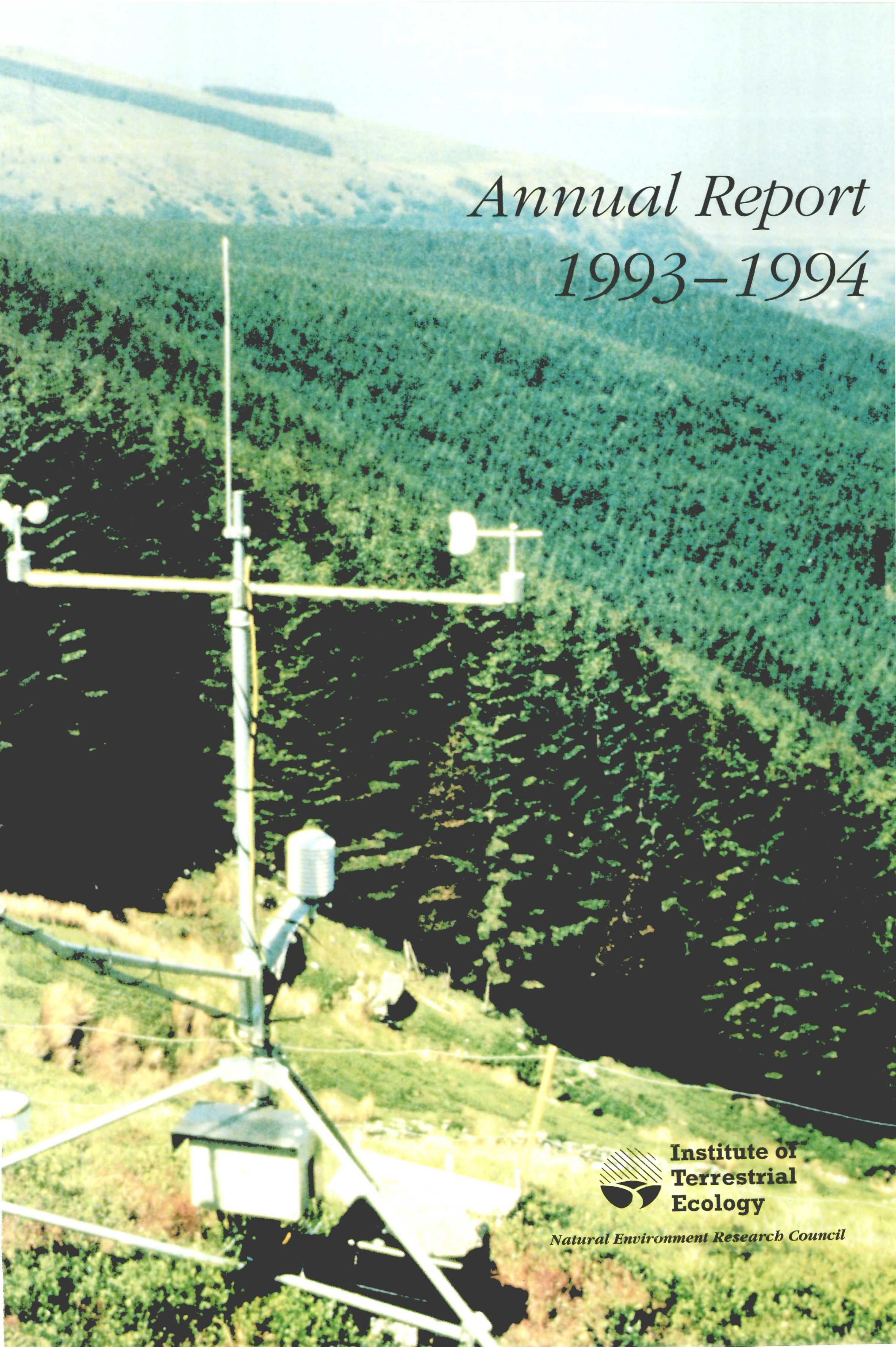
Annual Report 1993–1994



Institute of Terrestrial Ecology

Natural Environment Research Council

Foreword

The past year has been one of considerable change in the Natural Environment Research Council, both in the focus of its science and in its structures. The catalyst for these changes was the publication of the White Paper *Realising our potential: a strategy for science, engineering and technology* (Cm 2250). NERC was given a new mission for its science to embrace the concepts of meeting the needs of its user communities and contributing to wealth creation and the quality of life We have, of course, always paid close attention to these objectives, but there is now a clear need for a sharper focus and better articulation of what we do in these areas Basic science and long-term monitoring are also included in our mission, and due weight must be given to these when developing our science strategies.

The science directorates will cease to exist towards the end of 1994, and new structures will be put in place TFSD Institutes are being regrouped as the Centre for Ecology and Hydrology, with a unified ITE under a single Director However, the report of the Multi-Departmental Scrutiny of Public Sector Research Establishments is awaited, and decisions arising from this report may result in further organisational changes within NERC

An important activity during the year has been the preparation of a new science and technology strategy for the terrestrial and freshwater sciences. Publication is expected in July, and a number of research areas will be identified for priority support over the next five years.

This is my second and final foreword. During my relatively short time with NERC, I have come to appreciate and value the breadth and strength of our work in the terrestrial, freshwater and hydrological sciences Within ITE, for me, highlights of this year have been the report arising from Countryside Survey 1990 and the launch of the Land Cover Map It is because of these, and very many other successes, that I am confident we can continue to produce high-quality and competitive science in the post-White Paper environment. Both ITE(North) and ITE(South) were visited by separate Science Management Audit Groups during the year. It is to the great credit of everyone involved in ITE that the reports of both groups recognised a continued advance in quality across the whole of the Institute over the five years since the previous visits

