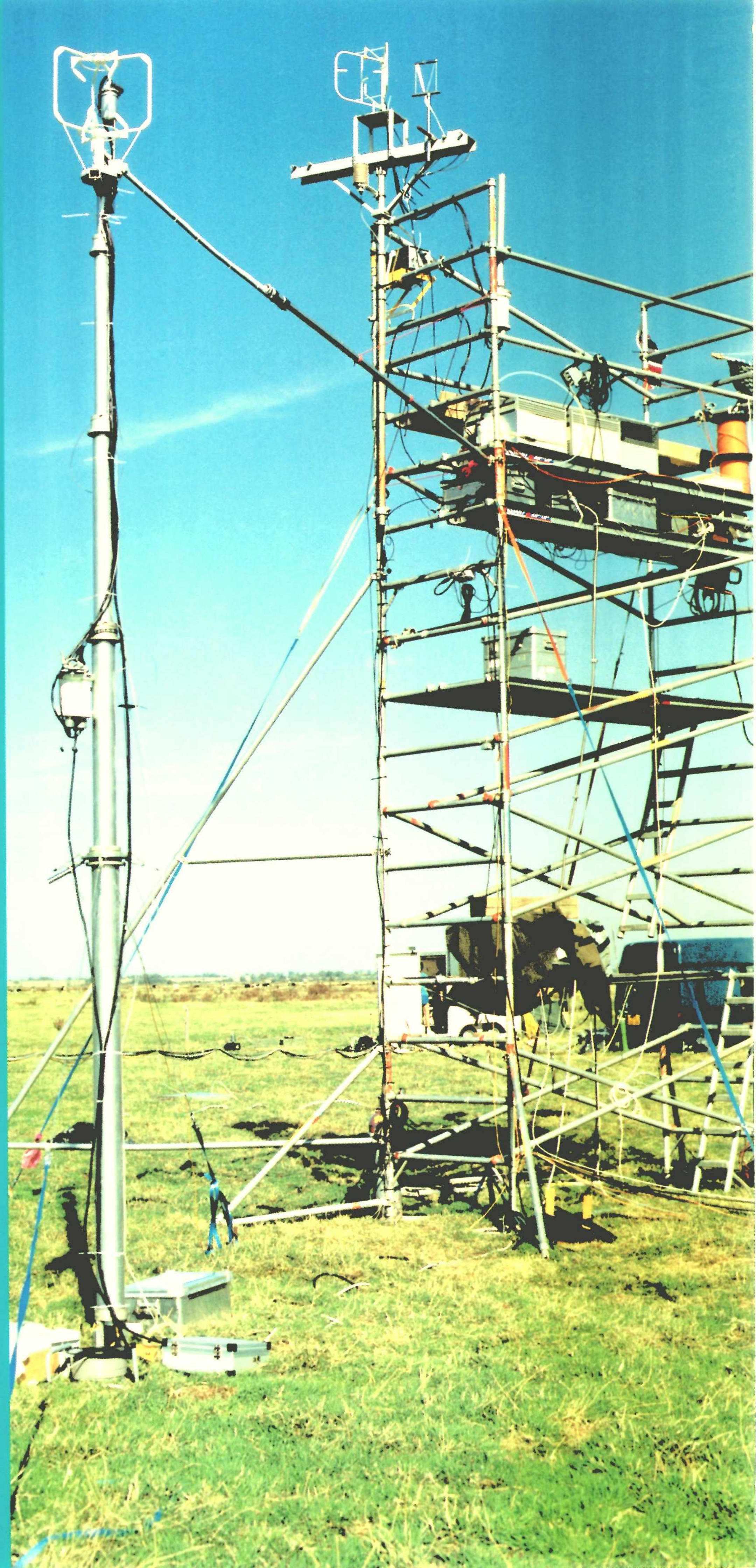
Institute of Terrestrial Ecology

Annual Report 1994–95

Centre for Ecology and Hydrology

Natural Environment Research Council



The ITE mission

The Institute of Terrestrial Ecology will develop long-term, multidisciplinary research and exploit new technology to advance the science of terrestrial ecology, leading to a better understanding and quantification of the physical, chemical and biological processes of the land.

Priority is placed on developing and applying knowledge in the following areas:

- the factors which determine the *composition*, *structure*, and *processes* of terrestrial ecosystems, and the *characteristics* of individual plant and animal species

- the dynamics of *interactions* between atmospheric processes, terrestrial ecosystems, soil properties and surface water quality

- the development of a sound scientific basis for *monitoring*, *modelling* and *predicting* environmental trends to assess past, present and future effects of natural and man-made change

- the securing, expansion and dissemination of ecological data to further scientific research and provide the basis for impartial advice on environmental protection, conservation, and the sustainable use of natural resources to governments and industry.

The Institute will provide training of the highest quality, attract commissioned projects, and contribute to international programmes.

ITE will promote the use of research facilities and data to enhance national prosperity and quality of life.

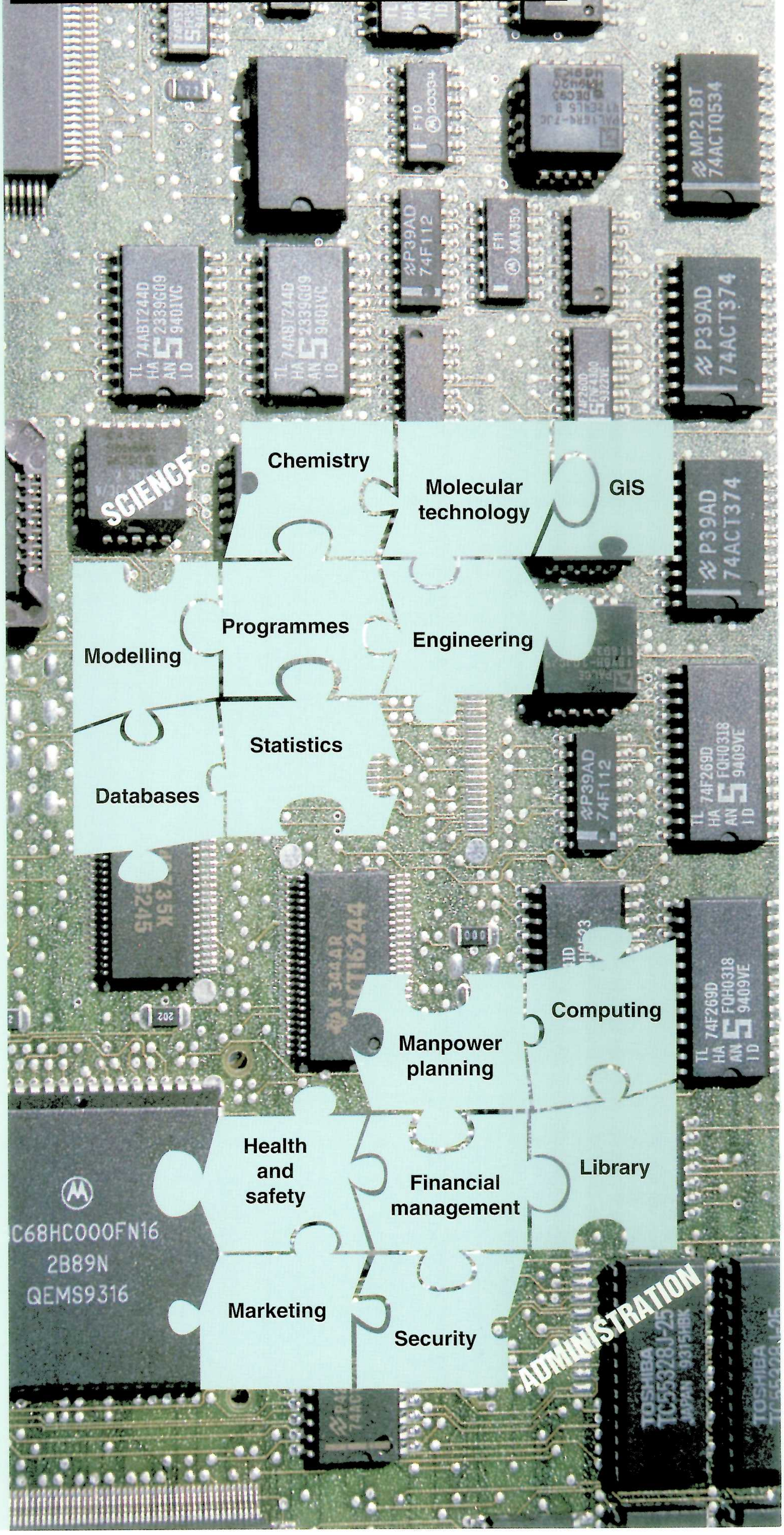
Report of the Institute of Terrestrial Ecology 1994–1995

Centre for Ecology and Hydrology

Natural Environment Research Council

Contents

Infrastructure



ITE infrastructure activities

The purpose of NERC's support for infrastructure is to provide those elements of underpinning support, service and facilities which are essential to the NERC community. It will include 'well-found laboratory' support to NERC Centres and Surveys, and scientific services and facilities for the NERC scientific community. NERC has established a single ITE Directorate at Monks Wood to manage the administration across the ITE sites. Networks have been established in ITE to manage the infrastructure activities effectively across the Stations. These networks will be integrated within a CEH-wide strategy.

Data centres

NERC also supports seven designated data centres which act as important national repositories of environmental data, ensuring accessibility of data to the broad user community, and providing information and advisory services. The Environmental Information Centre at ITE Monks Wood is one of these centres. A new NERC Data Strategy Group is assessing the priority actions and the funding for access of NERC by the wider science community.

NERC has decided to increase resources allocated to data in order to facilitate the appropriate accessibility, archaeology, inter-comparability and use of data, both by academics and by end-users. NERC has endorsed the policy of obtaining recognition by end-users, including Government departments, of the full cost of collecting and curating data. NERC sees the value to users of coherent integrated environmental data for the UK as a whole.

