classes																Upland
	3	12	11	25	2	4	9	14	26	10	1	15	6	27	5	16	13	8	7	17	28	20	19	18	31	22	32	29	21	24	23	30
Galium aparine	+	+																														
Cirsium vulgare		+																														
Anthriscus sylvestris			+																													
Heracleum sphondylium			+																													
Phalaris arundinacea	+				+																											
Filipendula ulmaria				+																												
Mentha spp.					+																											
Agropyron repens						+																										
Rumex conglom./sang.	+										+																					
Arrhenatherum elatius		+						+		+						+																
Hedera helix					+								+																			
Urtica dioica		+	+	+			+	+		+	+		+				+		+													
Cirsium arvense											+																					
Rubus fruticosus			+				+	+					+		+		+		+													
Apium nodiflorum			+																+													
Rumex obtusifolius									+					+																		
Ranunculus acris												+																				
Poa nem./triv.	+		+	+	+		+	+		+	+		+	+	+						+		+									
Agrostis stolonifera						+		+	+	+								+	+													
Dactylis glomerata								+								+		+														
Ranunculus repens				+		+			+	+		+	+	+	+	+				+	+	+	+	+								
Epilobium spp.											+	+			+					+												
Lolium perenne																+																
Pellia spp.															+		+															
Juncus effusus	+											+								+		+		+		+	+	+			+	+
Holcus lanatus									+	+				+	+	+		+	+		+	+	+	+								
Rorippa nasturtium-aquat.																			+													
Epilobium hirsutum																			+													
Stellaria alsine																				+												
Prunella vulgaris																						+										
Agrostis tenuis																				+				+	+		+					
Festuca ovina																									+							
Plantago lanceolata																									+							
Anthoxanthum odoratum																					+			+	+	+	+		+		+	
Nardus stricta																								+	+				+	+	+	
Galium saxatile																								+		+	+		+		+	
Viola riviniana																												+				
Carex nigra																									+						+	
Calluna vulgaris																									+			+	+	+		+
Molinia caerulea																												+		+		
Potentilla erecta																										+	+	+	+	+		+
Agrostis canina																														+		
Blechnum spicant																												+				+
Myrica gale																																+

Other linear features may be important reservoirs of species, eg the lines between crops, even though these may be as little as one metre wide. Headlands could also contain important fragments of previously widespread species assemblages. The initial analysis of further information collected in 1988 adds further emphasis to the importance of linear features. Studies are also proceeding to examine the extent of the resource of buried seed present in the soil. The maintenance of linear features and of the resource they contain could be of major significance in the future development of the countryside. Such features need not conflict with the main areas of agricultural production, and can make an important visual contribution to the attractiveness of the landscape.

Table 8. Occurrence of the most common species from the roadside verge quadrats in each land class.

Roadside verge species	Lowland													Land classes																		Upland
	3	12	11	25	2	4	9	14	26	10	1	15	6	27	5	16	13	8	7	17	28	20	19	18	31	22	32	29	21	24	23	30
Anthriscus sylvestris			+				+																									
Rumex obtusifolius							+																									
Urtica dioica		+			+					+																						
Matricaria matricoides								+				+				+																
Agropyron repens	+	+				+					+							+														
Heracleum sphondylium		+	+		+				+	+	+		+				+		+													
Arrhenatherum elatius		+						+		+		+	+				+	+	+													
Taraxacum agg.	+				+	+	+			+			+	+	+	+	+	+		+		+										
Poa trivialis				+										+							+	+										
Poa annua		+	+	+	+		+	+	+	+					+	+						+	+	+								
Achillea millefolium	+																		+							+						
Ranunculus repens																							+									
Trifolium repens				+					+					+	+				+	+		+		+	+		+					
Dactylis glomerata	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+			+					
Lolium perenne	+	+	+	+		+		+	+	+	+	+		+	+	+	+	+	+	+	+	+		+				+				
Agrostis stolonifera	+		+			+		+				+							+													+
Holcus lanatus			+	+									+	+		+			+		+					+	+	+				+
Plantago major					+							+								+				+								+
Poa pratensis																								+								
Plantago lanceolata																		+							+			+		+		
Rumex acetosa																									+							
Trifolium pratense																									+							+
Festuca rubra																					+		+							+		
Anthoxanthum odoratum																					+								+			
Cerastium holosteoides																					+		+	+		+		+	+	+		+
Bellis perennis																									+		+					
Luzula mult./camp.																										+						
Rhytidiadelphus squar.																										+						
Potentilla erecta																										+			+	+		
Agrostis tenuis																											+		+	+		
Nardus stricta																											+					
Festuca ovina																											+		+			
Centaurea nigra																												+				
Juncus effusus																												+				+
Prunella vulgaris																												+	+	+		+
Lotus corniculatus																												+				+
Calluna vulgaris																													+			
Cirsium vulgare																																+
Veronica officinalis																																+
Hypochaeris/Leontodon																																+

Table 9. Occurrence of the most common species from the hedgerow quadrats in each land class.

Hedgerow species	Lowland													Land classes																		Upland
	3	12	11	25	2	4	9	14	26	10	1	15	6	27	5	16	13	8	7	17	28	20	19	18	31	22	32	29	21	24	23	30
Prunus spinosa	+																															
Agropyron repens				+		+																										
Heracleum sphondylium	+				+				+																							
Arrhenatherum elatius	+	+					+	+		+	+	+		+	+		+	+														
Rubus fruticosus agg.	+	+	+		+	+		+	+	+	+	+	+		+	+	+	+	+													
Urtica dioica		+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+													
Galium aparine		+	+		+		+				+			+				+	+													
Hedera helix		+											+		+				+													
Dactylis glomerata	+			+		+	+	+		+		+	+	+	+	+	+			+		+										
Crataegus monogyna	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+			+	+	+		+								
Poa trivialis										+											+											
Taraxacum agg.																+																
Rosa canina													+								+											
Festuca rubra																			+		+											
Holcus mollis																				+												
Digitalis purpurea																				+												
Corylus avellana																				+												
Agrostis tenuis																				+				+								
Holcus lanatus																								+								

Vegetation change in the Dorset heathlands

Heathland, dominated by ericaceous plants, is a plagioclimax community dependent for its maintenance on man's use of the land. In the past, grazing, sporadic fires, the cutting of turves and peat, and the gathering of gorse (*Ulex* spp.) and bracken (*Pteridium aquilinum*) prevented succession to scrub and woodland, and maintained open, dwarf shrub vegetation. In lowland Britain, almost all heathlands have been reduced in extent and are now remnant patches in a matrix of farmland, forest and urban land. The Dorset heathlands are a typical and well-documented example.

In 1978 and 1987, these heaths were surveyed extensively by staff at ITE Furzebrook, and records of vegetation, the presence of rare plants, topography and land use were collected from over 3000 200 m grid squares. A data base was established on the NERC IBM computer at Wallingford, and Fortran programs were developed to sort and search the data base, to produce listings, or to draw maps for any specified combination of attributes.

Preliminary results from the 1978 survey were published in 1980, and vegetation characteristics were used to examine the patterns of diversity and composition of the invertebrate fauna in relation to heathland fragment size, isolation and composition of surrounding vegetation types.

Using planimetry, the area of dwarf shrub vegetation in 1978 was estimated to be 5930 ha (compared with an estimated 10 000 ha in 1959). However, for the earlier estimate, certain types of scrub and acid grassland were included as well as dwarf shrub vegetation and peatland, while the later estimate was restricted to dwarf shrub vegetation and peatland and included only a limited amount of scrub. Clearly, these two estimates of heathland area are not comparable, as they were based on different definitions.

Because estimates of cover were made for defined vegetational units, it was possible to calculate the area of any combination of these units, to fit any definition of heathland. The estimates of heathland area from the different sources are compared in Table 10. For 1978, there are three estimates: one produced by planimetry, another by calculation from a definition of heathland which included scrub and grassland, and another by calculation from a definition restricted to dwarf scrub and peatland. For 1987, estimates were made by planimetry, and only calculated areas are available.

Table 10. The extent (ha) of heathland in Dorset at various times.

Date	Estimated area (ha)	Type of estimate
1960	10 000	Planimetry
1978	5 930	Planimetry
1978	7 900	Calculated
1978	5 507	Calculated
1987	7 475	Calculated
1987	5 141	Calculated

A comparison of the changes in the main vegetational components of heathland shows an overall loss of 425 ha between 1978 and 1987, a 5% loss of heathland (Table 11). Most of this loss has been in the dry heathland and grassland types, which are more easily reclaimed than wet heath and peatland. Humid heath has increased in extent, but much of this area may be derived from heathland which had been recently burnt in 1978 and which has therefore been reclassified in the 1987 survey. The most striking change in the nine years has been the considerable and noticeable invasion of heathland by gorse, birch (*Betula* spp.) and Scots pine (*Pinus* sylvestris) scrub, which shows a 15% increase. This change is due to a lack of management, and it is now essential to control and reduce the invasion of woody vegetation.

Increasing fragmentation has accompanied the reduction in extent of the heathlands. It is difficult to define a fragment, and few research workers have described their criteria, so some subjective assessment is involved.

The recorded cover values have been used to define fragments by identifying all the squares in which heathland vegetation cover exceeds 1% (ie those in which some heathland is present). Two adjacent squares were considered to belong to the same fragment when they touched along their sides with any level of cover, or when they touched at a corner with at least one of the squares containing 75% cover. This procedure grouped the squares into 141 heathland fragments throughout the Poole Basin.

Heathland communities are characterised by low species diversity and the dominance of a few species. These are features of communities of early successional age and adverse environmental conditions. Diversity increases with successional age, and the distribution of species becomes more equitable, but such changes in species composition and succession represent a trend towards a community which cannot be regarded as typical heathland.

Changes in vegetational diversity have been studied in relation to fragment size on the Dorset heathlands. The results from 1978 have the general form of the diagram in Figure 21. For 141 heathland fragments, diversity was negatively related to fragment area. Large fragments (marked x) had a low diversity and were dominated by a few plant species. Small fragments were of two

Table 11. The area of heathland in Dorset in 1978 and 1987. The area surveyed in 1987 is that surveyed in 1978.

Vegetation type	1978 Area (ha)	1987 Area (ha)	Change (ha)	Change (%)
Dry heath + acid grassland	2597	2987	−510	−20
Humid heath	1476	1628	+152	+9
Wet heath	844	825	−19	−2
Peatland	590	601	+11	+2
Heathland scrub	1037	1213	+176	+15
Heathland carr	198	215	+17	+8
Recently burnt	618	328	−290	−47
Tracks/firebreaks/etc	304	334	+30	+9
Pools/streams/ditches	236	244	+8	+3
Totals	7900	7475	−500	−5

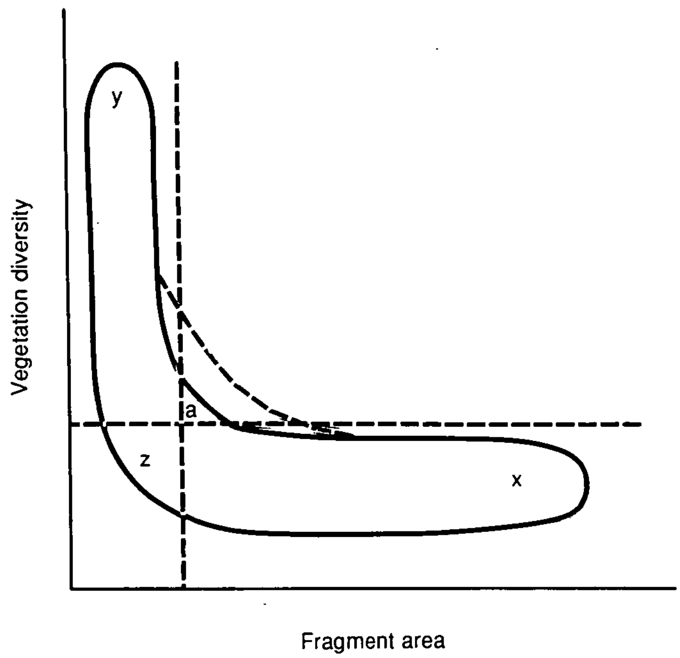


Figure 21. A diagram summarising the relationship between plant diversity on heathland fragments and fragment area. Fragments lying in the area bounded by the horizontal dotted line have a plant diversity comparable with that of typical heathland. Fragments within the area bounded by the verical dotted line have an unacceptably high vegetation diversity. The scatter of diversities is based on the survey in 1978. By 1987, the shape of the scatter had changed, as indicated by the dotted curved line.

types: those created by invasion from surrounding vegetation (marked y) which had high levels of diversity and greater equitability in the abundance of plant types; those (marked z) which were small but had low plant diversity. Many of the fragments in this last group had been created not through succession but by isolation, caused by road-building or the establishment of farmland, or similar activities.