Finally, I should like to state how much I have appreciated the friendships that I have established with so many members of our community It is these that will be my most valued and lasting memories of NERC

C Arme
Director of Terrestrial and Freshwater Sciences
Natural Environment Research Council

Report of the Institute of Terrestrial Ecology 1993–1994

Natural Environment Research Council

CONTENTS – Scientific Services

Scientific services

The main science programmes of ITE are continually undergoing change due to the influence of new research projects, demands from new customers, the transfer of technology to counterparts overseas, and collaborative activities with new research partners with novel ideas. To some extent, these trends govern the direction of the work of the small groups providing a range of services – specialist scientific, technological and professional.

These services are available at different levels throughout the organisation, ie at the station, Institute and NERC levels. Figure 72 provides an overview of these activities. Each of the specialist groups needs to update itself continuously on technological developments in its own area, initiate and complete research into new applications, develop new techniques, and to make itself aware of the current and future needs of the research teams they support. These groups have to compete for resources and they have to balance their activities in order to provide a service for many different projects – each with different objectives and deadlines.

The activities of the specialist groups are demonstrated with the aid of five different applications. Analytical chemistry emphasises the critical and ever-present need for quality control, an on-going requirement for method development as new research demands arise, and a recent new departure of individual staff members being involved within Institute research teams. The NERC stable isotope facility enables new insights to be gained into topics ranging from the assessment of nitrogen demand of conifer and eucalayptus (*Eucalyptus* spp.) plantations, through growth strategies of tundra plants relating to climate change, to the use of stable carbon and nitrogen isotope ratios in seabird feathers as tests of trophic relationships. This facility is currently handling between 3500 and 4000 samples each year. Valuable future potential activities are also highlighted. It may be possible, using this facility with updated equipment, to measure the pollution input from a single rain shower or to determine the signature of soil air in a microcosm. At present, these types of measurement are either very difficult or impossible to measure.