Introduction

An important and distinctive aspect of the Research Council Institutes stems from their ability to sustain operations in support of the scientific infrastructure. This characteristic, although not exclusive to the Institutes, is one to which they are particularly suited. It gains special importance in relation to activities with relatively long timeframes, including the functions of environmental monitoring that are now explicitly within the NERC mission. The new funding modes for NERC science, announced in the *1995 Corporate Plan update*, recognise the need to support essential infrastructure, both in NERC Institutes and in universities, and to provide services and facilities for the whole NERC community in support of its thematic, non-thematic and core strategic programmes.

ITE has always recognised and responded to the need for such infrastructural support, which extends across a wide range of scientific services, from data capture (eg specialist chemical analysis services and molecular techniques) through database management (data centres and library services) and data analysis (biometrics, modelling and geographical information systems). Since the amalgamation of ITE(North) and ITE(South) in September 1994, management has paid particular attention to improving the networks of infrastructure functions across the distributed network of ITE sites. Communication has been improved by use of the World Wide Web (on Internet) and Wordperfect Office across all sites. Specific networks have been established, and these link to evolving networks within the Centre for Ecology and Hydrology.

Chemical services

The ITE chemistry laboratories at Merlewood and Monks Wood are nationally unique specialist centres for the analysis of trace levels of major cations and anions, radionuclides, stable isotopes, trace metals and organic pesticide residues. The ITE chemical services not only support science carried out in the Institute, but also underpin wider NERC Community research programmes, including the Terrestrial Initiative in Global Environmental Research (TIGER) Programme, the Land/Ocean Interaction Study (LOIS), and future programmes such as those concerned with Environmental Diagnostics and Urban Environments.

Subject to availability of resources, these specialist skills may also be utilised in commercial applications, so as to defray some of the costs against the science budget. Examples of the use of gas chromatography–mass spectrometry in the detection and analysis of polychlorinated biphenyls and other organic residues are documented below.

Molecular ecology

As described later, recent developments in molecular ecology promise radical improvements in our capacity to undertake experimental research in population ecology. ITE has responded to these opportunities with three initiatives. The first is the establishment, jointly between ITE Banchory and the University of Aberdeen, of a research project in the application of molecular genetics to vertebrate population ecology. The second is the commissioning of a molecular ecology laboratory at ITE Furzebrook, which is focusing on the use of these techniques to investigate gene flow in plant populations. The third is the development of molecular microbial facilities to underpin studies on soil biodiversity and functional processes.

Environmental Change Network

Biometrics and modelling

Biometrics – especially the use of multivariate techniques – has long been one of the Institute's strengths. Of course, this is no coincidence; success in exploring ecological hypotheses is heavily dependent on good experimental design and a sound understanding of the underlying statistics. In recognition of the need, above all, for effective dialogue between biometrician and ecologist so as to ensure the uniform adoption of best practice, the Institute has established a network of statistical advice and support, with full-time biometricians located at most sites and accessible from all.

Edinburgh Centre for Tropical Forests

Rapid growth in the power of the computers available to scientists has transformed our approach to the solution of ecological problems. A factor which continues to limit progress in this field is the shortage of specialist skills required to transform ecological ideas and understanding into forms that can be represented through models. The

Institute has adopted a similar approach to that used for the successful promotion of statistical skills a network has been established, comprising staff with modelling skills or with strong interests in ecological applications of mathematical models, with the purposes of advancing technical expertise and understanding in this area and of encouraging cross-fertilization between applications In the following reports, applications of numerical modelling techniques across the Institute are reviewed

Geographical information systems

Much of the work of the Institute is concerned with elucidating and explaining the interactions in space and time which govern the relationships between individuals and populations and their environment Analysis and modelling of *spatial* relationships (at a variety of scales) are, therefore, intrinsic to ecological research, these are operations for which geographical information systems (GIS) are designed and are particularly well suited ITE has been an active user of GIS for many years, extending back to collaboration with NERC's pioneering work in digital mapping through its Experimental Cartography Unit Currently, the Institute has specialist GIS installations, comprising UNIX workstations running ARC/INFO, at each of its Research Stations The network is co-ordinated and supported from the Environmental Information Centre at Monks Wood, and staffed by specialists, but the intention is to achieve a full integration of these systems with the science applications that they service, while adopting a common approach to issues of data management By this means, it will be possible to access and use geo-referenced databases throughout the Institute for a wide variety of applications

Library

Information, whether in the form of published documents or as data in electronic media, is a vital research commodity In the NERC context, such data must be organised in ways that provide compatibility across the Institute and wider, in order to support the cross-media studies that are commonplace in environmental research

The Institute is making extensive use of innovative developments in information technology, with a strong emphasis on data exchange across the Internet Use of the World Wide Web to access descriptive information about ITE and its scientific programmes is described later

The ITE Library Service is well placed to participate in the development of a national or regional strategy for library provision for research, recently recommended by the Follett Review of Libraries in Higher Education It uses the LIBERTAS library management system, which includes an on-line public accessible catalogue (OPAC) to libraries and researchers via the UK Joint Academic NETwork (JANET) and the worldwide Internet

(telnet library nkw ac uk)

OPAC contains records of all book accessions since 1979 (about 10 000 records), and of all journal holdings (about 1000 titles) It also includes records of library holdings of the NERC British Geological Survey, with which ITE shares use of the LIBERTAS system

Records of publications by ITE scientific staff are maintained by the ITE Library Service as part of the CEH Management Information System, which is held as a STATUS database on a microVAX at ITE Merlewood A menu system has been developed so that end-users are able to extract lists of publications, but direct access is only permitted from within NERC

Access to OPAC and the publications database is possible on World Wide Web via the ITE 'homepage'

(http //www nmw ac uk/ite),

and the former is also accessible via the NISS Information Gateway

(http //www niss ac uk)

within the Higher Education pages

Data centres

The Environmental Information Centre (EIC), located at Monks Wood, is one of seven data centres designated by NERC with responsibility for handling its corporate data and for implementation of published NERC policy on data management and dissemination EIC lies at the centre of a distributed data network which takes in all groups in the Institute engaged in significant programmes of data acquisition and management EIC has overall responsibility for data documentation, for issues of compatibility and inter-operability, and for links outside the Institute EIC also functions as a shop window for Institute data holdings, and formally manages most (but by no means all) of the Institute's large datasets, including, in particular, the Biological Records Centre, the Land Cover Map and the CORINE Biotopes database EIC is the home of the UK National Critical Loads Mapping Centre and is a component of two European Topic Centres (on Nature Conservation and on Land Cover) within the European Environment Agency EIC is the location for a data centre which services the needs of coastal ecologists in the NERC LOIS programme, similar specialist data centres are likely to be established within EIC to cater for future NERC thematic programmes

The Environmental Change Network (ECN) is an inter-agency initiative for the acquisition and management of data on long-term change ECN is co-ordinated by staff at ITE Merlewood and is described below in greater detail

It is a guiding principle in ITE that those best qualified to promote and to facilitate the use of scientific data are its originators For example, the Land Use Section at ITE Merlewood manages, as part of the ITE data network, a database which is arguably the most complete record in existence describing change in the British countryside The Countryside Information System, developed by the Merlewood team to facilitate access to and analysis of these data, is described elsewhere in this *Report*

Exploitation of science

NERC's revised mission places renewed emphasis on the utilisation of its science in applications with relevance for wealth creation and quality of life In addition to the more traditional channels for disseminating scientific results through the scientific literature, the Institute also has in place more radical solutions to the challenge of achieving a closer interface with its users An important function for EIC is the promotion of the Institute's information resource and scientific capability, this is achieved through a Business Development Unit A rather different approach has been taken at ITE Edinburgh, where membership of the Edinburgh Centre for Tropical Forests (see below) provides a unique capacity to ally skills within the Institute to complementary skills in other Edinburgh-based organisations in pursuit of practical applications of science for solving the problems of tropical forest management

B K Wyatt

Research applications of gas chromatography–mass spectrometry

(The developmental work in this paper was funded by the NERC Land/Ocean Interaction Study)

The Analytical Chemistry Section at ITE Monks Wood was set up in 1961 within the Toxic Chemicals and Wildlife Section of the Nature Conservancy. It carries out analysis of tissue, vegetation, soil and water for a wide range of toxic organic and inorganic residues to study long-term trends in environmental levels of persistent pollutants.

The majority of organic compounds measured are organochlorine pesticides (OCs) and polychlorinated biphenyls (PCBs). The traditional analytical technique for OCs and PCBs is capillary gas chromatography with detection by electron capture detector (GC–ECD). To determine the presence or absence of a particular compound in a sample, a pure preparation of that compound is required for comparison. If a higher degree of confidence in the analytical results is required, they can be confirmed by further sample processing. However, this is expensive and is not possible for every compound. Analysis by GC–ECD is suited to work where standard methods are used for specific compounds (eg most OCs) and every result does not require further confirmation.

Up until three years ago most of our work was of this type but, since then, we have moved into other areas and the nature of the analysis required has changed. The research at Monks Wood now includes the investigation of large-scale industrial accidents, mapping of the metabolic breakdown pathways of toxic organic compounds, and monitoring of the environment for new pollutants. We are now looking for a much wider range of compounds and require a higher level of confidence in the results. In this research we do not always have a clear idea of the identity of the compounds we are looking for and such work would not, therefore, be feasible using our traditional analytical techniques.