This simple conceptual model could provide a basis for choosing between heathland fragments for conservation. If we consider typical heathland to have a diversity represented by fragments in the vicinity of point x (see Figure 21), then, as fragment area decreases, the slope of the diversity line increases, until a point is reached where the rate of change in diversity is unacceptable and the heathland becomes less representative. By making an arbitrary decision about an acceptable rate of change in diversity,/a minimum area for the selection of heathland fragments can be obtained.

The values of diversity for fragments at y are such that they are unrepresentative of heathland, and the rate of change of diversity through the pressure of successional processes is too high. These fragments are also impossible to maintain as heathland. Sites with diversity values in the vicinity of point 'a' (Figure 21) require additional criteria, such as the presence of rare species, for their selection.

Analysis of vegetational diversity from the 1987 survey has shown that the diversity of many medium-sized fragments has increased to the limit indicated by the dotted line in Figure 21. In the absence of factors such as grazing, cutting, burning, turf- and peat-cutting, and conservation management, succession is proceeding unhindered. By analysis of the changes in diversity, it is possible to judge the need for, or the success of, conservation management.

There is evidence that existing vegetation determines the nature of the succession and the extent to which various woody species can invade. The pattern and rate of succession on these heathlands are being examined in relation to fragment size, existing vegetation, and the composition of the surrounding vegetation types.

In order to answer questions about the environmental impact of pollutants, modern technological developments, or land use, it is necessary to understand how biological systems work and how and why they are affected by external factors. The section which follows describes four very different ITE projects in fundamental biology.

Vegetation succession under developing birch woods

It has recently been shown that birch (*Betula pendula* and *B. pubescens*), unlike heather (*Calluna vulgaris*) and many conifers, has an ameliorating effect on soils; they become less acid and soil nutrient availability increases. Birch readily colonises heather moorland in the absence of regular burning, and successional changes occur in the field layer under the developing birch canopy. It is not known to what degree the changes in composition of the vegetation can be attributed to soil changes or to other factors such as reduced light intensity, leaf litter, or changes in grazing pressure.

As part of an NERC (CASE) studentship project at ITE Banchory, an experiment was designed to examine how changes in light intensity and soil nutrient status affect the growth and relative competitive abilities of the main species involved in the successional changes shown in Figure 22. The decline of heather appears to be attributable primarily to shading by the developing birch. The results of an experiment involving the other three species, bilberry (*Vaccinium myrtillus*), wavy hair-grass (*Deschampsia flexuosa*) and common bent-grass (*Agrostis tenuis*), are presented here.

Rooted tillers of the three species were collected from the field and placed four to a pot in the following five mixtures: bilberry alone and with wavy hair-grass; hair-grass alone and with bent-grass; bent-grass alone. The following treatments were given: no shade, 65% shade (corresponding to a mature birch stand, see Figure 23) and 87.75% shade (corresponding to young dense birch), each with or without NPK Ca Mg fertiliser.

The experiment ran from April 1985 to April 1987, when all plants were harvested, dried and weighed. Wooden

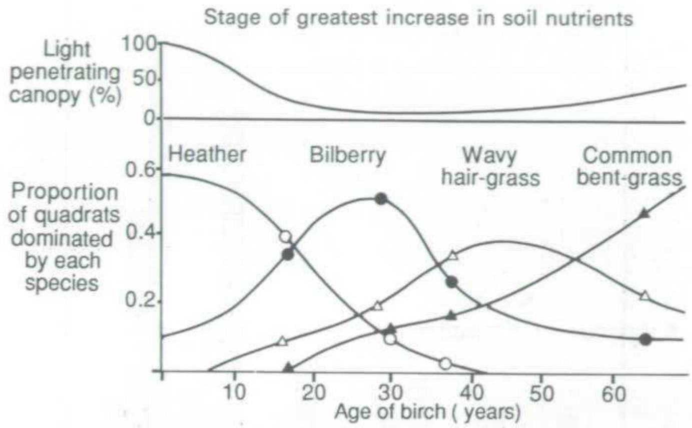


Figure 22 Generalised changes in dominance of main species beneath increasing ages of birch at Glenlivet, Grampian Region. The vegetation data were collected from 432 5 cm x 5 cm squares within each aged stand. Light levels shown were recorded by J Miles

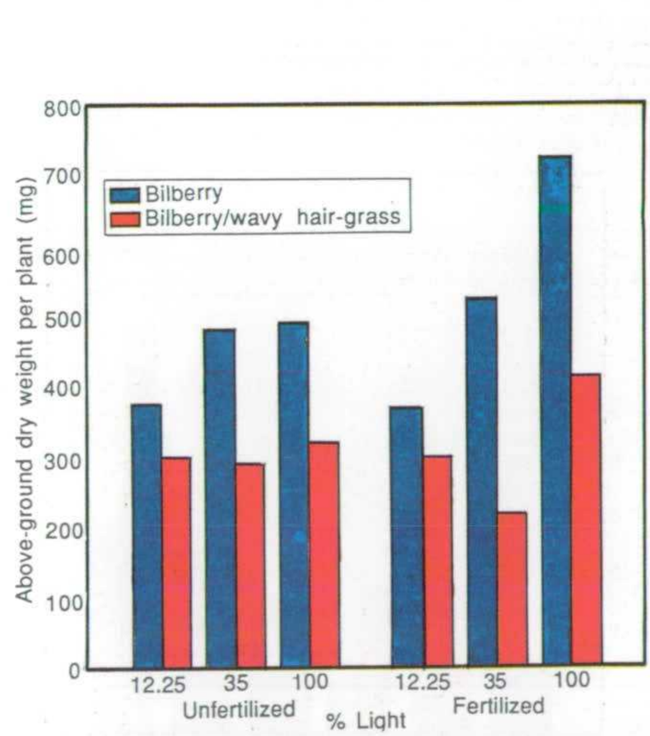


Figure 23 Above-ground mean dry weight of bilberry plants grown under different conditions of light, soil fertility and species combination

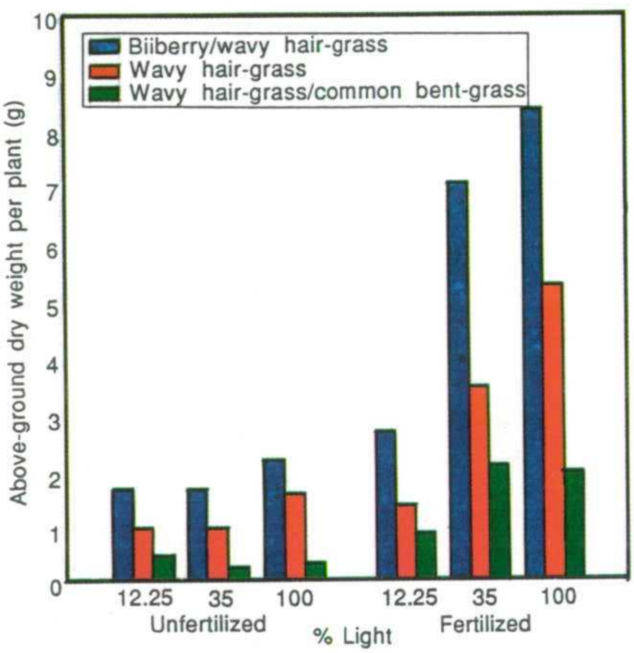


Figure 24. Above-ground mean dry weight of wavy hair-grass plants grown under different conditions of light, soil fertility and species combination.

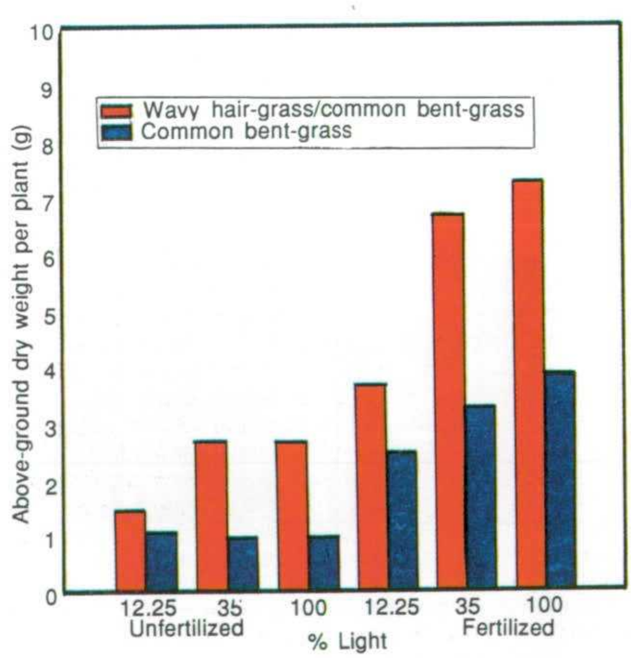


Figure 25. Above-ground mean dry weight of bent-grass plants grown under different conditions of light, soil fertility and species combination.

shade frames were put in place from May to November each year, and fertiliser was applied twice annually, in June and August. The fertiliser was designed to relate to nutrients released from birch leaf litter and to soil nutrient contents recorded beneath developing birch.

The addition of fertiliser improved the yield of both hair-grass and bent-grass in all conditions of shade and in all species combinations (Figures 24–25), but appeared to have no effect on the yield of bilberry. All species grew less well in increased shade. Both hair-grass and bent-grass responded better to increased light in fertilised soil than in unfertilised soil. The effects of growing species together were as follows: the yield of bilberry was consistently higher when alone than with hair-grass; hair-grass consistently grew better in mixture with bilberry than alone, and grew least well in mixture with bent-grass, where the effects of shading were also not significant; bent-grass grew consistently better in mixture with hair-grass than alone.

The apparent competitive superiority of hair-grass over bilberry, even in experimental conditions of dense shade and low soil fertility, suggests that bilberry will only become dominant after the decline in heather if it is already established in the moorland vegetation before colonisation by birch. The positive effect of fertiliser on hair-grass suggests that nutrient increases under the developing birch will give this species a further advantage over bilberry. Similarly, the consistent competitive superiority of bent-grass over hair-grass suggests that hair-grass becomes dominant before bent-grass because it colonises the area earlier.

Grazing apparently has a much more detrimental effect on bilberry than on hair-grass, and on hair-grass than on bent-grass. Wild herbivores often select vegetation with a higher nutrient content. In addition, animals frequently shelter within woodlands. Therefore, if grazing pressure increases, as shelter increases and as nutrients increase in the herbage beneath birch, this factor is also likely to contribute to the changes in dominance shown in Figure 22.

The results of the experiment suggest some ways in which soil fertility and shading by birch may affect the abundance of bilberry, hair-grass and bent-grass during the succession from heather moorland to mature birch woodland, and give a better understanding of the processes involved in the successional system. This sort of information is of practical value for the management of birch woods and their associated flora and fauna in the Highlands.

Spartina anglica — new approaches to a 100-year-old problem

The cord grass *Spartina anglica* is one of the classic examples of a species produced in nature by hybridisation between two different species followed by chromosome doubling (an allopolyploid). It is currently the focus of some intriguing research questions. Electrophoretic studies at ITE Furzebrook have discounted the possibility of its origin by chromosome doubling of either of the putative parents (autopolyploidy), *S. maritima*, a European species, and *S. alterniflora*, a native of North America. Banding patterns in several enzyme systems strongly support its allopolyploid origin; *S. anglica* and its F1 hybrid antecedent, *S.* x *townsendii*, have identical patterns which combine the very different sets of bands found in the parents. All bands present in the parents appear in the two descendants.