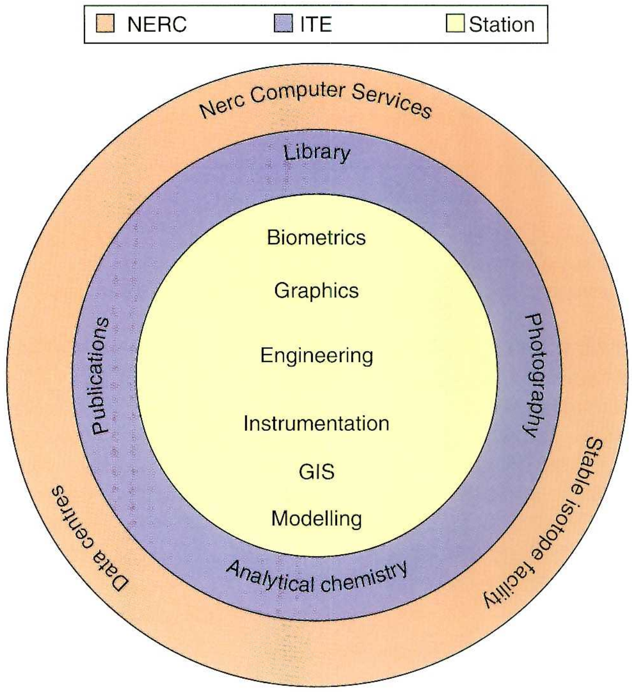


Figure 72. Distribution of services throughout the Natural Environment Research Council

A global positioning system (GPS) used for mapping aquatic zones of a Scottish loch is also described. Within the loch, different animals live and feed in different habitats and it is important to determine the extent of the habitat. To do this, the exact positions of the main macrophyte and emergent plant zones need to be measured. The project team from ITE Banchory has solved the problem of locating the zones using a sophisticated GPS on loan from NERC's geophysical equipment pool at the British Geological Survey in Edinburgh. They emphasise that, with a little experience, this GPS technique proved reliable and accurate (10 cm instead of some 10 m). They also feel that sharp boundaries were probably mapped about ten times faster and point sampling speeds about doubled, compared to conventional survey methods.

The last two areas of specialist activity reported both use geographical information systems (GIS) for storing and manipulating a wide range of data for two very different applications. The first describes the Land Cover Map of Great Britain and its applications. Examples of land cover relevant to a variety of social issues, conservation and wildlife, management of natural resources, environmental chemistry, and environmental impact assessments are presented. The second GIS application illustrates its use in an important application area of the combined use of national databases with other small-scale data sets in scoping studies. A hypothetical example is presented to demonstrate scoping for development control, based on one of the first industrial applications of the GIS-based scoping method. British Gas turbines, used to maintain pressure in its National Transmission system, operate close to the NO_x consent levels set by Her Majesty's Inspectorate of Pollution (HMIP). British Gas needed a method to help identify and focus attention upon the receptors and indicators most likely to be sensitive to nitrogen deposition around the source. They found this method to be both rapid and cost-effective for assessing the potential impact of their gas turbines.

The active use of in-house scientific services within ITE has long been a key feature of its structure. The trends of increased specialisation, limited resources for expensive capital items, steep learning curves needed to produce a rapid working service, the difficult 'art' of keeping complex equipment running continuously all suggest that there is a continuing demand for scientific services. However, it is important that there is an on-going dialogue between the users and providers of these services so that value for money is obtained at all times, and that these services play their part in advancing the leading edge of science.

D K Lindley and J A Parkinson

Analytical chemistry

Introduction

Over recent years, the number of samples analysed by the Analytical Chemistry Section at ITE Merlewood has varied between 8000 and 10 000 per year (Figure 73). Waters have been the dominant sample type submitted for analysis in each of the last 15 years, starting from the initiation of a series of studies involving analysis of bulk deposition, throughfall, soil water and drainage water chemistry. The focus of the research projects has, however, changed over that period from the impacts of acid inputs and forest management to nitrogen deposition and climate change. There has also been an increase in the number of determinands requested per sample, which has arisen partly because technological advances in analytical instrumentation allow multi-element capability and increased automation, enabling analysts to offer a wider choice of options to the research scientists.

The type of project supported by the Section has also changed over the last five years, with a large increase in Community Programme projects (Figure 74) in the last two years.