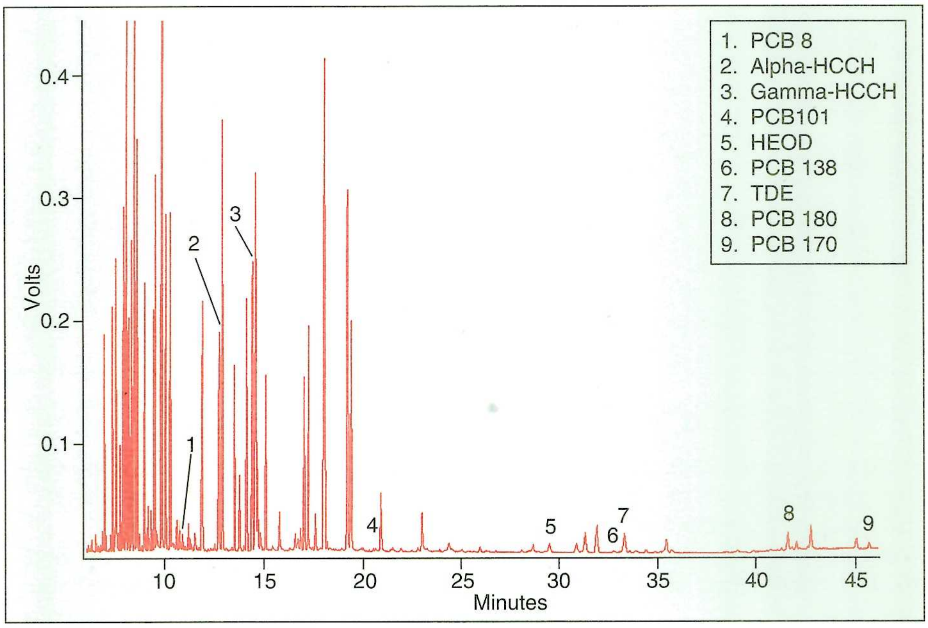


Figure 70. GC–ECD chromatogram of a water sample from the River Aire

To help overcome these problems and to improve the quality of our traditional analysis, we have just completed the commissioning phase for a low-resolution gas chromatograph–mass spectrometer (GC–MS) (Plate 37). The advantages of GC–MS over GC–ECD are that it gives the mass spectrum for a compound which provides an almost unique 'fingerprint'. The GC–MS interfaced with a computer identifies the unknown compound by comparing its mass spectrum with a library of the mass spectra of 70 000 known compounds until a match is found. GC–MS software can give reasonable identifications of 100 unknown compounds in a sample in a matter of minutes. Such powerful identification using GC–ECD or similar techniques would be impossible. Once the compound has been identified by its mass spectrum, it is then confirmed by comparison with a pure standard of that compound. If the unknown compound is not in the library, then the structural information provided by the mass spectrum can be used to determine what it may be, thus making the further work required to identify the compound far easier.

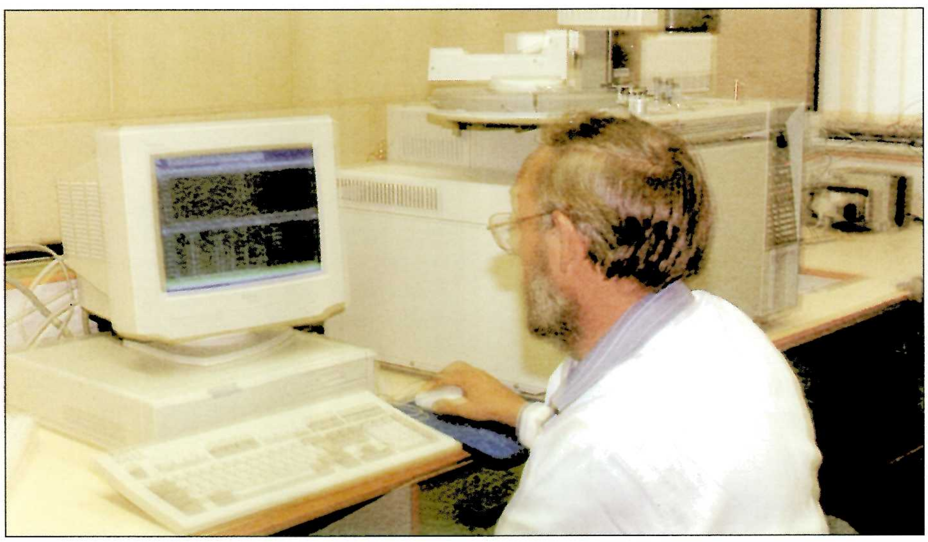


Plate 37. The GC–MS in operation

Once the mass spectrum of an unknown has been collected it may be stored, and other samples may then be monitored for this compound with a high degree of confidence without initially having to know its actual identity. This facility would enable a database of pollutants to be created, with the view that, if concern over a particular class of compounds is raised, archived spectra of environmental samples would be available to assess environmental trends of these compounds. For the identification of unknowns, the GC–MS is used in scan mode. If the GC–MS is used in select ion

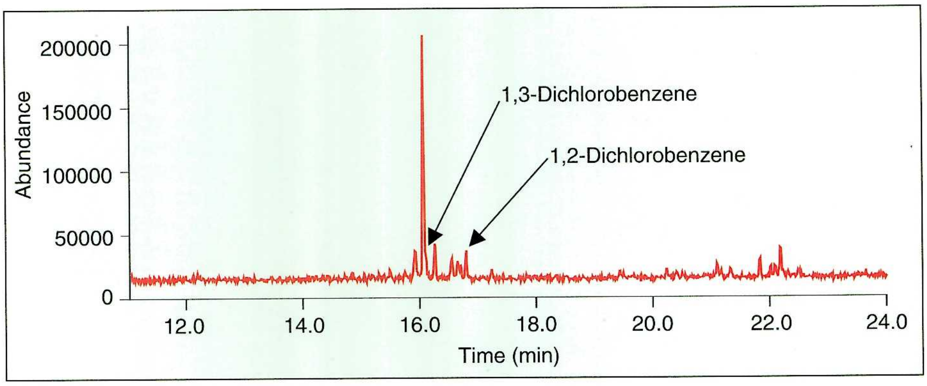


Figure 71. Scan mode GC–MS chromatogram of a water sample from the River Aire

monitoring mode (SIM), then selectivity of the instrument can be changed so that only one compound or group of compounds is detected, which reduces interference and increases sensitivity.

The analysis of river water samples for the NERC Land/Ocean Interaction Study (LOIS) demonstrates what a powerful technique GC–MS is in cases where the identity of compounds being investigated is unknown. Our role in the LOIS programme is to measure the levels of PCBs in river water so that the amount of PCBs entering the North Sea from the Humber Estuary can be calculated and modelled. The expected PCB levels were too low for the GC–MS and so the samples were analysed by GC–ECD (which has greatly enhanced sensitivity for chlorinated compounds compared to GC–MS). The chromatogram in Figure 70 is the output from the GC–ECD, and each peak represents a single compound. Figure 70 shows that small amounts of PCBs were detected, but it also shows the presence of a great many other compounds that could not be identified.

To identify these compounds using GC–ECD would have involved predicting what they might be, buying pure samples of these compounds, and then comparing the pure standards with the sample. This approach would be costly and time-consuming. Instead, the samples were run on GC–MS and the compounds detected were identified by a library search. The GC–MS chromatogram (Figure 71) shows that fewer compounds were detected using GC–MS than GC–ECD, because of the lower sensitivity of the GC–MS to chlorinated compounds. Not all of the compounds detected could be identified, either because the amount of compound was too low to provide a good spectra or because they were not in the GC–MS library. However, the spectra from these compounds were stored to see if the compounds occur regularly in other samples; if they do, then it may well be worth doing further work to identify the compound.

Among the compounds identified by GC–MS were a variety of chlorobenzenes and polyaromatic hydrocarbons (PAHs), both of which are persistent organic pollutants that are highly toxic and accumulate in terrestrial and aquatic food chains. Chlorobenzenes are industrial solvents and include the pesticide hexachlorobenzene. PAHs are constituents of fossil fuels and products of the combustion of a wide range of organic material. Once identified by library search, the chlorobenzenes and PAHs could then be confirmed with standards of these compounds and routine quantitative analysis set up using selective ion monitoring. The quantitative analysis for chlorobenzenes could have then been done using GC–ECD, but GC–MS using selective ion monitoring is far less prone to interference from other compounds and the confidence in the results is greater. Figure 72 shows the GC–MS SIM mode chromatogram for chlorobenzenes in a sample from the River Aire. Comparison with the GC–ECD chromatogram (Figure 71) shows that GC–MS can pick out chlorobenzenes from a complex mixture of similar compounds. Comparison of the GC–MS chromatograms in SIM mode and scan mode (Figure 71) shows the increased sensitivity that can be achieved using SIM mode. To analyse PAHs without the GC–MS would have meant setting up another GC instrument with a different detector, and then having to accept results of a lower quality.

The GC–ECD was also used for measuring the organochlorine pesticides in these samples. Two isomers of the pesticide lindane were found in many samples, and confirmation of these results was required. Confirmation was done by GC–MS in a fraction of the time taken by traditional techniques, and then routine analysis of lindane and its isomers was set up on the GC–MS to complement the GC–ECD analysis.

GC–MS improves the quality of our existing routine analysis and enables us to carry out research that would otherwise have been impracticable or impossible. Future developments at Monks Wood will involve increasing the sensitivity so that unknown compounds may be identified at lower levels, expanding the range of compounds routinely measured, thus enabling new areas of research.

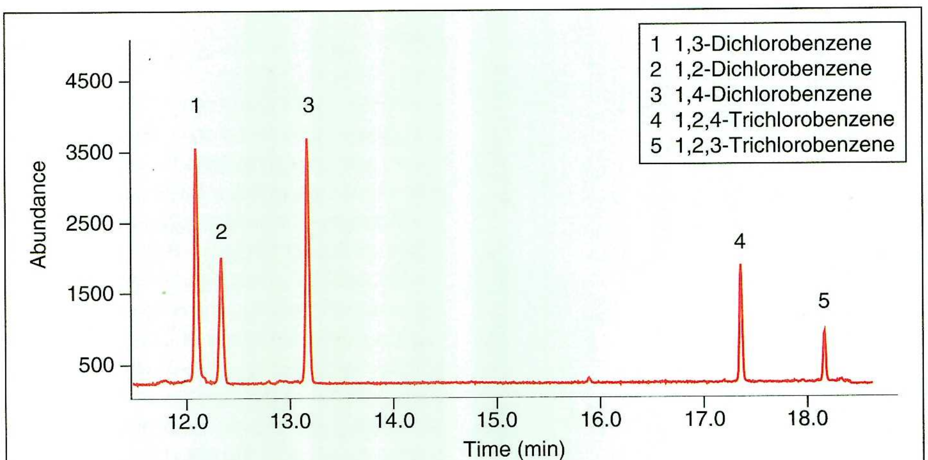


Figure 72. SIM mode GC–MS chromatogram of chlorobenzenes in a water sample from the River Aire

J Wright and A Meharg

Developing DNA molecular genetics techniques to answer questions in vertebrate population ecology

Population ecology has a long history of studying traits of known, marked individuals that comprise populations. Knowledge of a population's composition according to its individuals (their ages, sexes, body weights) is fundamental to understanding population processes, especially of vertebrates.