Studies at Birmingham University have gone further and examined both isozyme and total protein variation in several *S. anglica* populations. Even seed storage proteins, which can show considerable variation in natural populations of plant species, show almost no electrophoretically detectable genetic variation. The lack of genetic variability might be expected from what is known about the species' origin, particularly if the hybridisation and/or chromosome doubling, neither of which have been repeated under controlled conditions, occurred only once. However, some variability should have been generated by genetic recombination in the century since the plant's origin. Recombination may be severely limited by a predominantly asexual mode of reproduction (vegetative growth and seed production without meiosis) or by the preferential pairing of identical chromosomes (ie those produced by the recent doubling) at meiosis during sexual reproduction.

Where variation has been found in *S. anglica*, both in isozymes and in the plant's morphology, it has usually been underlain by differences in chromosome number. For example, seedlings collected from Keyhaven, Hampshire, which displayed a small amount of variation in the enzyme glutamate oxaloacetate transaminase, were found to have a reduced number of chromosomes. Most of the morphological variants described in the literature have had a reduced chromosome number.

These findings point to the presence of a narrow genetic base in the species, and even allow the possibility that *S. anglica* is comprised of one or a few individuals which have spread (and been planted) to occupy very large areas of intertidal mudflats in temperate zones throughout the world. There is some indirect evidence to support this hypothesis — for example, the species' high susceptibility to infection by ergot (*Claviceps purpurea*), which has been observed in many saltmarshes in the south of Britain.

In complete contrast is the habitat-correlated morphological variation observed in several populations (eg in the Ribble estuary), which appears to be retained in common garden and reciprocal transplant experiments. An NERC (CASE) student at Liverpool University has demonstrated, by growing plants under identical conditions, the presence of extensive and frequently fine-scale morphological differentiation between populations in a range of variables, such as plant height, leaf length and tillering rate.

These findings raise the intriguing question of how such variation is generated. It is clearly not simply an environmental effect as differences are retained, at least in the relatively short term, in a uniform environment. Perhaps selection during the seedling stage, *via* the mechanism of cytoplasmic differentiation, which has been demonstrated to occur in young rye-grass (*Lolium perenne*) genotypes, is an important factor. Alternatively, the plants grown in common garden conditions may still be subject to 'carry over' effects from the environment from which they were sampled. A further possibility is that selection is occurring in the wild on a genetically variable outbreeding species to produce the genotype/environment correlations known from many other examples of flowering plants. The lack of enzyme and protein variation might be seen as unrepresentative of the levels of genetic variation as a whole, so that electrophoretic techniques, in this case, do not give a particularly useful picture.

The answers to some of these questions can be found in an analysis of the polymorphisms of the plant's DNA. If this 'genetic finger-printing' also reveals a lack of genetic variation in the species, the hypothesis that phenotypic plasticity, perhaps involving some cytoplasmic differentiation, is the major cause of habitat-based morphological variation must be preferred. Work using these molecular techniques is continuing in Birmingham.

An added complication is introduced by the observation that *S. anglica* has some form of self-incompatibility, at least under glasshouse conditions. In the light of what is known about self-incompatibility systems in grasses, the fact that *S. anglica* is highly polyploid (probably 12 x), and the probability that the species consists of very few genotypes, the chance of a compatible cross occurring seems extremely low. How, then, does *S. anglica* ever set seed? Do these findings help explain the very poor seed set in natural populations of the species? Is seed set only under certain restricted conditions (such as very hot summers), when the self-incompatibility mechanism breaks down? There are clearly many unresolved aspects of the plant's breeding system and reproductive biology.

Whatever its evolutionary and genetic background, *Spartina* continues to attract attention by the scale of its environmental effects. A relationship between the spread of the species and the decline in numbers of dunlin (*Calidris alpina*) wintering in British estuaries has recently been demonstrated, arousing concern for the conservation implications of *Spartina* invasion in those western and northern estuaries, such as Morecambe Bay, where the species is beginning to spread rapidly. Control and eradication are being advocated by several conservation groups. At the same time, in the south and east, where *S. anglica* marshes have continued to die back since the 1930s, signs of serious erosion and the weakening of sea walls have led to a renewal of plans (and some actual operations) for deliberately planting the species to assist mudflat stabilisation and to improve sea defences.

Research on breeding in birds

Research at ITE Monks Wood, in collaboration with the AFRC Research Group on Photoperiodism and Reproduction at the University of Bristol, has improved understanding of how change in daylength acts as the major proximate factor timing the start and end of breeding in birds. Using the European starling (*Sturnus vulgaris*) as a model species, results indicate that daylength has two distinct effects on the cells in the brain which synthesise the peptide, gonadotrophin-releasing hormone (GnRH), upon which reproductive function ultimately depends. Long days cause synthesis of GnRH to stop, and short days cause it to resume. Once synthesis has begun under short days, the rate of release of GnRH is proportional to daylength; the longer the daylength, the more is released. Thus, gonadal maturation actually begins in autumn, but the rate of maturation increases during spring, and so breeding commences. Breeding ends during summer when long days stop GnRH synthesis.

These processes explain why young birds do not breed until the spring of the year after that in which they hatch. Young develop in a physiological state analogous to that of post-breeding adults, so GnRH synthesis does not begin until the short days of autumn. The process which initiates the reproductive function for the first time is essentially the same as that which causes it to resume each year in adults. Seasonality is, in effect, a repeated puberty.

Thyroid hormones are important. The process by which long days stop GnRH synthesis is totally dependent on the presence of thyroid hormones, whereas the process controlling GnRH release rate is only marginally affected. Thus, if birds experience long days after the removal of the thyroid glands, the gonads grow almost normally, but they then never regress. If the thyroid glands are removed from birds already on long days, the gonads grow spontaneously.

The same is true for young birds. If thyroid glands are removed from very young birds, their gonads grow prematurely. However, in this case, because thyroid hormones are also required for normal somatic growth and development, these birds retain juvenile characteristics in adult life, a condition known as neoteny. One group of birds, the Ratites, which includes ostriches, is normally neotenous; adult birds are essentially overgrown chicks. Could thyroid dysfunction be involved here, and, if so, could treatment with thyroid hormones reverse the process? In other words, if young ostriches were treated with thyroid hormones during their development, would they develop into true morphological adults? ITE has set up an experiment in Israel to investigate this possibility.

Fluctuations in the populations of red grouse

Simple empirical models can give good predictions of the future densities of grouse populations. Ecologists at ITE Banchory have derived the following equation from their intensive field studies on red grouse (*Lagopus lagopus scoticus*) and used it successfully to make good predictions:

$$N_{t+1} = N_t(1 + R')S \qquad (1)$$

where N_t is the number of adults in a breeding population in year t, R′ the number of young reared per breeding adult and remaining on the study area in late summer, and S the mean annual local survival rate. The field studies from which the above equation was derived also showed that R′ exhibited delayed density-dependence.

The fact that an empirical model makes good predictions of changes in numbers does not mean that the causes of such changes are understood. R′and S are both easily observed, but can be affected by a complex variety of factors, such as food, cover, weather, predators, parasites and disease. More interestingly, perhaps, R′ is not simply the number of chicks reared by each adult but is determined partly by movement. During a study at Kerloch Moor in Kincardineshire, young birds emigrated out of the area during the summer. Emigration is a form of spacing behaviour which the ITE scientists consider to be a major factor limiting grouse densities. In particular, they think that cyclic fluctuations in red grouse densities, which are associated with delayed density-dependent variations in R′, are caused by changes in spacing behaviour.

Whatever the cause of population cycles, the basic concept of delayed density-dependence had not been tested experimentally until recently, in any animal species. Figure 26 summarises an experiment on Rickarton Moor (Plate 17), near Aberdeen. The idea underlying the experiment was that, if cyclic fluctuations are caused by delayed density-dependent factor(s), then preventing a cycling population from reaching its peak should prevent or delay the subsequent decline.

Grouse numbers on the control area were not manipulated. They increased from a trough in 1979 to a peak in 1983 and subsequently declined, as predicted by the empirical model. On the experimental area, breeding numbers were kept down to approximately the 1981 level by removing between 10 and 20 cocks each spring from 1982 to 1986; an equivalent number of hens then disappeared and presumably left the area. By 1986, numbers had declined for three years on the control area, but numbers on the experimental area were greater each spring than they had been after the previous year's removals.

Breeding was poor in 1985, associated with very severe weather-induced browning of heather (*Calluna vulgaris*) shoots in late-winter 1985, that reduced by about 80% the amount of green heather per unit area. Despite this reduction, grouse numbers on the experimental area had again increased in spring 1986, although they continued to decline on the control. Conversely, good breeding on the control area in the peak year of 1983 was followed by a decline in numbers, a result which shows that the usual association between breeding performance and subsequent change in breeding densities does not always hold.

The abundance of parasitic threadworms (*Trichostrongylus tenuis*) was assessed each year by counting worm eggs in the birds' droppings. Threadworm burdens were generally below the level of 3000–4000 worms per bird, above which one would expect the birds' condition to be poorer. If anything, worm burdens were greater on the experimental area. Nevertheless, it was the population on the control area that continued to decline, whereas the experimental population increased, evidence that seems to rule out the suggestion that red grouse population cycles are due to

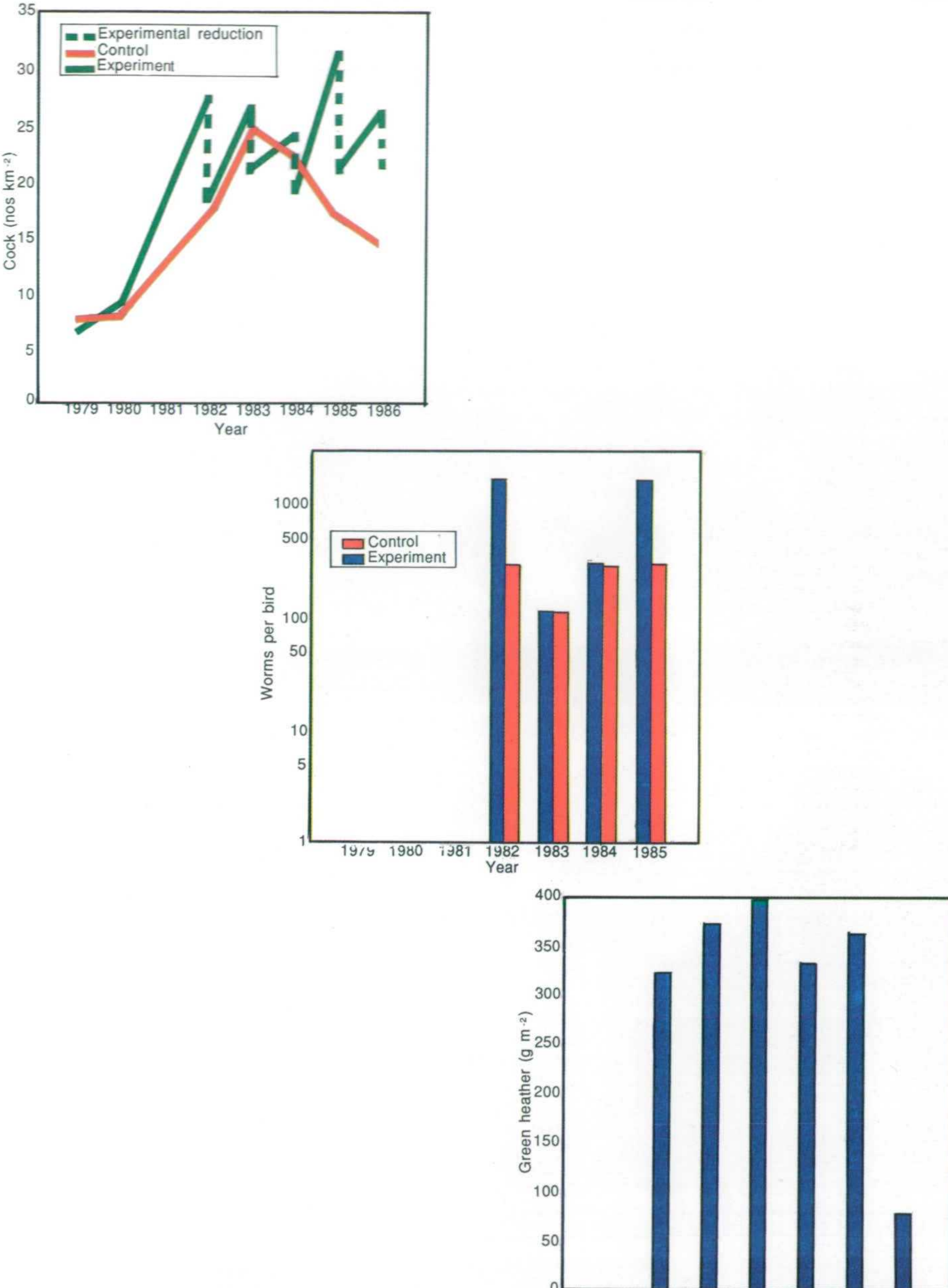


Figure 26 Spring density and breeding success of red grouse on experiment and control, numbers of parasitic threadworms, and amount of green heather.
Top: number of cocks per km^2 in spring on experimental area
(o o o, vertical dotted lines showing experimental reductions) and control (-----), and number of young per hen in August on experiment (upper pair of values) and control (lower of each pair). Density eventually declined on the experimental area in 1987.
Middle: worm numbers on experiment (open) and control (stippled).
Bottom: dry weight of green heather shoots per m^2 in spring. Data are for both areas combined; results on experiment and control differed little, and both showed a large decline of green shoots in 1985.

Plate 17. Burning heather on Rickarton Moor — a standard management practice on grouse moors

delayed density-dependent burdens of threadworms.

The experiment showed that delayed density-dependent declines can occur independently of poorer food, higher parasite burdens and poorer breeding success, and that, if peak densities are not reached, a decline is not inevitable.

Current work aims to test the hypothesis that population declines are caused by changes in spacing behaviour. Nevertheless, many factors affect grouse numbers, and different factors probably have different relative importance in different geographical areas; the problem is to make a simple, accessible, testable statement of how these factors interact. Starting with equation (1) and assuming that the population is regulated by emigration, the relationship between R′ (number of young reared per adult after the emigration of some young) and R (young, including emigrants, reared per adult) can be defined as

$$R' = R(K - N)/K \qquad (2)$$

where K is the value of N at which R′ = O. Resource levels (Q), population density (N) and the intensity of spacing behaviour (α) are assumed to interact to determine K:

$$K = Qe^{-\alpha N} \qquad (3)$$

The hypothesis that population cycles are determined by spacing behaviour is, in this model, equivalent to saying that cycles are the result of delayed density-dependent variations in α. An important question, of course, is what happens to the emigrants, and this aspect is being investigated.

Emigration from one population implies immigration into another. There is only limited evidence on immigration, but 'sink' populations with relatively low R and S, which are not limited by net emigration, could absorb emigrants from 'core' populations. Such 'sink' populations can occur in the poor habitat which covers extensive areas in the west of Scotland, and where average grouse densities are low. In the east of Scotland, 'sink' areas are probably less extensive and average densities are higher. Here, sink habitat may not be able to absorb all the emigrants, which may find nowhere to settle permanently and suffer heavy mortality before the next breeding season. It may be under such circumstances that spacing behaviour becomes the dominant limiting factor over large areas of ground, and population cycles become of major importance. If these ideas are correct, traditional small-scale population studies may need to be augmented by studies over very large areas of ground.

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Grade 7	Dr Welch R C
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SSO	Mr French M C
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SSO	Mr Fuller R M
SSO	Mrs Greene D M
SSO	Dr Marrs R H
SSO	Dr Parr T W
SSO	Mr Preston C D
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SSO	Dr Village A
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Grade 7	Dr Merrett P
Grade 7	Dr Thomas J A
Grade 7	Dr Ward L K
Grade 7	Dr Webb N R C
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SSO	Dr Daniels R E
SSO	Dr McGrorty S
SSO	Dr Reading C J
SSO	Mr Snazell R G
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SSO	Mr Dale J
SSO	Mr Evans D F
SSO	Mr Hewett D G
SSO	Dr Moss D
SSO	Mr Rafarel C R
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SSO	Mr Spalding D F
SSO	Mr Stevens P A
SSO	Dr Walton K C
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HSO	Mr Brown N J
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Grade 7	Mr Smith I R
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SSO	Dr Crossley A
SSO	Mr Deans J D
SSO	Mr East K
SSO	Mr Jones D H
SSO	Dr Mason P A
SSO	Dr Milne R
SSO	Dr Watt A D
SSO	Dr Wilson J
HSO	Dr Eamus D
HSO	Dr Lightowlers P J
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HSO	Mr Murray T D
HSO	Mr Ottley R F (*Snr Nurseryman*)
HSO	Dr Sheppard L J
HSO	Mr Smith R I
HSO	Mr Munro R C (*in Kenya*)
SO	Miss Dick J M
SO	Mr Harvey F J (*in Malawi*)
SO	Mr Ingleby K
SO	Mr Kirika A
SO	Mr Leith I D
SO	Mrs Murray M B
SO	Mr Storeton-West R L
SO	Mr Wilson R H F
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AO	Mrs Holgate A (PT)
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Grade 7	Dr Bunce R G H
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BAND 8	Mr Littlejohn A D
BAND 8	Mr Robertson A C

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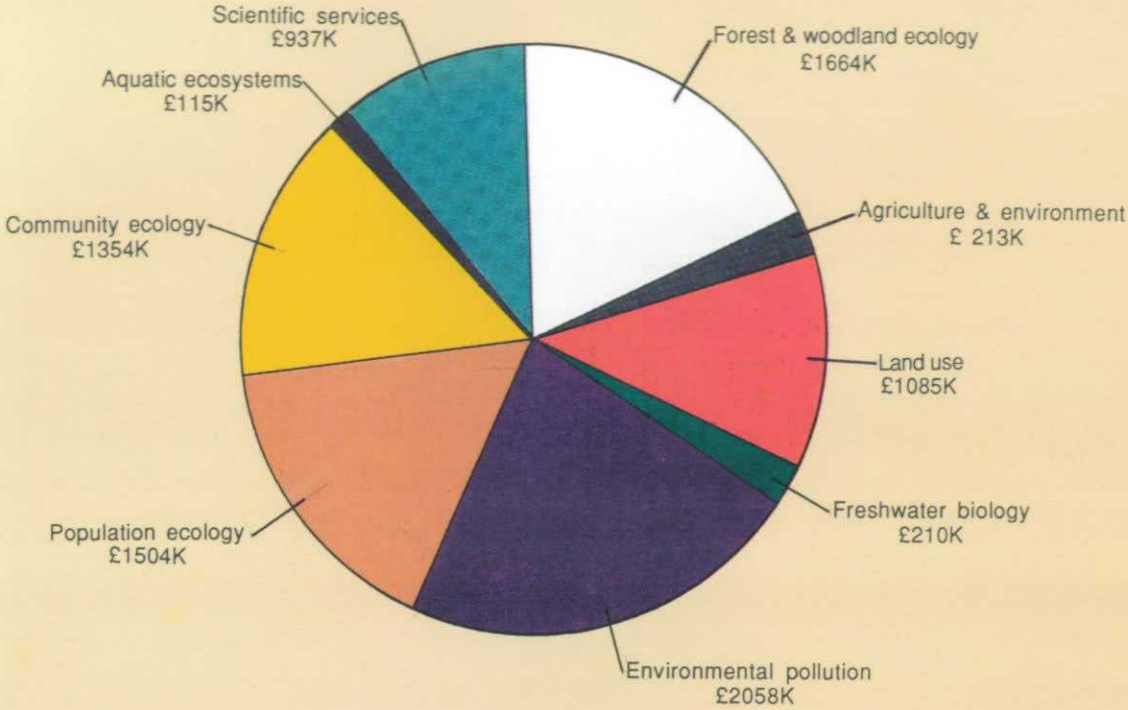
Grade 7	Dr Kruuk H
Grade 7	Dr Miller G R
Grade 7	Dr Moss R
Grade 7	Mr Welch D
SSO	Dr Bayfield N G
SSO	Mr Cummins R P
SSO	Mr French D D
SSO	Dr Marquiss M
SSO	Mr Parr R A
SSO	Mr Paterson I S
SSO	Mr Picozzi N
HSO	Mr Catt D C
HSO	Mr Conroy J W H
HSO	Mr Young W F
SO	Mr Scott D
SO	Mr Trenholm I B
PTO	Mr Morris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

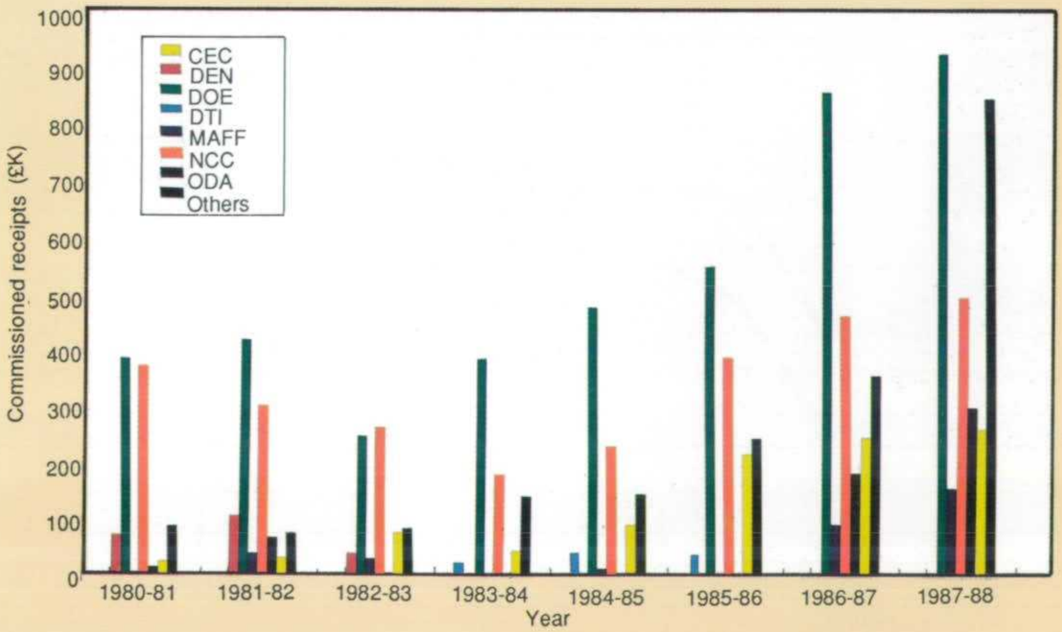
Appendix 2 **Finance and administration**

The following diagrams indicate levels of funding for the Institute, and provide details of expenditure.

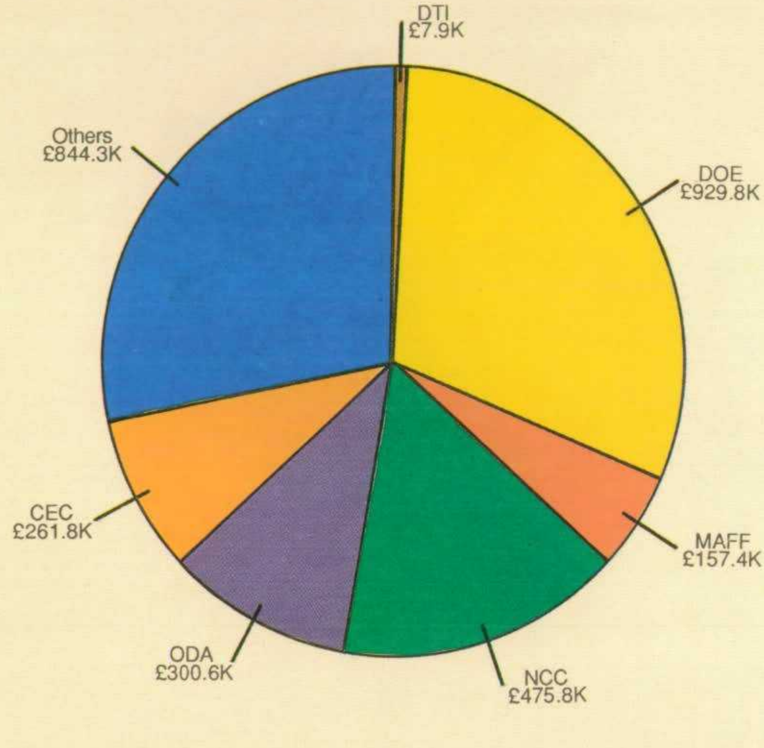
The pie chart shows Institute expenditure (as full economic cost) for the year 1987–88 by scientific programme of work.