Until very recently, in order to identify individuals, ecologists have relied either on catching and marking individuals or on records of unique plumage or body characteristics. These methods are labour-intensive, and not universally applicable. Similarly, estimates of kinship, family sizes and parentage have been based on observing parents with their offspring: this has long been recognised as inadequate in promiscuous species, where the adults attending a family are not always the genetic parents of all the offspring.

Recent advances in molecular genetics have not only enabled definitive assignments of parentage, but are also beginning to offer the ability to describe population structure without having to observe family groups – even, perhaps, without having to catch or observe individuals at all. In order to investigate how useful these new genetic techniques may be to understanding details of ecological processes, NERC has funded a joint research project between ITE Banchory and the University of Aberdeen. The group is based in the Zoology Department, with close links to the Department of Molecular and Cell Biology and ITE Banchory (Plate 38). It currently comprises one lecturer, two post-doctoral fellows, two technicians and PhD students. Its work is co-ordinated by Professor Paul Racey (Professor of Natural History at Aberdeen University) and Dr Philip Bacon of ITE. An equivalent number of other University personnel with research programmes in molecular ecology and fish stock definition will work alongside the group. Initially, the group is concentrating on three disparate, but complementary, projects.

Plate 38. DNA samples being prepared in the laboratory

Kinship effects of red grouse on their population dynamics

The red grouse (*Lagopus lagopus*) (Plate 39) is an important gamebird of British moorlands whose numbers often fluctuate in regular 'cycles' of five to 12 years. There are currently two contending hypotheses to explain these fluctuations: first, that the cycles are due to host/parasite interactions (Hudson, Dobson & Newborn 1985); and, second, that they are due to time-lagged effects of local kinship structure (Watson *et al.* 1994). The kinship hypothesis predicts both that grouse tolerate their kin as neighbours more readily than they tolerate strangers, and thus that close kin should settle near each other, and that

Plate 39. An aggressive red grouse on a heather moor

the average relatedness of neighbours should change with the phase of the population cycle.

Current field methods can establish the relatedness of only a small proportion of the breeding population because many recruits come from outside the study areas and are of unknown origins. Employing suitable micro-satellite DNA markers (originally developed for chickens and provided by Dr Oliver Hanotte of the University of Leicester), we are now able to do much better. Given a single feather or blood sample, we can now not only establish parentage with certainty for any two birds but also tell whether birds are close siblings or unrelated migrants and, indeed, estimate the closeness of the relationship between any pair of birds. Preliminary data from a grouse study area for 1994 strongly suggest that neighbouring territory holders are more closely related than non-neighbours on the same moor.

Home ranges and population structure of otters

The Eurasian otter (*Lutra lutra*) (Plate 40) is a secretive and endangered carnivore. It is very difficult to study, in most habitats in the field, being elusive and frequently nocturnal and occurring at low densities. The best data on individuals usually come from radio-tracking, but this requires first capturing the animal, which is often difficult. Advances in DNA techniques over the past few years have shown that DNA suitable for laboratory analysis can be obtained from hair and even droppings. Otter droppings, called spraints, are usually easy to collect: they

Plate 40. An otter

are used as social signals between members of the population, and often deposited in obvious positions. The group has managed to extract usable otter DNA from spraints, and is working to develop micro-satellite primers that will allow both individual identity and 'close' relatedness to be established by analysing such DNA extracted from spraints. If this work succeeds, then we will be able to describe in some detail the home ranges of individual otters, and their relatedness to other otters in the local population, just by collecting spraints and without having to catch the otters. We hope to assess this approach over the next few years.

Dispersal and recolonisation of fragmented water vole populations

Water voles (*Arvicola terrestris*) were formerly common throughout the UK but have declined markedly in recent years because of habitat loss and predation by feral American mink (*Mustela vison*). The steep decline has produced gaps in the range, and the chances that populations will persist and recolonise depend on their dispersal ability. Dispersal in small mammals is strongly sex-specific: males tend to disperse and females to remain. New populations are only likely to become establised if both sexes reach a new site, and female dispersal may be limiting. The group is developing mitochondrial DNA markers, which are only passed on via the mother, to contrast with micro-satellite markers passed on by both sexes. These markers will be used to assess population structure and dispersal in a detailed study of water voles in north-east Scotland.

These three projects represent the group's present focus. In order to accomplish them, the group is developing expertise in a wide range of DNA techniques that will be used to address other ecological topics as opportunities arise. For example, an associated project on the genetics of outbreak populations of winter moths (*Operophtora brumata*) has shown genetic variation in the control loop of mitochondrial DNA amongst populations feeding on different plants.

P J Bacon and J Dallas[1]

[1]NERC Ecological Molecular Genetics Group, University of Aberdeen University

References

Hudson,P.J., Dobson,A.P. & Newborn,D. 1985. Cyclic and non-cyclic populations of red grouse: a role for parasitism? In: *Ecology and genetics of host-parasite interactions*, edited by D. Rollinson & R.M. Anderson, 79–89. London: Academic Press.

Watson, A., Moss, R., Parr,R., Mountford,M.D. & Rothery,P. 1994. Kin land-ownership, differential aggression between kin and non-kin and population fluctuations in red grouse. *Journal of Animal Ecology*, 63, 39–50.

Mathematical modelling in ITE

Recent expansion in modelling

In recent years there has been a marked increase in the development and application of formal mathematical and statistical models within ITE. This expansion has been reflected in the establishment of the Ecosystem Process Modelling Section at ITE Edinburgh, the appointment of specialist modellers at Monks Wood, Furzebrook and Bangor, the widespread use of modelling software including geographical information systems (GIS) (centred at the Environmental Information Centre at Monks Wood), and the demand by numerate and computerate staff for ever more powerful computers, including use of the most powerful machine in UK science – the CRAY parallel processor at the University of Edinburgh. This is, therefore, an opportune time to take stock of the types of modelling that are being done.

Purposes of modelling

Modelling, in its widest sense, is now an integral part of virtually all of the science activities in ITE. In their simplest form, models are being used to describe, simplify and communicate knowledge, and to gain understanding. Simple pictures of reality, in explicit mathematical notation, are routinely constructed to test ideas or assumptions about the behaviour of systems. More sophisticated models have been built to predict input from output – often in circumstances where measurements cannot be taken, such as over extensive geographical areas or over long or future time periods. When the models have been well tested, so that we are confident about their predictions, they have been developed to advise our user communities as 'decision support' tools.

The advantages of modelling are well known and are widely exploited. They include:

- the synthesis of data and knowledge – including the use of statistical models,
- the clarification of ideas – forcing the scientist to specify processes, interactions and feedbacks,
- extrapolation to conditions that have not been measured or do not yet exist, and
- the execution of sensitivity and

Soil/plant/animal processes

Research questions	Types of models	ITE location and staff	
• Responses of vegetation to climate, pollutants and management, vegetation/climate interactions at regional and global scales, tree/crop interactions, sustainable forest management, carbon storage in vegetation and soils	• Process-based, physiological models, driven by climate, of the pools and fluxes of carbon, nutrients and water in the soil/vegetation/atmosphere system, at a stand or individual plant level	*Edinburgh* *Merlewood* *Monks Wood*	Thornley, Friend, Arah, Milne, Mobbs, Lawson, Cannell Lindley Pakeman
• Effects of nitrogen deposition on acidification and nitrogen in groundwaters, especially in forests, pathways of radionuclides and other pollutants, effects of climate warming on biogeochemistry of upland soils	• Process-based biogeochemical models, especially of the nitrogen and water cycles in the soil/vegetation/atmosphere system and of the pools and fluxes of pollutants	*Bangor* *Merlewood* *Monks Wood*	Reynolds, Emmett Ineson, Howard (BJ) Pakeman, Osborn, Meharg, French
• Understanding particular processes, such as stomatal conductance, methanogenesis, other soil processes, saltmarsh dynamics, vegetative propagation, partitioning and mycorrhizal function	• Process-based models representing the essential elements of particular systems, used as research tools	*Edinburgh* *Monks Wood*	Thornley, Arah, Friend, Dick, Mason Boorman

Table 6 Soil/plant/animal processes

stability analyses, so that the important feature of a system can be identified

Types of modelling in ITE

Most of the models used in ITE are small and are written for specific purposes The small, purpose-built models are typically focused on particular species or ecosystems Larger models have been built to describe the transport, chemistry and fate of pollutants in the atmosphere, soils and waters At ITE Edinburgh, some very large ecosystem models have been developed, which couple the atmosphere/plant/soil system with respect to carbon (energy), water and nitrogen (Hybrid, the Edinburgh Forest Model, and the Hurley Pasture Model)

There are many ways of classifying models One way is to separate three logical types theoretical, correlative and predictive Examples of theoretical modelling in ITE would be the exploration of ideas on assimilate partitioning, stomatal conductance and predator/prey cycles Correlative models mostly fall in the realm of statistical analysis and data processing, while predictive models are generally those that deal with dynamic processes

An alternative, and perhaps more useful, way to classify the modelling work in ITE is on the basis of the subject being modelled – the questions being asked This type of classification is given below, separating out three types of models

i biophysical models which address hypotheses of process,

ii dynamic models of biological populations and processes – including statistical and rule-based models which address hypotheses of relationship, and

iii models that enable data to be presented as maps

Biophysical models

This modelling is based on mathematical representation of underlying physical, chemical and physiological processes involving the flows of energy and matter in soils, vegetation, animals and the atmosphere The models may be conveniently divided into those representing processes in the soil/plant/animal system (Table 6) and those dealing mainly with the physics and chemistry of the atmosphere (Table 7)