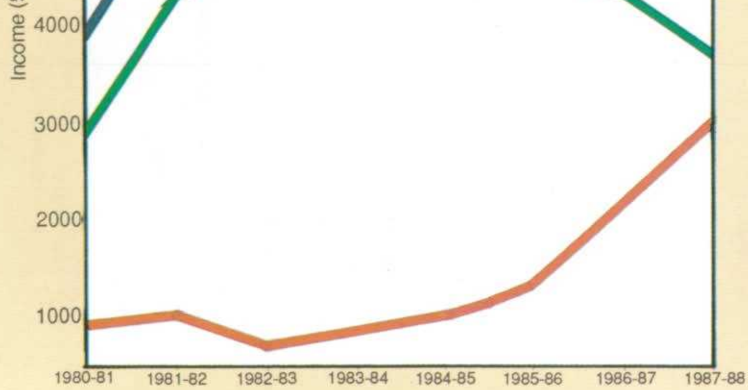
The bar chart illustrates the changing pattern of receipts from major customers during the period 1980 to 1988 (at constant prices – 1980–81 to 1986–87 revalued to 1987–88 using GDP indices).



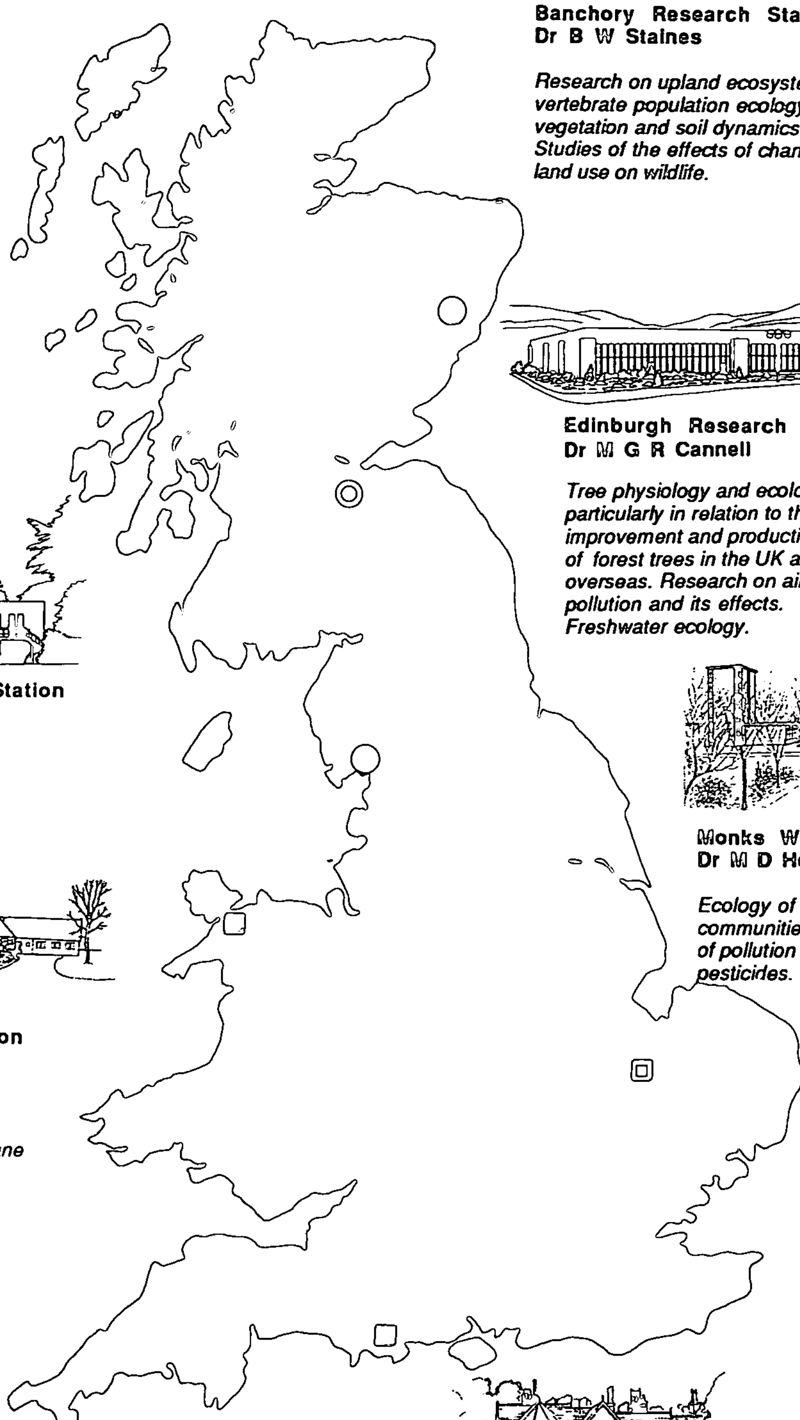
The pie chart shows a complete breakdown of 1987–88 commissioned receipts by major customers.



The graph shows the overall trend in income from science budget and from commissioned receipts for the period 1980 to 1988.



Locations of the six ITE research stations.



◎ **Director (North)**
Dr O W Heal

Banchory Research Station
Dr B W Staines

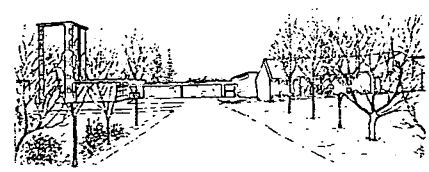
Research on upland ecosystems, vertebrate population ecology, vegetation and soil dynamics. Studies of the effects of changing land use on wildlife.

Edinburgh Research Station
Dr M G R Cannell

Tree physiology and ecology, particularly in relation to the improvement and production of forest trees in the UK and overseas. Research on air pollution and its effects. Freshwater ecology.

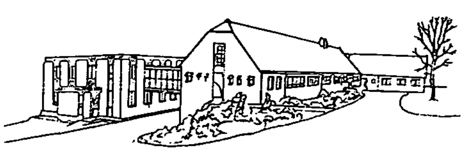
Merlewood Research Station
Dr M Hornung

Ecology of woodlands, soil microbiology, radioecology. Computer-based ecological and land use studies.



Monks Wood Experimental Station
Dr M D Hooper

Ecology of invertebrates, plant communities and birds. Studies of pollution by heavy metals and pesticides. Biological Records Centre.



Bangor Research Station
Dr C Milner

Remote sensing, pedology, geochemical cycling, plant community dynamics, montane studies and mathematical modelling. Environmental information data base.

Furzebrook Research Station
Dr M G Morris

Research on lowland heath and coastal habitats. Invertebrate ecology, plant genecology.

▣ **Director (South)**
Dr J P Dempster

Appendix 3 **Research projects at ITE stations at 31 March 1988**

MONKS WOOD EXPERIMENTAL STATION

Programme 2 Agriculture and the environment

T02001-5	**Farming and wildlife**	***B N K Davis***
T02001a2	Modern agriculture and wildlife	T Parish
T02001b2	Land use and ecology of Swavesey Fens - the fauna and flora in relation to both established and changing management	T Parish
T02001c1	Pesticide drift and impact	B N K Davis
T02002-5	**Historical ecology**	***J Sheail***
T02002a5	Historical aspects of environmental perception	J Sheail
T02002c2	Agricultural practices and soil erosion in the UK: historical and geomorphological perspectives (proposal)	G Rattenbury
T02003-5	**Grassland ecology and management**	***T C E Wells***
T02003c2	Monitoring floristic changes	T C E Wells
T02003e1	Cutting of chalk grassland (proposal)	T C E Wells
T02008-3	**Agriculture and the environment (special topic programme)**	***J Sheail***
T02008f3	Reducing residual soil fertility of abandoned agricultural land for the restoration of native vegetation	R H Marrs

Programme 3 Land resources and use

T03008-1	**Ecological appraisal of developments**	***M D Hooper***
T03008b1	Avalon Lakes design studies (proposal)	M D Hooper
T03008c1	Channel Tunnel construction - monitoring terrestrial (and freshwater) ecology	R C Welch
T03008d1	Folkestone terminal — specialist advice (proposal)	M D Hooper
T03008e1	Ecological appraisal of A34 Newbury bypass (proposal)	M D Hooper
T03008f1	Ecological appraisal of a potential power station site — Phase 1 (proposal)	M D Hooper
T03009-5	**Remote sensing of vegetation change**	***R M Fuller***
T03009b2	Remote sensing techniques for habitat surveys	R M Fuller
T03009c1	Dungeness vegetation survey	R M Fuller

Programme 4 Management of aquatic ecosystems

T04033-5	**The numbers of Atlantic salmon in some Scottish rivers**	***K H Lakhani***

Programme 7 Environmental pollution

T07014-5	**Pollution analyses and their interpretation**	***I Newton***
T07014a5	Birds and pollution	I Newton
T07015-1	**Data on toxic chemicals**	***S Dobson***
T07015b1	Development of data profiles on chemicals from the IRPTC working list	S Dobson
T07015e1	Consultancy to Health and Safety Executive (proposal)	S Dobson
T07016-2	**Residues and effects**	***F Moriarty***
T07016a2	Residues, and effects on individuals, of pollutants in freshwater organisms	F Moriarty
T07017-5	**Aquatic chemistry**	***K R Bull***
T07017c1	Classification and comparison of river and lake catchments using computing techniques	K R Bull
T07017d2	Concentrations of aluminium in streams during storm events and after the application of lime to streams and stream catchments	K R Bull
T07017e2	Dipper egg examination	K R Bull
T07017f5	Remote sensing of Eskdale and Dunnerdale	K R Bull/ B K Wyatt
T07018-5	**Acid rain and amphibia**	***C P Cummins***
T07018a2	Life history of the common frog	C P Cummins
T07018b1	Froglet production related to water chemistry and tadpole density in semi-natural pools (proposal)	C P Cummins
T07020d1	Impact of climatic change on coastal ecosystems (proposal)	L A Boorman
T07023-3	**Animal ecotoxicology (special topic programme)**	***A S Dawson***
T07023d3	Interactive effects of pesticides on reproduction in birds	C Walker/ A S Dawson
T07026-5	**Toxicological studies on bats (proposal)**	***R F Shore***
T07026a2	Heavy metals in bats (proposal)	R F Shore
T07026b1	Bats and pollution (proposal)	R F Shore
T07026c2	Hedgehogs and pollution (proposal)	R F Shore

Programme 8 Population ecology

T08014-5	**Population dynamics of birds**	***I Newton***
T08014a5	Population ecology of sparrowhawks (*Accipiter nisus*)	I Newton
T08015-5	**Bats**	***R E Stebbings***
T08015a5	Population ecology of bats	R E Stebbings
T08016-2	**Plant species dynamics**	***T C E Wells***
T08016a2	Population studies on orchids	T C E Wells
T08017-2	**Physiology and reproduction in birds**	***A S Dawson***
T08017b2	Physiological factors causing deferred sexual maturity in birds	A S Dawson
T08017c2	Environmental control of breeding cycles in birds	A S Dawson
T08018-5	**Vegetation dynamics**	***T W Parr***
T08018a2	Roadside vegetation dynamics	T W Parr
T08018b2	Modelling competition in grass swards	T W Parr
T08018c2	Field plot survey — Monks Wood	R Cox
T08018f1	Effects of growth retardants on the ecology of roadside vegetation in west Sussex (proposal)	T W Parr
T08018g1	*Phragmites* seedlings — their use in RBTS sewage treatment	T W Parr
T08018h1	Factors affecting the establishment and performance of reeds (*Phragmites australis*) in RBTS systems: a survey in the UK of reed bed treatment (proposal)	T W Parr
T08018i1	Experimental studies on the management of reed beds for RBTS sewage treatment (proposal)	T W Parr
T08019-5	**Birds on farmland**	***A Village***
T08019a2	Kestrels in farmland	A Village
T08019b5	Birds on arable farmland (proposal)	A Village
T08021-5	**Butterfly abundance**	***J P Dempster***
T08021a5	Butterfly monitoring scheme	M L Hall
T08021b2	Food resource limitation in the orange-tip butterfly	J P Dempster