Atmospheric physics and chemistry

Research questions	Types of models	ITE location and staff	
• The sources, concentrations and residence times in the atmosphere, transformation in the atmosphere, dispersal and sinks of atmospheric pollutants and greenhouse trace gases Solar radiation exchange properties of vegetation	• Physical, chemical & physiological processes determining the land/atmosphere exchange of trace gases, deposition models, dynamic modelling of critical loads, plume trajectory and dispersal models, models of atmospheric chemistry and radiation balance	*Edinburgh* *Monks Wood* *Merlewood*	Fowler, Cape, Hargreaves, Sutton, Skiba, Smith Wadsworth, Eastwood, RSADU staff Hornung, Howard (DC)

Table 7 Atmospheric physics and chemistry

Animal population dynamics

Research questions	Types of models	ITE location and staff	
• Factors controlling vertebrate populations interactions between predators and prey, kin selection by grouse, seabird foraging, relationships between vegetation and herbivores, spatial distribution and populations of waders, woodland fragmentation and song birds, raptor dispersal and abundance, squirrel interspecific relationships	• Deterministic difference/differential equation models of average population responses Individual based models, including game theory in which, eg, individuals maximise food intake and survival with density-dependent competition, metapopulation dynamics of passerines in woodlands	*Banchory* *Furzebrook* *Monks Wood*	Bacon, Kruuk, Harris, Staines Goss-Custard, Caldow, Stillman, Clarke, Kenward Hinsley, Newton, Rothery
• Factors controlling invertebrate populations effects of habitat (eg manipulation, spatial pattern and fragmentation) on large blue/ant interactions, brown hairstreak butterfly and other invertebrates, climatic effects, outbreaks of forest pests, shellfish population dynamics	• Cellular automata simulating variable habitats at a site, stochastic density-dependent mortality based on life table data, population synchrony at different spatial scales, trend analysis in relation to climate, life table analysis combined with process and spatial modelling	*Furzebrook* *Monks Wood* *Edinburgh*	Thomas, Elmes, Clarke, McGrorty, Stillman Moss, Yates, Sutcliffe Watt

Table 8 Animal population dynamics

Plant/vegetation dynamics

Research questions	Types of models	ITE location and staff	
• Predicting changes in species dispersal and distribution in response to climate change	• Organism dispersal models, climate envelopes bounding species ranges	*Monks Wood*	Hill, Carey, Wright
• Effects on vegetation of burning or bracken clearance (heathland), submergence (salt marshes), disturbance (forests) and set-aside practices	• Succession modelling, regression, analysis of permanent quadrat life tables	*Monks Wood* *Furzebrook*	Hill, Firbank, Pakeman, Eastwood Gray, Warman, Rose, Clarke
• Understanding the population dynamics of species (eg weeds) and the spatial dynamics of communities	• Plant dynamics at two interlinked spatial scales, using cellular automata, life history models	*Monks Wood* *Furzebrook*	Firbank Bullock

Table 9 Plant/vegetation dynamics

Spatial modelling

Research questions	Types of models	ITE location and staff	
• Amounts of pollutants in the air and deposited over the UK, identification of areas receiving damaging levels of pollutants	• Air pollutant levels in the UK, maps of pollutant deposition and 'critical loads'	*Edinburgh* *Merlewood* *Monks Wood*	Fowler, Smith, Sutton Hornung Bull, Hall
• Vegetation cover of the UK and how it is changing	• Land use and land cover mapping, based on ground survey and satellite imagery	*Merlewood* *Monks Wood*	Bunce, Barr, Howard (DC), Gillespie Wyatt and staff in EIC
• Applications of models and spatial databases to predict change or impacts over a region, the UK or the world Examples are the effects of climate change on species, habitats and global vegetation, and species distribution in relation to habitat and landscape factors	• Various applications of GIS or similar systems	Many applications at all ITE sites	

Table 10 Spatial modelling

ITE expertise is concentrated at Edinburgh, Monks Wood, Merlewood and Bangor.

Dynamic models of biological populations and processes

This modelling uses mathematics, including statistical techniques and multivariate analysis, to estimate parameters in order to extrapolate/ generalise from particular observations. The model relationships and processes are often expressed in mathematical forms for which the parameters can be estimated from both existing and planned field and laboratory data. The models often serve to synthesise our knowledge and data to some meaningful statements that are of general value. Also included here are modelling techniques using game theory, cellular automata (rule-based dimensionless systems), life tables and other methods used to derive rules that govern the behaviour of complex systems. The models used in ITE deal mostly with population dynamics and often include stochastic processes. The models may be conveniently divided into those simulating animal population dynamics (Table 8) and those dealing with plant or vegetation dynamics (Table 9). ITE expertise occurs mainly at Banchory, Furzebrook, Monks Wood and Edinburgh.

There are, in addition, modelling activities which use a mixture of statistical techniques and mathematical representation of processes. An example in ITE is work at Monks Wood on pollution impacts, which involves simulating the transport of pollutants, their activity and metabolism.

Spatial representation of data

Although the use of geographical information systems and similar techniques for data manipulation may not be regarded by many as modelling, it is included here because the biophysical, statistical and other models described above are often used to generate maps, employing large spatially resolved databases (Table 10). Many GIS applications contain models. Consequently, those doing modelling are often involved in GIS and database management.

Future developments

There are several growth areas involving modelling in ITE. First, the large process-based ecosystem models, which are currently being used to simulate the responses of vegetation to climate globally, can be incorporated into general circulation models of the oceans and atmosphere, to produce comprehensive 'earth system' models. The new parallel processors will make this possible. Second, there is a growing need for models to evaluate the impacts on vegetation, and the risks to human and animal health, of chemicals in the environment. Third, there is continuing scope to extend ITE's work on spatial modelling, using models in conjunction with GIS in fields such as landscape ecology. Lastly, ITE's users increasingly require decision support systems and models that can determine the impacts of policy options.

M G R Cannell

The UK Environmental Change Network

(The work of the the ECN Central Co-ordination Unit is partly funded by the Department of the Environment)

The United Kingdom Environmental Change Network (ECN) was officially launched in January 1992 as the UK's integrated network for monitoring environmental change. The broad aim of the network is to identify and quantify environmental changes associated with man's activities, distinguish man-made change from natural variations and trends, and give warning of undesirable effects. Its objectives are:

- to establish and maintain a selected set of sites within the UK and obtain comparable long-term datasets by means of measurements at regular intervals of variables identified as being of major environmental importance;
- to provide for the integration and analysis of these datasets, so as to identify environmental changes, and to improve understanding of the causes of change;
- to make these long-term datasets available as a basis for research and prediction;
- to provide, for research purposes, a range of representative sites where there is good instrumentation and reliable environmental information.

ECN now consists of an expanding network of terrestrial and freshwater sites. It is operated by a consortium of sponsoring organisations with an interest in land use and the environment, and managed by the Natural Environment Research Council (NERC) from the Central Co-ordination Unit (CCU) at ITE Merlewood. NERC also sponsors monitoring at two of ECN's terrestrial sites at Wytham and Moor House/Upper Teesdale (Plate 41).

The role of ECN and long-term monitoring

The merits of monitoring compared to hypothesis-based scientific research have been much debated, but there is now a

Plate 41. ECN monitoring at Moor House in the northern Pennines

growing consensus that these are complementary approaches to common problems and that each requires clear objectives in order to be successful. The UK Department of the Environment (DoE) defines three broad roles for long-term monitoring (DoE 1992). These are: (i) as an obligatory monitoring programme to fulfill statutory or regulatory requirements, including commitments to international agreements; (ii) as an 'alert' mechanism to provide early warnings of environmental change; and (iii) as a science research facility to provide data to distinguish natural and man-made causes of change. The rationale behind the development of ECN since its launch in 1992 has ensured that the network can serve all three of these roles. This rationale is that:

i. a network of sites must be established which covers a wide range of environmental conditions and the principal natural and managed ecosystems within the UK;
ii. variables must be monitored which reflect current and future environmental concerns and issues;
iii. monitoring must be done consistently across the network according to strict and agreed quality control procedures so that valid comparisons in space and time can be made;
iv. all data from the network must be managed and made available to researchers and other users;
v. an administrative structure is required to ensure that activities within the network and its future development are adequately co-ordinated.

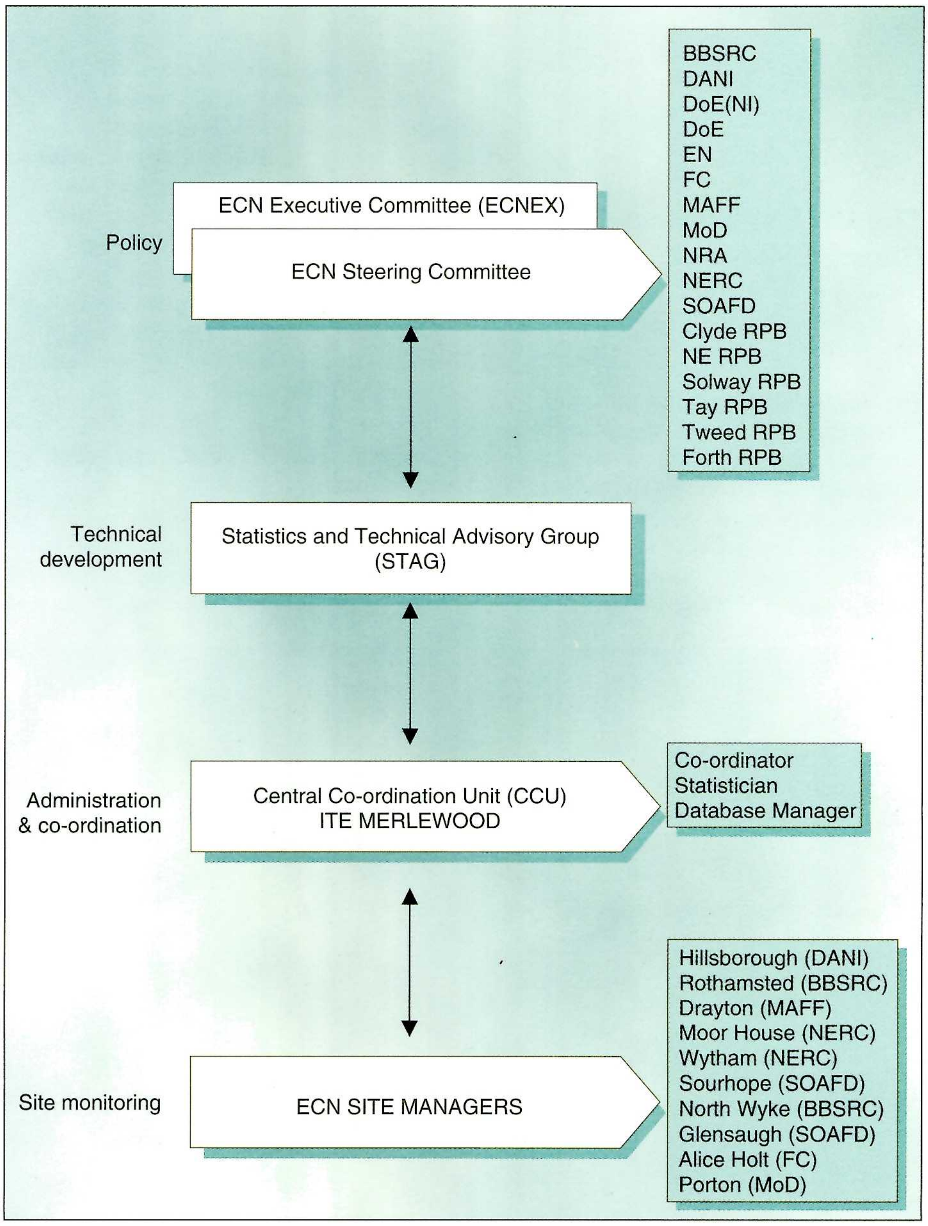


Figure 73. Organisation of ECN (April 1995)

Network administration

ECN relies on the co-operation and interaction of a wide range of organisations and individuals for its operation. The administrative structure is summarised in Figure 73. Policy level decisions are taken by the Steering Group consisting of representatives from the ECN sponsoring organisations. Technical decisions on the development of the protocols and analysis of results are made by the Statistical and Technical Advisory Group (STAG) which draws upon expertise from a range of universities, departments and institutes. The Central Co-ordination Unit at ITE Merlewood is responsible for the day-to-day running of the network including data management and data analysis. The CCU is also developing links with other global and European initiatives in long-term monitoring, including the Global Terrestrial Observing System (GTOS), the UN-ECE Integrated Monitoring Programme (IMP), the Chinese Ecological Research Network (CERN) and the Long-Term Ecological Research Network (LTER).

The site network

The UK has many sites with a long history of environmental data collection and repeated surveys. ECN has capitalised on this resource by selecting sites with, as far as possible, known management histories, existing data and a background of environmental research. There are currently ten terrestrial sites, ranging from small (2 km^2) intensively managed lowland agricultural establishments to large (65 km^2) semi-natural upland areas, and 37 freshwater sites (Figure 74). Each site is sponsored by a Government department or agency which is then responsible for ensuring the long-term management and monitoring of the site according to a series of strict protocols.

With only ten sites in the terrestrial network there are inevitably some gaps in coverage. The most significant of these in relation to climate are in the wetter western parts of GB and in the marginal upland areas of England where the climate is intermediate between that of the lowland sites in the south and the upland sites in the north. The network is currently expanding and priority will be given to sites which help to fill these gaps.

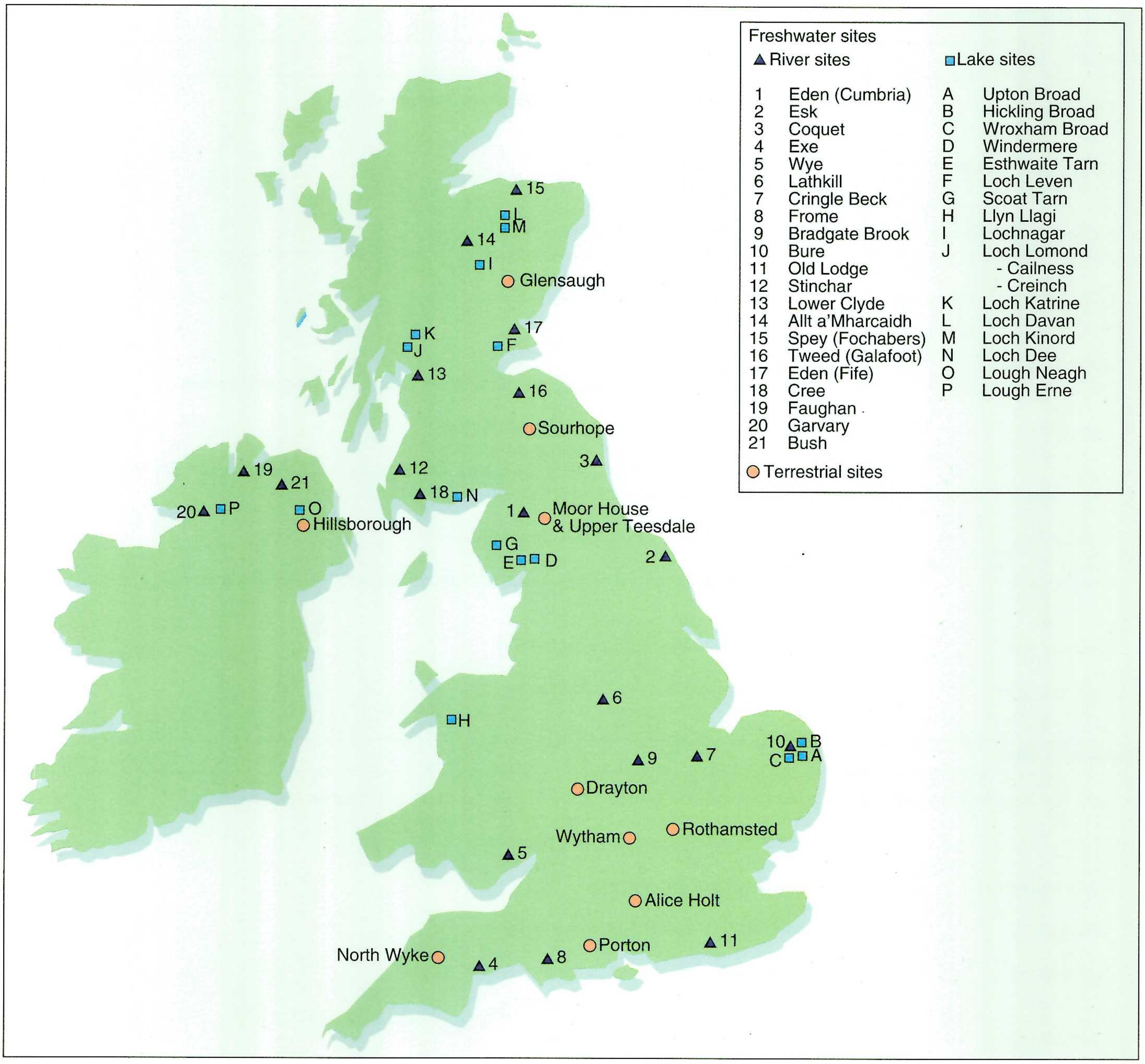


Figure 74. Distribution of sites in the UK Environmental Change Network

ECN measurements

ECN aims to contribute data for general state-of-the-environment monitoring and for specific issues such as monitoring of pollutants, climate change impacts, land use change, biodiversity and sustainability. ECN monitoring is, therefore, centred around a series of 'core measurements' which are made, wherever possible, at all the sites (Table 11). The measurements relate to variables which are expected to be important in driving environmental change, and to ecosystem response variables which have been identified as being sensitive or responsive to such change. Standardised recording began at most terrestrial sites in 1993 and covers measurements on: meteorology, surface water drainage, surface water quality, atmospheric chemistry, precipitation chemistry, soil properties including soil solution chemistry, vegetation, invertebrates (moths, butterflies, ground predators and tipulids), vertebrates (rabbits, bats, common birds, moorland birds, frogs) and site management. Vegetation maps and aerial photograph coverage are available for each site. There is a corresponding set of core measurements for the freshwater sites, where monitoring began in 1994.

The use of standardised methods of data collection is an important principle of ECN and is achieved by using agreed standard protocols for all the measurements. Scientists from a number of research institutes and universities have collaborated in devising these protocols.

Development of the ECN database

Data from all sites are collected and maintained in a central database by the ECN Central Co-ordination Unit at ITE Merlewood. Site managers are responsible for ensuring that the

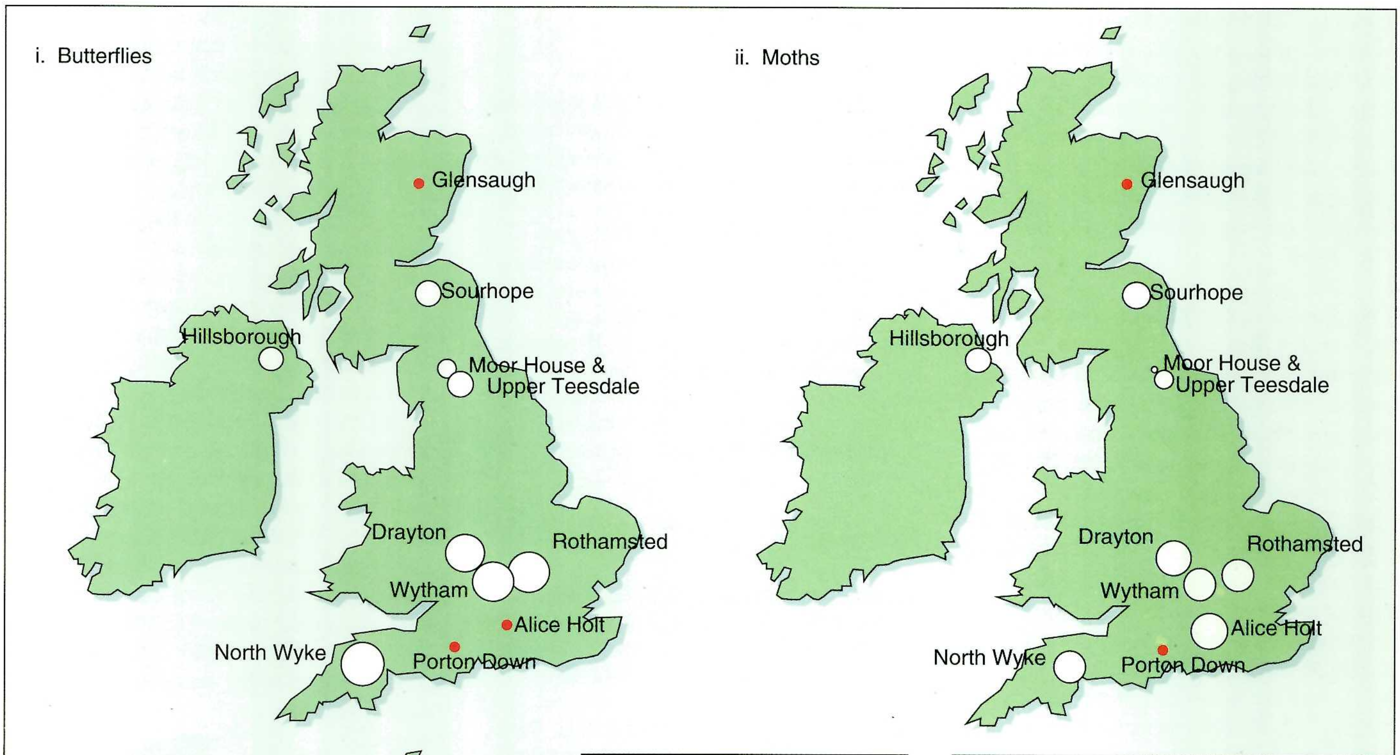
Table 11 ECN 'core measurements'