Programme 9 Community ecology

T09012-5	**Vegetation management, especially to combat erosion**	***L A Boorman***
T09012a2	Sand dune ecology	L A Boorman
T09012c1	Plant establishment in woodland	L A Boorman
T09012e1	Studies on saltmarsh erosion (proposal)	L A Boorman
T09012g1	The role of vegetation in the sea defences of East Anglia (proposal)	L A Boorman
T09013-5	**Plant/animal interactions**	***B N K Davis***
T09013b2	Plant succession in a limestone quarry	B N K Davis
T09013c1	Martins Farm landfill site: creation of wildlife habitat	B N K Davis
T09013d2	European insect fauna of *Urtica* species	B N K Davis
T09013e1	Design and management of urban green space	B N K Davis

T09014-5	**Invertebrate ecology and management**	***R C Welch***
T09014b2	Invertebrate fauna of native and introduced broadleaved trees in Britain	R C Welch
T09014c1	Management guidelines for the conservation of invertebrates, especially butterflies, in plantation woodlands	R C Welch
T09015-5	**Heathland and nitrogen cycling**	***R H Marrs***
T09015a2	Heathland management research	R H Marrs
T09015b2	Long-term studies of vegetation change at Moor House NNR	R H Marrs
T09015c2	Nitrogen mineralization in tropical forest soils	R H Marrs
T09016-5	**Distribution and dynamics of vegetation**	***J O Mountford***
T09016c1	Nitrogen fertiliser experiment in the Somerset levels	J O Mountford
T09016d1	British Rail-sponsored grassland experiments (proposal)	J O Mountford

Programme 13 Scientific services

T13011-5	**Biological Records Centre**	***P T Harding***
T13011a5	Biological Records Centre: botanical recording schemes	C D Preston
T13011b5	Biological Records Centre: vertebrate recording schemes	H R Arnold
T13011d2	The distribution and ecology of non-marine isopoda	P T Harding
T13011e5	Biological Records Centre: terrestrial and freshwater invertebrate recording schemes	B C Eversham
T13011g5	Biological Records Centre: general	P T Harding
T13011h2	Population fluctuations in annual legumes	C D Preston
T13011i5	Biological Records Centre: data bank	D M Greene
T13012-2	**Information, systems and survey**	***M O Hill***
T13012a2	Effects of grazing in Snowdonia	M O Hill
T13013-2	**Statistical advice 1**	***K H Lakhani***
T13013a2	Estimation of population parameters	K H Lakhani
T13013b2	Statistical consultancy	K H Lakhani
T13014-2	**Statistical advice 2**	***M D Mountford***
T13014b2	Population regulation and estimation	M D Mountford
T13014c2	Statistical consultancy in ITE	M D Mountford
T13036a1	Small consultancies at ITE Monks Wood	M D Hooper

FURZEBROOK RESEARCH STATION

Programme 1 Forest and woodland ecology

T01024-5	**Squirrel ecology**	***R E Kenward***
T01024a2	Grey squirrel damage and management	R E Kenward
T01024b1	Goshawk population dynamics	R E Kenward
T01024c2	Foraging and reserve storage in red and grey squirrels	R E Kenward
T01024d1	Raptor ecology of Kluane Valley	R E Kenward

Programme 3 Land resources and use

T03007-1	**Impacts of the energy industry**	***R E Daniels***
T03007c1	Wytch farm development: biological monitoring	R E Daniels
T03007d1	Purbeck-Southampton pipeline: biological monitoring	R E Daniels
T03007f1	Hinkley Point public enquiry (proposal)	R E Daniels
T03007h1	British Petroleum: Holton Heath development (proposal)	C J Reading
T03007i1	Rehabilitation of oil well sites (proposal)	R E Daniels

Programme 8 Population ecology

T08008-5	**Butterfly studies**	***J A Thomas***
T08008a5	The conservation of the large blue butterfly	J A Thomas
T08008e1	Woodland fritillary butterflies	J A Thomas
T08009-2	**Butterfly/ant interactions**	***G W Elmes***
T08009a2	Social biology of *Myrmica* species	G W Elmes
T08009c2	Large blue butterfly/*Myrmica* ant interactions	J A Thomas
T08009d2	Population ecology and adaptive speciation of *Myrmica*	G W Elmes
T08010-5	**Basic wader biology**	***J D Goss-Custard***
T08010a2	Predator/prey interactions between the oystercatcher, *Haematopus ostralegus*, and its prey, particularly the mussel, *Mytilus edulis*, on the Exe estuary and adjacent coastal areas	J D Goss-Custard
T08010b2	Winter feeding ecology of juvenile oystercatchers on the Exe estuary	J D Goss-Custard
T08010c2	Habitat contraction, breeding density and reproductive output in waders: a feasibility study	J D Goss-Custard
T08011-5	**Genecology and population biology of plants**	***A J Gray***
T08011a2	Iso-enzyme studies in *Sphagnum*	*R E Daniels*
T08011c2	*Spartina* population ecology, particularly the genecology of *Spartina anglica*	A J Gray
T08011f5	Genetic variation in *Phragmites australis*	R E Daniels
T08011g2	Nitrogen economy of *Drosera* species	R E Daniels
T08011i1	*Spartina* niche model: marginal vegetation in a post-barrage environment	A J Gray
T08011j1	Poole Bridge environmental enhancement (proposal)	A J Gray
T08011k1	Poole Bridge replacement: environmental impact assessment	N R Webb
T08011l5	Culture and supply of reed plants (proposal)	R E Daniels
T08011m2	Population biology in peatland angiosperms	R E Daniels
T08012-5	**Spider ecology**	***P Merrett***
T08012b2	Ecology of *Eresus niger*	P Merrett
T08013-2	**Studies of amphibia and reptiles**	***C J Reading***
T08013a2	Breeding success and survival in the common toad	C J Reading
T08013b2	Ecology and population dynamics of the grass-snake (*Natrix natrix helvetica*)	C J Reading

Programme 9 Community ecology

T09007-1	**Impact of barrage schemes**	***J D Goss-Custard***
T09007a1	Wash birds and invertebrates	J D Goss-Custard
T09007b1	Predicting post-barrage densities of invertebrates and shorebirds: birds	J D Goss-Custard
T09007c1	Cardiff Bay barrage feasibility study	C J Reading
T09008-5	**Ecology of wetlands**	***S B Chapman***
T09008a2	Nutrient cycles in lowland heath	S B Chapman
T09008b2	Autecology of the marsh gentian	S B Chapman
T09008c1	Review of Coombe Rigg Moss	S B Chapman
T09008d1	An ecological assessment of the Holm Hills-Griggsgreen copse woodland complex (proposal)	S B Chapman
T09009-5	**Grassland/scrub studies**	***M G Morris***
T09009a2	Grassland management — invertebrates	M G Morris
T09009b2	Study on scrub succession on chalk at Aston Rowant NNR	L K Ward
T09009d2	Scrub management at Castor Hanglands NNR	L K Ward
T09009f5	Juniper regeneration experiments (proposal)	L K Ward
T09010-5	**Heathland studies**	***N R Webb***
T09010b2	Heathland invertebrates	N R Webb
T09010c1	Restoration of heathland	N R Webb
T09010d1	Restoration experiments for New Forest gas pipeline	N R Webb
T09010e2	Dorset heathland survey	N R Webb
T09010f1	Ecological survey at Feltham, Middlesex	R E Daniels
T09010h1	Ecological appraisal of Lyndhurst bypass	S B Chapman
T09010i1	Heathland turfing trials	N R Webb
T09010k1	Survey at Uddens Heath	N R Webb
T09010l1	Survey at Canford Heath	N R Webb
T09010m1	Survey at Sandford Heath (proposal)	N R Webb
T09011-2	**Phytophagous insects**	***L K Ward***
T09011a2	Phytophagous insects data bank	L K Ward
T09011b2	Weevil studies	M G Morris

Programme 13 Scientific services

T13016-2	**Statistical and computing services in Wareham**	***R T Clarke***
T13016a2	Statistical and computing services at Furzebrook	R T Clarke
T13016b2	Statistical and computing services at the River Laboratory	R T Clarke
T13016c2	Statistical research	R T Clarke
T13036b1	Small consultancies at ITE Furzebrook	M G Morris

BANGOR RESEARCH STATION

Programme 1 Forest and woodland ecology

T01022-1	**Nature conservation in upland conifer forests**	***J E G Good***
T01023-5	**Woodland ecology**	***J E G Good***
T01023f2	Clonal selection in *Betula* and *Salix*	J E G Good

Programme 3 Land resources and use

T03003-1	**EEC Corine biotopes**	***B K Wyatt***
T03003a1	EEC Programme CORINE. Project: Biotopes	B K Wyatt
T03004-5	**Upland remote sensing**	***B K Wyatt***
T03004a2	Study of the use of remote sensing for mapping land-cover and monitoring change	B K Wyatt
T03004e2	Correction of satellite imagery for topographic effects on land cover classification in mountainous terrain	A R Jones
T03004f1	Remote sensing in the Less Favoured Areas: models for rural land use planning	B K Wyatt
T03004g5	Characterisation of grassland type and condition using remotely sensed data	B K Wyatt
T03005-5	**Remote sensing of arid lands**	***B K Wyatt***
T03005d5	Use of remote sensing for mapping and monitoring Sahelian rangelands	B K Wyatt
T03006-5	**Land use data bases**	***G L Radford***
T03006a2	National land characteristics and classification	G L Radford
T03006d2	Air photo interpretation of land cover and landscape features and their recent changes	G L Radford
T03006f2	Habitat change in Lleyn	A Buse
T03010-2	**Ecological Data Unit**	***G L Radford***
T03014-5	**Upland land use**	***J E G Good***

Programme 7 Environmental pollution

T07010-1	**Fluorine pollution studies**	***D F Perkins***
T07012-5	**Pollution in Wales**	***T W Ashenden***
T07012b5	Pollution study of Wales	T W Ashenden
T07012c1	Effects of nitrogen dioxide on bryophytes and ferns (proposal)	T W Ashenden
T07012d2	Effects of acid mist on arctic-alpines (proposal)	T Ashenden
T07013-5	**Ecosystem pollution by fluoride and trace metals**	***K C Walton***
T07013c2	Fluoride and magpies	D C Seel
T07013d2	Trace metals in terrestrial ecosystems	K C Walton
T07013e1	Influence of fluoride ions on leaching of aluminium from metal cooking vessels	K C Walton
T07013f2	Trace metals in rabbit bones from England and Wales, 1971-72 (proposal)	K C Walton
T07014g2	Grey heron research	A A Bell
T07017f5	Remote sensing of Eskdale and Dunnerdale	K R Bull/ B K Wyatt
T07025-5	**Radionuclide studies in Wales**	***D F Perkins***
T07025a2	Radiocaesium in the Snowdonia sheepwalk ecosystem (proposal)	D F Perkins
T07025b2	Radiocaesium cycling in *Nardus stricta* (proposal)	D F Perkins

Programme 9 Community ecology

T09004a5	Geochemical cycling in the uplands	B Reynolds
T09005-5	**Forestry practice and nutrient cycling**	***M Hornung***
T09005a5	Effects on site properties of clear-felling in upland forests	P A Stevens
T09006-2	**Effect of grazing on vegetation**	***D G Hewett***
T09006a2	Sand dune management in Wales	D G Hewett
T09006c2	Ecology of arctic-alpine species in Snowdonia	C Milner