Terrestrial sites	
Meteorology	Automatic weather station 12 variables summarised hourly Manual back-up
Atmospheric chemistry	NO_2 passive diffusion tubes Two-weekly analyses
Surface water discharge, chemistry & quality	Continuous discharge measurements Weekly dip samples for major ions, continuous pH, turbidity, temperature, conductivity
Soil solution chemistry	Replicated suction lysimeters at base of a & b horizons Two-weekly samples for major ions
Soil properties	Survey at 1 10 000 or 1 25 000 Five-yearly cores for major ions, 20-yearly pits for heavy metals and physical properties
Vegetation	Whole site survey with up to 500 systematic quadrats Related to National Vegetation Classification (NVC) 50 random grid plots every nine years, plot in each NVC type every three years In addition linear features, permanent grass, cereals, woodland plots
Vertebrates	Annual census of birds, rabbits, deer, bats and frogs
Invertebrates	Moths daily, butterflies weekly, spittle bug nymph density and adult colour morphs, ground predators two-weekly
Soil organisms	Tipulid larvae extracted April and September
Site management	Records of management activities at the site
Freshwater sites	
Surface water chemistry & quality	Dip samples analysed for major ions – monthly for rivers, four times per year for lakes Continuous pH, temperature, conductivity, turbidity recording Temperature and dissolved oxygen profiles for lakes
Surface water flow	Stage and discharge at river sites
Chlorophyll a	Monthly for rivers, four times per year for lakes
Invertebrates	Annually at river sites, every three or five years at lake sites Species presence, abundance and distribution
Macrophytes	Recording every three or five years Species presence, abundance and distribution
Zooplankton	Sampling at lake sites four times per year
Phytoplankton	Sampling at lake sites four times per year
Periphyton	Sampling at lake sites four times per year, annual sampling at river sites Samples archived for future analysis

protocols are followed and that the data are sent in a standard format to the CCU Rigorous quality assurance procedures in data processing and data management have also been developed to ensure that the quality of the data is as high as possible Standard data recording forms and transfer formats have been produced for each of the core measurements and for the associated quality information Data are sent from ECN sites to the CCU via electronic mail or on disk, using agreed procedures Sites are responsible for checking data before submission but validation, corrections and the addition of quality flags are done centrally at the CCU

The ECN database uses the relational database management system ORACLE, which is linked with the geographical information system (GIS) Arc/Info, as its software platform A meta-database holds important accompanying information on datasets and their specification, quality and ownership Software for data input, validation and retrieval is being developed for each ECN core measurement, and for access to the database and to the meta-information system as a whole

Sets of site maps in digital format, showing, for example, time series of



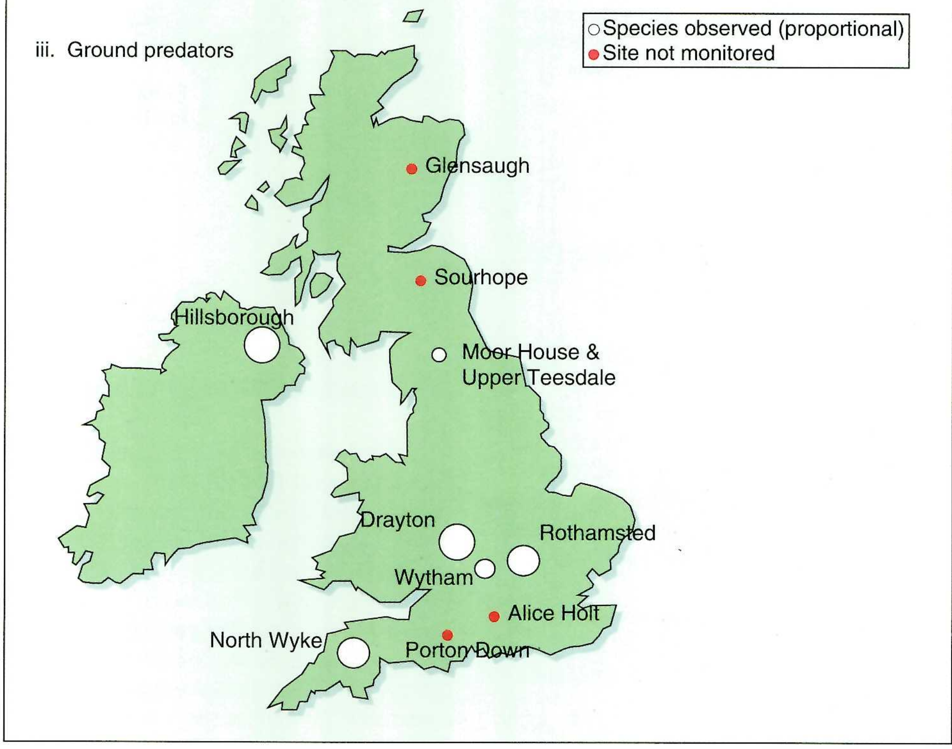


Figure 75. ECN sites monitor a variety of invertebrate species. In 1993 25 butterfly species, 335 moth species and 69 ground predator species were observed. The area of each open circle on the maps is proportional to the number of species observed at each site. Filled circles represent sites where monitoring was not carried out in 1993

vegetation cover, soils and detailed locations of sampling sites used for core measurements, are being established within the Arc/Info GIS.

Data licensing arrangements are currently being agreed with the site sponsors, and over the next two years work is planned to provide licensed users with direct on-line access to the ECN database through a user-friendly interface. Development of appropriate ECN database access mechanisms will begin in earnest this year. ECN is in negotiation with DoE over its particular requirements for summary statistics and forms of access to ECN data for inclusion in its annual *Digest of environmental statistics*. On-line access to the database is currently possible over the Internet through ORACLE/SQL, but this requires a knowledge of SQL and details of the logical links within the database. A broad range of possible development software is now available which provides different access styles and facilities. For complex long-term databases, it is particularly important to evaluate user requirements, to select appropriate software tools to suit these requirements, and to ensure that resources and developments are properly targetted. Other factors such as the reliability and integrity of software tools, future software support, user computing/networking resources, and wide-area network performance will be taken into account.

Data analysis

The routine analysis of ECN data is now well established. Summary tables for 1993, the first year of operation of the network, will be released in mid-1995 as the first in a series of ECN annual digests. The aim is to give an overview of the environment and ecology of each site and to facilitate site comparison. Future digests will also include information on changes from previous years. It is planned to complete the second digest, for 1994, by the end of 1995. Figure 75 summarises some of the results from the 1993 digest, showing variations in the number of butterfly, moth and ground predators recorded across the network. As time series data become available, the challenge will be to develop means of spatial and temporal analysis which enable us to forecast trends, and identify and interpret unexpected departures from these.

A number of more detailed analyses of the data are also currently being undertaken, utilising both ECN data and historic data from ECN sites. A paper analysing changes in soil chemistry over the past three decades at Moor House (Adamson *et al* 1995) has been submitted which uses historic data to identify changes in a variety of moorland soil types, at a range of altitudes in an area of moderately high atmospheric pollution. All three major soil groupings showed a trend towards acidification which was most marked at the soil surface. The results indicate that the critical loads concept, applied on the basis of mineralogy, may not be appropriate for the highly organic surface horizons of some of these soils.

Future priorities

Over the next five years, ECN aims to achieve

i. a modest expansion of the terrestrial network at the rate of one new site per year,
ii. routine presentation of ECN data in state-of-the-environment reports produced by DoE,
iii. publication of ECN's monitoring protocols,
iv. increased use of ECN sites and data in environmental research programmes,
v. the development of active international links, particularly within the European Union,
vi. the development of forecasting and modelling techniques based on ECN data.

Further information on ECN is available from the ECN Co-ordinator at ITE Merlewood. ECN also publishes a biannual newsletter and has a 'homepage' on the Internet World-Wide-Web (URL http://www.nmw.ac.uk/ecn/), through which text and graphical information on the programme, sites, measurements and newsletters can be selected via hypertext links.

T W Parr, W A Scott and A M J Lane

Acknowledgments

The ECN sponsoring organisations are Biotechnology & Biological Sciences Research Council, Forestry Commission, Department of Agriculture for Northern Ireland, Ministry of Agriculture, Fisheries and Food, Department of the Environment, Department of the Environment for Northern Ireland, English Nature, Ministry of Defence, National Rivers Authority, Natural Environment Research Council, Scottish Office, Agriculture and Fisheries Department, Clyde River Purification Board, North East River Purification Board, Solway River Purification Board, Tay River Purification Board, Tweed River Purification Board, and Forth River Purification Board.