Programme 13 Scientific services

T13006-2	**Publications**	***C Milner***
T13006b2	Publication of collected data	D C Seel
T13006c2	Publication of collected data	J Dale
T13008-2	**Engineering**	***C R Rafarel***
T13008a2	Engineering development (mechanical and electronic)	C R Rafarel
T13008b2	Microprocessor development studies	C R Rafarel
T13009-5	**Remote sensing — applications centre of excellence**	***B K Wyatt***
T13009c4	NERC Remote Sensing Applications Centre in TFS	B K Wyatt
T13010-2	**Digital cartographic service**	***G L Radford***
T13034-2	**Development and maintenance of site of Bangor glasshouse unit**	***T W Ashenden***
T13036c1	Small consultancies at ITE Bangor	C Milner

EDINBURGH RESEARCH STATION

Programme 1 Forest and woodland ecology

T01001-5	**Evaluation and selection of genotypes**	***M G R Cannell***
T01001a2	Evaluation of conifer clones and progenies	M G R Cannell
T01001b2	Evaluation of red alder	L J Sheppard
T01001c5	Selection of conifer genotypes (proposal)	A Crossley
T01001d1	Genetic improvement of tea	M G R Cannell
T01002-5	**Tree seedlings and their establishment**	***J D Deans***
T01002c2	Effects of EFG's seedling storage and handling practices on outplanting survival and performance	J D Deans
T01002d2	Influence of mycorrhizas on root growth potential (proposal)	P A Mason
T01005-2	**Tree growth processes**	***M G R Cannell***
T01005a2	Measurement and modelling of transpiration in plantation Sitka spruce	R Milne
T01005b2	A model of tree growth	R I Smith
T01005c2	Partitioning of assimilates between branchwood and foliage in forest trees	M G R Cannell
T01005d2	Partitioning of assimilates of stems and structural roots of forest trees	J D Deans
T01005e2	Light use efficiency of coppice	M G R Cannell
T01005f2	Cone initiation: its interactions with and consequences for the carbon balance in lodgepole pine (*Pinus contorta*)	J McP Dick
T01007-5	**Analysis of windthrow**	***R Milne***
T01007a2	The silviculture of re-spacing Sitka spruce	J D Deans
T01007b2	Operation of the Rivox field site	R Milne
T01007d2	Mechanics of windthrow in commercial forests	R Milne
T01007e5	Tree stability: interactions within groups of trees under wind loading	R Milne
T01008-5	**Mycorrhizas and tree production**	***J Wilson***
T01008a2	Mycorrhizas and tree growth	P A Mason
T01008b2	Characterization of sheathing mycorrhizas	P A Mason
T01008c2	Occurrence of fruitbodies of mycorrhizal fungi in field plantings of different provenances of Picea sitchensis and Pinus contorta	J Wilson
T01008f1	Mycorrhizal research links with India	J Wilson
T01008h1	Large-scale production of mycorrhizal inocula (proposal)	J Wilson
T01008i1	Training of Philippines research worker (proposal)	J Wilson

T01009-5	**Improvement of tropical trees**	***R R B Leakey***
T01009a2	Domestication of tropical hardwoods	R R B Leakey
T01009b5	Domestication of tropical trees by in vitro culture	R R B Leakey
T01009c1	Seed production and tree improvement in Cameroon	R R B Leakey
T01009d1	World Bank forestry— EFG & ONAREF	R R B Leakey/ K A Longman
T01009e1	Vegetation propagation of Eucalyptus grandis	R R B Leakey
T01009f1	Propagation of *Lovoa trichilioides* in Cameroon	R R B Leakey
T01010-1	**Tropical forestry and agroforestry**	***R R B Leakey***
T01010c1	Agroforestry and mycorrhizas in E Africa	R R B Leakey
T01010e1	Comparative ecology of endomycorrhizas and nutrient cycling in indigenous species plantations in Cameroon	R R B Leakey/ P A Mason
T01025-1	**UNESCO contracts**	***O W Heal***
T01025a1	UNESCO MAB contracts	O W Heal

Programme 4 Management of aquatic ecosystems

T04001-5	**Management of aquatic ecosystems**	***A E Bailey-Watts***
T04001a2	Effects of acidification on freshwater plants and invertebrates	K H Morris
T04001c1	Status and conservation of British freshwater fish	A A Lyle
T04001d1	Ecology and conservation of charr in Loch Doon	L May
T04001g1	Status of fish populations in acidified waters in Wales	I R Smith
T04001h2	Synoptic survey of freshwater ecosystems in Scotland	K H Morris
T04001i2	Coldingham Loch (proposal)	A E Bailey-Watts
T04001j2	Rotifer resting eggs to indicate acidification in freshwater environments	L May
T04001k2	Crustacean remains in sediment cores	D H Jones
T04003-5	**Eutrophication**	***A E Bailey-Watts***
T04003a2	An assessment of the current loading of phosphorus to Loch Leven and a reconsideration of eutrophication control by point-source phosphorus removal	A E Bailey-Watts
T04003d1	Loch Eye, Easter Ross — eutrophication case study	A E Bailey-Watts
T04003e2	The effects of phosphorus fertilisers and forestry on algal growth in loch waters receiving runoff	A E Bailey-Watts
T04003f2	The analysis of Loch Leven nutrient loading data	A E Bailey-Watts

Programme 7 Environmental pollution

T07001-5	**Dry deposition**	***D Fowler***
T07001a2	Monitoring atmospheric concentrations of sulphur dioxide and oxides of nitrogen, and the chemical composition of precipitation at Devilla	D Fowler
T07001b2	Measurement of the rate of dry deposition of S02 on to a Scots pine forest	D Fowler
T07001c2	The influence of rainfall acidity on the transport and exchange of gases between plants and the atmosphere	J N Cape
T07001d5	Atmosphere-surface exchange of oxides of nitrogen, ozone and ammonia (NO_x, O_3 and NH_3 dry deposition)	D Fowler
T07001e5	Rural O_3, NO and NO_x concentrations	D Fowler
T07002-5	**Wet deposition**	***D Fowler***
T07002a2	The chemical composition of rainfall	J N Cape
T07002b1	Variation of acidic deposition with altitude	D Fowler
T07002c1	The effects of acidic deposition on the terrestrial environment	C Pitcairn
T07002d1	Snow chemistry and deposition on hills (proposal)	D Fowler
T07003-5	**Effects of pollutants on trees**	***J N Cape***
T07003a2	Interaction of airborne pollutants with natural surfaces, in particular the epicuticular wax of Scots pine (*Pinus sylvestris*)	J N Cape
T07003c5	Forest decline and atmospheric pollutants	J N Cape
T07003e1	Review and interpretation of throughfall and stemflow measurements	J N Cape
T07003f5	Organisation of workshop on 'Scientific basis of forest decline symptomatology'	J N Cape
T07004-5	**Physiological responses to pollutants**	***D Fowler***
T07004b5	Pollution studies using open top chambers in western Europe (proposal)	D Fowler
T07004c2	Responses of conifer trees to artificial acid mist	C G M Henderson
T07004d5	Accumulation and effects of atmospheric particulates on forests	A Crossley
T07004e2	Chamber development for mature trees	A Crossley
T07005-5	**Effects of pollutants on spruce**	***M G R Cannell***
T07005a5	Frost hardiness of red spruce in relation to forest decline and effects on red spruce of winter exposure to SO_2 and NO_2	M G R Cannell
T07020-5	**Ecological effects of climatic change**	***O W Heal***
T07020a5	Climate change: desk studies	M G R Cannell
T07021-1	**DOE umbrella: acid deposition and its effects**	***M A Booth***
T07021a1	Subcontract to Aberdeen University	M A Booth/ M Cresser
T07021b1	Subcontract to Lancaster University	M A Booth/ T A Mansfield
T07021c1	Subcontract to Nottingham University	M A Booth/ J Colls
T07022-3	**The effects of atmospheric pollutants on forests and crops (special topic programme)**	***B G Bell***

Programme 8 Population ecology

T08001-2	**Insect pests**	***A D Watt***
T08001a2	The population ecology of the pine beauty moth	A D Watt
T08001b2	The population ecology of the winter moth in Sitka spruce plantations	A D Watt
T08001c2	Population dynamics of forest insects conference	A D Watt

Programme 9 Community ecology

T09001-2	**Community ecology**	***B G Bell***
T09001a2	Biological monitoring of the Forth Valley	B G Bell
T09001c2	Ecology of rock-colonising mosses in Britain	P J Lightowlers
T09001d2	Taxonomy of bryophytes	B G Bell
T09001e2	Bryophyte ecology conference, Edinburgh, 1988	P J Lightowlers

Programme 11 Freshwater biology and chemistry

T11001-2	**The dynamics of plankton and fish populations with special reference to long-term changes**	***A E Bailey-Watts***
T11001a2	Long-term changes in zooplankton	L May
T11001b2	Predation on freshwater zooplankton	D H Jones
T11001c2	Species succession and population dynamics of the phytoplankton of Loch Leven, with special reference to the effects of nutrients and zooplankton grazing	A E Bailey-Watts
T11001e2	Zooplankton communities in freshwater lakes	D H Jones
T11001f2	Zooplankton population dynamics	L May
T11001g2	Morphometric studies of British lampreys	K H Morris
T11002-2	**Hydraulic conditions in rivers and lakes and their ecological implications**	***I R Smith***
T11002a2	The influence of events on population growth	I R Smith
T11002b2	Hydro-climate services	I R Smith
T11002c2	Aerial remote sensing of Lochs Leven, Lomond and Tay — 1984	A A Lyle
T11002d2	Mixing and spatial variation in lakes	I R Smith
T11002e2	River condition scale	I R Smith

Programme 12 Atmospheric science and hydrological extremes

T12019-3	**Atmospheric chemistry. Phase 1 (special topic programme)**	***J N Cape***
T12020g3	The surface/atmosphere exchange of gaseous ammonia	J Moncrieff

Programme 13 Scientific services

T13001-5	**Glasshouse and plant support**	***R F Ottley***
T13001a2	Glasshouses and nursery: support and development	R F Ottley
T13001d1	Plant culture for Inveresk Research International — winter wheat II	R F Ottley
T13001e1	Potato culture for Inveresk Research International	R F Ottley
T13001f1	Glasshouse consultancy to IRI (proposal)	R F Ottley
T13001g1	Apple culture for IRI (proposal)	R F Ottley
T13002a2	Utilization of STATUS in ITE libraries: cataloguing	S M Adair
T13006d2	Graphics, photography and scientific illustrations (proposal)	R H F Wilson
T13017-2	**Biometrics and modelling in Edinburgh**	***R I Smith***
T13017a2	Biometrics and modelling at ITE Edinburgh (proposal)	R I Smith
T13035-5	**Controlled environmental facilities at ITE Edinburgh (proposal)**	***R Milne***