References

Adamson, J K, Rowland, A P, Scott, W A & Hornung, M 1995. Changes in soil acidity and related variables in the north Pennine uplands, UK. *Soil Use and Management*. In press.

Department of the Environment 1992. *Long term monitoring*. (Science and technology guidance note 1/92.) London: Chief Scientist Group, Department of the Environment.

The Edinburgh Centre for Tropical Forests

Tropical forests are such complex and diverse environments that it is not possible to cover all aspects of their study under one roof. Hence, the Edinburgh Centre for Tropical Forests (ECTF) was set up in 1990 to exploit the concentration of expertise in the Edinburgh area and bring together the complementary skills of

- Natural Environment Research Council (mainly involving ITE),
- School of Forestry in the University of Edinburgh,
- Royal Botanic Garden, Edinburgh,
- LTS International Ltd, and
- Forestry Commission.

These organisations work together as an informal consortium which exchanges information and makes collaborative bids for funding for large projects. They are actively involved in research, training, and consultancy in over 70 developing countries in the tropics.

The Centre is managed by a full-time administrator and there are regular meetings to discuss activities. Partners are now much more aware of each other's skills, with the result that there have been many collaborative bids for funding involving two or more partners. An example of a co-operative project which involves ITE is the UK Indonesia Tropical Forest Management Project (ITFMP), which is concerned with the sustainable management of dipterocarp production forest. This £9M sterling project is jointly funded by the British Government and the Government of Indonesia. Richard Scott of ITE Merlewood filled the position of team leader on the research sub-project and was seconded to Kalimantan for two years; other ITE staff members contribute to the project through consultancy and training. Many much smaller projects have also benefited from ECTF collaboration, and several conferences and short meetings have been organised under ECTF's auspices. Additionally, staff of ECTF contribute to a number of university courses, including flexible training schemes tailored to individual needs.

Edinburgh Centre for Tropical Forests

J Wilson

ITE and the World Wide Web

Initially developed at CERN, the European Laboratory for Particle Physics, in Switzerland, the World Wide Web is a facility for making data and information available via the Internet. The Internet is a world-wide network of more than 30 000 independent networks connected to each other using the IP and other similar protocols. At present, the Internet has an estimated 40 million users worldwide, including international and government organisations, university and research establishments, commercial organisations and private individuals.

The Web is based on a technology called hypertext, which is a method of presenting information where selected words in the text are links to another part of the same document, or to a completely different document. Behind every link is the network-wide address (URL) of the document to which it refers. Activating the link causes another document to be

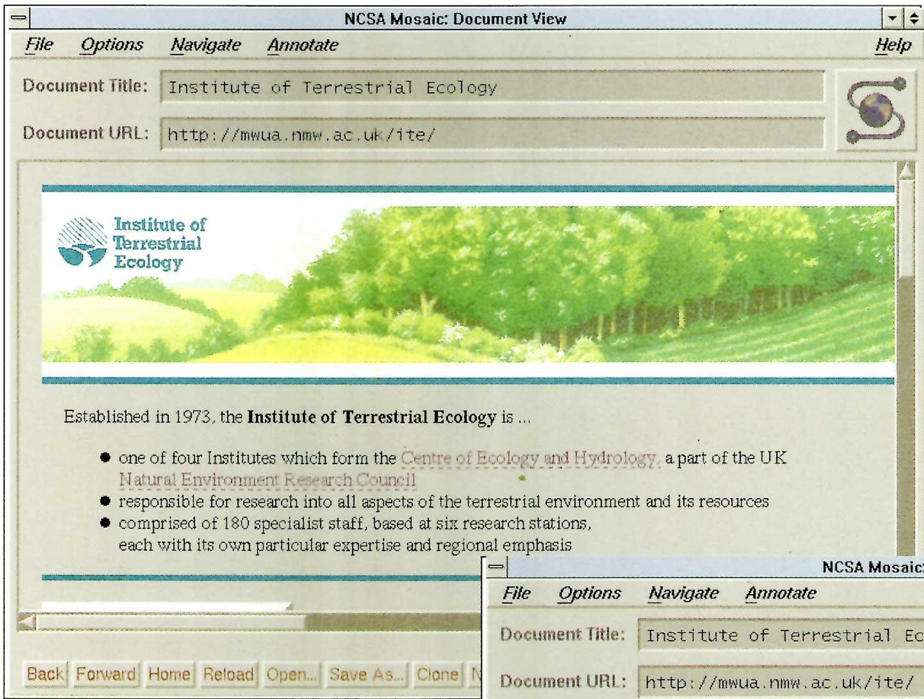


Figure 76. The ITE 'homepage' and menu

Information about the various parts of NERC is gradually being published on the Web, and during the year of this *Report* documents relating to ITE's objectives, its research activities and the resulting publications.have been made available. Figure 76 shows the 'homepage' for ITE viewed through Mosaic on a PC. A homepage is a hypertext document which is a starting point for a user. There are vertical and horizontal scroll bars to bring the rest of the page into view. The page contains a mixture of text and graphics, and the text which is underlined indicates that there is an underlying link to another page or graphic to which the reader is connected when he clicks with his 'mouse' within retrieved and displayed: it is like reading a book and being able to jump to the cross-references at the touch of a button.

The World Wide Web is the universe of hypertext servers (computers) which allow text, graphics, sound files, etc, to be mixed together. It is accessible via an application known as a browser or client: Mosaic and Netscape are the most widely used.

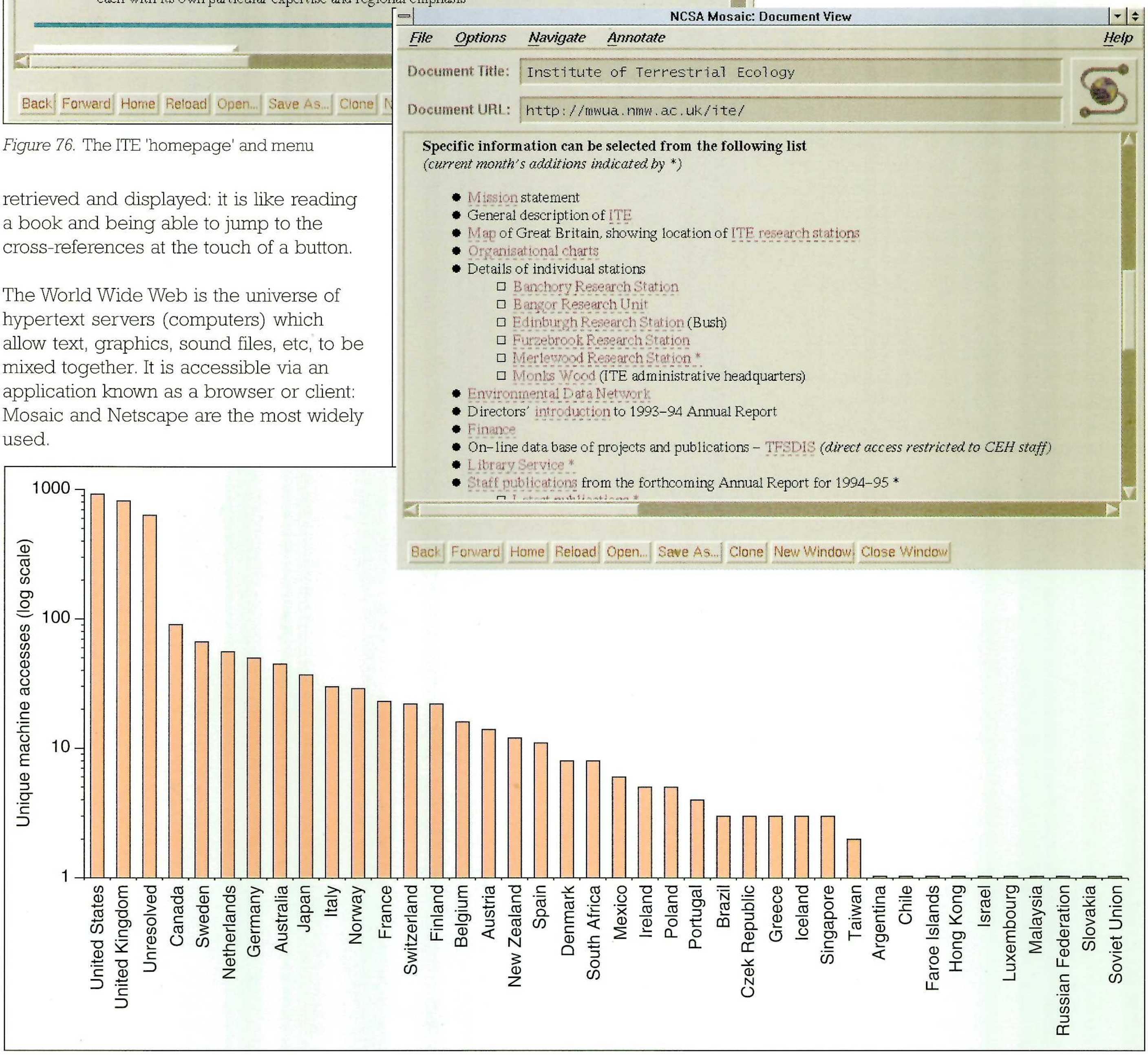


Figure 77. Histogram showing number of times that the ITE WWW server has been accessed by country between January and July 1995

the blue area The ITE homepage has been designed as a menu system, and provides the reader with various options (see Figure 76)

The World Wide Web is also a means of locating and accessing data and information which may be relevant to the work of the Institute Within the ITE homepage, the ITE Library Service is maintaining lists of sources available on the Web which are likely to be of special interest

- select list of environmental WWW servers,
- select list of national and European WWW servers,
- select list of university WWW servers,
- select list of WWW servers for publishers and booksellers

An example from the first list, giving direct access to environmental data from the *Classical Experiments* and more contemporary sources, is the Electronic Rothamsted Archive In order to discover other information, searching tools such as WebCrawler are now available to scan the entire resources of the Web for the occurrence of specified terms, and to retrieve a list of servers in the form of hypertext links

Since being included in World Wide Web in January 1995, the ITE pages have been accessed by over 3000 users from more than 40 different countries, as shown by the histogram in Figure 77

P A Ward and J Beckett