MERLEWOOD RESEARCH STATION

Programme 1 Forest and woodland ecology

T01013-2	**Ecology of woodland soil fungi**	***J Dighton***
T01013a2	Role of fungi in nutrient cycling with special reference to *Mycena galopus* in forest soil	J C Frankland
T01013c2	An assessment of the status of mycorrhizas in the soil ecosystem	J Dighton
T01013d2	Phosphorus uptake by mycorrhiza of birch (proposal)	J Dighton
T01013f2	Faunal/microbial interactions related to nutrient cycling and agricultural stocking of the uplands	J C Frankland
T01014-5	**Soil nutrient dynamics**	***A F Harrison***
T01014a5	A comparison of biological and chemical assessments of the fertility of soils	A F Harrison
T01014b5	Cycling of key nutrients in forest soils and their interrelationships	A F Harrison
T01014c2	Liming and earthworm inoculation in forests (proposal)	C Robinson
T01014d5	Field methods in terrestrial nutrient cycling studies (proposal)	A F Harrison
T01014e1	Effects of vitamin addition on nutrient mineralisation	J Dighton
T01014f5	Assessment of P and K fertiliser responses of Sitka spruce (proposal)	A F Harrison
T01014g5	Assessment of P-deficiency in Sitka spruce, Pen-y-bont, Wales (proposal)	A F Harrison
T01015-2	**Afforestation: vegetation and fauna response to tree species**	***J M Sykes***
T01015a2	Monitoring at Stone Chest, Cumbria	J M Sykes
T01015b2	Monitoring of woodlands — long-term dynamics of forest ecosystems	J M Sykes
T01016-2	**Mixtures: interactions between tree species**	***A H F Brown***
T01016a2	The Gisburn experiment	A H F Brown
T01016b2	The effects of management in lowland coppices	A H F Brown
T01016c2	The effects of different silvicultural systems on flora, fauna, soil, timber production and visual amenity	A H F Brown
T01016d2	Soil and water acidity under different trees (proposal)	M Iles
T01017-1	**Agroforestry: potential mixtures of trees and crops**	***G J Lawson***
T01017a1	Agroforestry: experimental assessment of novel biomass systems	G J Lawson
T01017b1	Review of knotweed control (proposal)	R Scott
T01018-5	**Regional variations in forest nitrogen dynamics in Europe**	***P Ineson***
T01018a2	Regional aspects of forest dynamics in Europe	P Ineson
T01018b5	Nutrient cycling in European forests (proposal)	P Ineson
T01019-5	**Plant growth in semi-arid environments (Sudan)**	***D K Lindley***
T01019a5	Environmental crisis in the Sudan (a) Rehabilitation of degraded agricultural soils (b) Application of water-storing soil polymers for increased tree seedling survival (c) Alternative supplies of biomass	D K Lindley
T01020-5	**Forest succession and nutrient dynamics**	***D K Lindley***
T01020a5	The scientific management of renewable natural resources in China	D K Lindley
T01021-2	**Forest vegetation and pedogenesis**	***P J A Howard***
T01021a2	The role of forest vegetation in pedogenesis	P J A Howard
T01021b2	Soil biological aspects of nurse effects (proposal)	P J A Howard

Programme 2 Agriculture and the environment

T02008h3	The future environmental implications of a possibly less intensive agricultural industry in England and Wales	R G H Bunce

Programme 3 Land resources and use

T03002-5	**Land use change and ecological impacts**	***R G H Bunce***
T03002a2	An ecological survey of Britain	R G H Bunce
T03002c1	The environmental and socio-economic effects of the CAP	M Bell
T03002d1	Countryside implications of changes in CAP (proposal)	R G H Bunce
T03002e1	Environmental issues, agriculture and forestry land use options in Devon	R G H Bunce
T03002f1	Ecological consequences of land use change	R G H Bunce
T03002h1	Environmental constraints on the UK wind energy resource (proposal)	R G H Bunce
T03002i1	Mapping heather in England and Wales (proposal)	R G H Bunce
T03012-5	**Soil assessment**	***M Hornung***
T03012a5	Assessment of the principles of soil protection in the United Kingdom (proposal)	M Hornung

Programme 7 Environmental pollution

T07006-5	**Radionuclides in vegetation and soil**	***A D Horrill***
T07006a1	The distribution and dynamics of radionuclides in relation to land use in west Cumbria	A D Horrill
T07006b2	The concentrations and movement of americium in a coastal ecosystem in Cumbria	A D Horrill
T07006e1	Post-Chernobyl radiation levels in soils and vegetation	A D Horrill/ G R Miller
T07006g1	Radioactivity and wildlife: a desk study	A D Horrill/ V H Kennedy
T07006h1	The evaluation of data on the transfer of radionuclides in the food chain (proposal)	A D Horrill
T07006i1	The influence of mycorrhizas, potassium nutrition and microbial activity on radiocaesium cycling in heather-dominated ecosystems	A F Harrison
T07007-5	**Radionuclide-animal transfers**	***B J Howard***
T07007b1	Sheep feeding trials	B J Howard
T07007c1	Radioecology of ^{134}Cs and ^{137}Cs in sheep pasture systems following the Chernobyl accident	B J Howard
T07007d2	Comparative radioecology of Ag-110m and Cs-137	N A Beresford
T07007e1	The dynamics of radionuclide uptake by sheep	B J Howard

T07008-5	**Geochemistry of radionuclides**	***F R Livens***
T07008b5	Relationships between soil organic matter and the actinide elements (actinides in soil organic matter)	F R Livens
T07008c2	Terrestrial geochemistry of transuranic elements	A S Hursthouse
T07008d1	Radionuclides in freshwater systems	F R Livens
T07009-5	**Soil microbial response to pollutants**	***P Ineson***
T07009a1	Effects of forest fumigation with SO_2 and O_3 on roots and mycorrhizas of trees	J Dighton
T07009c1	Effects of air pollution (proposal)	P Ineson
T07009d2	Effects of atmospheric pollution on mycorrhizas (proposal)	J Dighton
T07009e2	Effects of sulphur dioxide on litter-decomposing fungi in deciduous woodland	J C Frankland/ P Ineson
T07009f5	Liming and faunal inoculation of forest soils: protection from acidification (proposal)	P Ineson
T07011-1	**Acid waters in Wales**	***M Hornung***
T07011a1	Acidification of waters in Wales	M Hornung
T07022h3	Effects of elevated inputs of nitrogen on the uptake metabolism, retention and allocation of nitrogen in tree crops	G R Stewart/ A F Harrison
T07024-3	**Environmental radioactivity (special topic programme)**	***V H Kennedy***
T07024b3	Uptake of radiocaesium by plants and the role of mycorrhizal fungi in mediating uptake	J Dighton
T07024c3	Effects of sward conditions on radiocaesium cycling in hill and upland sheep systems	R Mayes/ B J Howard
T07024d3	Dynamic modelling of pathways for radionuclides from the atmosphere to grazing animals	M H Unsworth/ B J Howard
T07024g3	Migration and retention of radionuclides in soils	A G O Donnell/ D Rimmer/ P Ineson

Programme 8 Population ecology

T08006-2	**Plant strategies: response to environmental stress**	***T V Callaghan***
T08006a2	Plant responses to environmental stress at high altitudes	T V Callaghan
T08007-2	**Vertebrate population dynamics: swan genetics**	***P J Bacon***
T08007a2	Population genetics of mute swans	P J Bacon
T08022-2	**Mammalian studies**	***V P W Lowe***
T08022a2	Ecology of red deer on the Isle of Rhum	V P W Lowe
T08022b2	Taxonomic studies, as a basis for mammalian autecology	V P W Lowe

Programme 9 Community ecology

T09004-5	**Geochemical cycling**	***M Hornung***
T09005b1	Effect of forest management on soil (proposal)	M Hornung
T09012f1	Salt marsh management in NW England (proposal)	R Scott

Programme 13 Scientific services

T13002-2	**Library services**	***J Beckett***
T13004-5	**Chemical support**	***J A Parkinson***
T13004a2	Chemical support studies	J A Parkinson
T13004b5	Analyses for certification of EEC international tree leaf reference materials	J A Parkinson
T13004c2	Radiochemical development	F R Livens
T13005-4	**NERC mass spectrometer service**	***C Quarmby***
T13005a4	Mass spectrometer service (stable isotope facility for 15-N analysis)	C Quarmby
T13006a2	Graphics and publications	C B Benefield
T13007-5	**Biometrics support**	***D K Lindley***
T13007a2	Biometrics and modelling support services at Merlewood	D K Lindley
T13018-4	**Management information systems**	
T13018a4	TFS management information system	P A Ward
T13025-1	**Contract chemical analyses at Merlewood**	***J A Parkinson***
T13025a1	Chemical analyses for Nature Conservancy Council i. Orkney waters. ii. Speyside lochwater	J D Roberts
T13025b1	Chemical analyses for universities	J A Parkinson

BANCHORY RESEARCH STATION

Programme 1 Forest and woodland ecology

T01011-2	**Population ecology of upland herbivores**	***B W Staines***
T01011a2	Deer in production forests	B W Staines

Programme 3 Land resources and use

T03001-5	**Human impact, erosion rehabilitation**	***A Watson***
T03001a1	Human impact in the Cairngorms	A Watson
T03001b1	Revegetation after disturbance	J Miles
T03001c2	Ecological impact of downhill skiing developments in north-east Scotland	G R Miller
T03001d1	Aonach Moor development plan	N G Bayfield
T03001e1	Footpath rehabilitation studies for the Yorkshire Dales National Park Committee	N G Bayfield
T03001f1	Soil erosion on north-east Scottish farmland	A Watson
T03001g1	Effects of past management on the potential of upland soils to support plant growth (proposal)	G R Miller
T03001h1	Restoration of upland vegetation (proposal)	N G Bayfield
T03001i1	Path revegetation trials on the Pennine Way	N G Bayfield/ G R Miller
T03001j1	Survey of soil erosion and vegetation damage at Cairngorm in 1988	A Watson
T03001k1	EIA — Cairngorm ski development (proposal)	A Watson/ N G Bayfield
T03001m1	Environmental impact assessment of Intake 8 (proposal)	N G Bayfield
T03011-5	**Ecological monitoring in Scotland**	***R Moss***
T03011a5	Impact of changes in land use in scenic upland areas on soil, vegetation, wildlife (flora and fauna) and landscape (proposal)	R Moss

Programme 8 Population ecology

T08003-5	**Population ecology of upland birds**	***R Moss***
T08003a2	Population dynamics of red grouse	R Moss
T08003b5	Demographic effects of nest predation on golden plovers and other moorland waders	R A Parr
T08003c5	Population ecology of capercaillie	R Moss
T08003e2	Epidemiology of the nematode *Trichostrongylus tenuis* in red grouse	J L Shaw
T08003f1	Effects of afforestation on moorland birds and their predators	R A Parr
T08003g5	Waders of agricultural land	N Picozzi
T08004-5	**Population ecology of predators**	***H Kruuk***
T08004c2	Herons and pollutants in aquatic ecosystems	M Marquiss
T08004e2	Occurrence of some heavy metals and PCBs in otters in Shetland	H Kruuk
T08004f5	The effects of environmental factors on populations of otters and fish in the north of Scotland	H Kruuk
T08004g5	Piscivorous birds in Scottish salmon rivers	M Marquiss
T08004h5	Ecology of the pine marten	D Balharry
T08004i5	Effect of water temperature on the behaviour and ecology of the European otter (*Lutra lutra*)	P S Taylor
T08005-1	**Population ecology of seabirds**	***M P Harris***
T08005b1	Development of monitoring of seabird populations and performance	M P Harris

Programme 9 Community ecology

T09001b2	Interactions between mosses and vascular plants (in abeyance)	N G Bayfield
T09002-5	**Interactions between grazing and vegetation**	***G R Miller***
T09002a2	Quantity and quality of seeds produced by montane plants	G R Miller
T09002b5	Effects of grazing on *Nardus* and *Calluna* moorland	D Welch
T09002c2	Development of subalpine scrub at northern Corries, Cairngorms SSSI	G R Miller
T09002d1	Response of *Gentiana nivalis* population to withdrawal of sheep grazing	G R Miller
T09002e1	Modelling the agricultural and environmental consequences of sheep and red deer grazing heather moorland (proposal)	B W Staines/ D Welch
T09003-5	**Vegetation and soil dynamics**	***J Miles***
T09003a2	Vegetation dynamics and soils	J Miles
T09003b5	Cellulose decomposition in the subantarctic	D D French
T09003c2	The effects of birch on moorland soils and vegetation	J Miles
T09003d2	Effects of soil chemistry on decomposition	D D French
T09003f2	Early changes in soils under birch and heather	A J Ramsay
T09003g2	Dynamics of *Macchia* (proposal)	J Miles

Programme 13 Scientific services

T13003-5	**Services at ITE Banchory**	***(B W Staines)***
T13003b1	Ecological advisory appointment with SDD (proposal)	J Miles
T13003c5	Caring for the high mountains — conservation of the Cairngorms	J W H Conroy
T13003d1	Brathens consultancies	B W Staines
T13003e2	Computing and statistical advice	D D French
T13003f1	Scottish Office consultancy (proposal)	J Miles

Appendix 4 **Publications by ITE staff in 1987–88**

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