Development of facilities

There has been a considerable injection of capital into the analytical chemistry facility over the last five years, enabling the purchase of:

- an up-to-date atomic absorption spectrometer (AAS);
- a sequential/simultaneous inductively coupled plasma optical emission spectrometer (ICP/OES);
- updated continuous flow colorimetry and customised benching;
- an automatic diluter;
- uninterruptable power supply (UPS);
- personal computers linked to each instrument and the local area network.

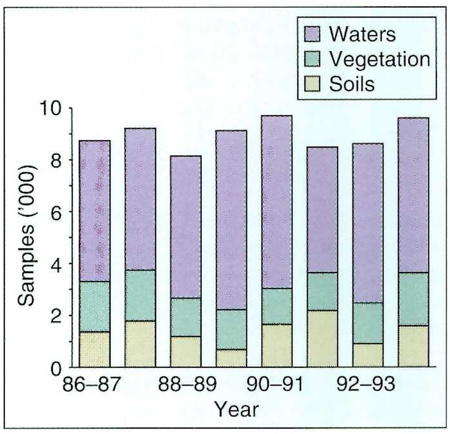


Figure 73. Number of samples analysed by the Analytical Chemistry Section at ITE Merlewood

This investment has provided the Section with:

- reliable state-of-the-art equipment;
- automation of all main analytical processes to allow 24-hour operation;
- multi-element analysers;
- transfer of data from analysers to main station computer and, via electronic mail, to customers.

These upgrades have resulted in improved efficiency, increased capacity and faster throughput, and have reduced the number of staff committed to routine analysis, thus releasing analysts to work directly on ecological projects or for consultative work.

Quality assurance

Routinely, quality is measured through the analysis of 'internal' reference samples and monitoring of the results using *Shewhart* quality control charts. Over the last few years, the quality control system has been modified and developed. Wherever possible, certified reference materials are now analysed to provide verification of methods and traceability for internal quality control (QC) samples. In addition, the Section participates in interlaboratory exchange schemes:

Water	AQUACHECK – Water Research Centre, Medmenham
Vegetation	International Plant Exchange (IPE) – Wageningen Agricultural University, The Netherlands
Soil	International Soil Exchange (ISE) – Wageningen Agricultural University, The Netherlands.

These measures of performance consistently show that the Section fulfills its commitment to produce accurate and precise data which are fit for the purpose of the study.

Nevertheless, QC data obtained over several years highlight a number of problems in soil nutrient analysis which cannot necessarily be solved by good laboratory QC procedures. The availability of certified reference materials (CRMs) for total concentrations of soil potassium (K), calcium (Ca), magnesium (Mg) and phosphorus (P) contrasts with the lack of CRMs and universally accepted extractants for the measurement of extractable K^+, Ca^{2+}, Mg^{2+}, PO_4^{3+}, and NH_4^+. Quality control procedures have been developed by the Section to address these problems. Without access to CRMs, analytical bias can be controlled by the use of homogeneous internal soil reference samples. Analytical accuracy can be assessed by participating in interlaboratory comparison exercises and sample exchange schemes (Kennedy, Rowland & Parrington 1994)

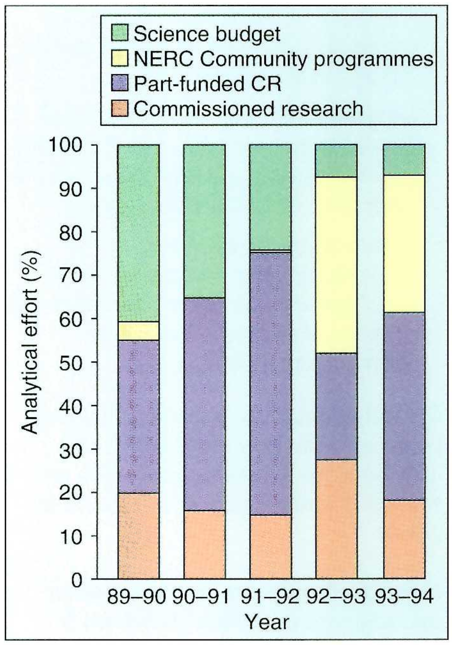


Figure 74. Percentage analytical effort by funding source

Method development

It is essential that the service offered by the Section is able to provide the data required by current Institute science. It is important to this end that flexibility is maintained to change methods and procedures and to maintain a research and development programme in response to research demands. Recent examples of method development include:

- introduction of a method for determining stable strontium and caesium in support of environmental radioactivity research;
- special calibration procedures for

nitrogen fractions when analysing samples submitted as part of studies into critical loads for nitrogen,

- suitable methods for the analysis of hydrocarbons in soils, vegetation and waters, resulting from studies into the disposal of oiled beach material,
- procedures for extraction of ^{35}S-labelled sulphur compounds from ecological materials in connection with studies of sulphur cycling and atmospheric pollution

Recently published work has involved lignin and cellulose fractionation and investigations into the preservation and storage of water samples, as described below

Lignin and cellulose fractionation in decomposition studies (Rowland & Roberts 1994)

Lignin methods based on acid-detergent fibre pre-extraction were evaluated for grass, straw, heather (*Calluna vulgaris*) and spruce (*Picea*) litter Quantification following oxidative attack to destroy the lignin by permanganate proved to be unreliable for the woody heather material and spruce litter In contrast, the method of isolation involving hydrolysis of the cellulose component with 72% sulphuric acid was precise and robust The acid-detergent reagent dissolves most of the hemicellulose and offers the opportunity to quantify the residual alpha-cellulose fraction

This method was further evaluated in a study where stem internodes of leaves of wheat (*Triticum aestivum*) straw were buried in litter bags in an arable soil The bags were sampled after 13, 22 and 32 weeks to determine the comparative frequency of fungal species and the change in chemical composition of the straw The internodes of lower resource quality with their high C/N ratio and high lignin decomposed more slowly than the leaves (Robinson *et al* 1994)

The effects of chemical preservative and temperature storage conditions on cations and anions in natural water (Bull, Lakhani & Rowland 1994)

The effect of storage on cation and anion concentrations in freshwater samples was investigated experimentally using chemical preservation treatments (mercuric chloride and/or acidification with hydrochloric acid) combined with three separate temperature levels (20°C, 4°C or frozen) Two storage times were used, 21 days and approximately 90 days Results were interpreted using analysis of variance and comparison of various means with results at day 0 Cations (Ca^{2+}, Mg^{2+}, Na^{+}, K) were analysed in two different laboratories, yielding comparable results Cation concentrations were generally resistant to change and were best untreated or preserved with mercuric chloride at any of the three temperatures For anions, storage at 4°C with no chemical preservatives proved good or adequate Particular storage treatments, such as removal of suspended matter by filtration and the use of iodised bottles for preserving phosphate, were important for some analyses The biggest changes in ion concentrations occurred between 21 and 90+ days, and early analysis of stored samples is recommended

Involvement of Section staff in research projects

A new departure in the Section's work over the past three years has been the increasing involvement of staff in research projects as individual members of the research team, providing chemical expertise as opposed to service analysis The following examples describe current projects in which Section staff are involved

Mobile laboratory

From March 1992, the Analytical Chemistry Section has been involved in the commissioning and operation of a mobile laboratory It consists of a gas chromatograph with its associated gas supplies and data processing system housed in a twin-axled box trailer with an external 4 KVA diesel generator supplying the electrical power

The laboratory, and associated gas collection equipment, has been designed to quantify N_2O, CH_4 and CO_2 emissions from natural upland soils in the field In order to collect the data, the mobile laboratory is required to operate in remote locations, unattended for the majority of the time, for periods of up to four weeks

Disposal of oiled beach material

The Section is leading a lysimeter investigation which forms part of this major study into the environmental aspects of the disposal of oiled beach materials by landfarming or burial The lysimeter study is using lysimeter tubes, 200 cm long × 30 cm diameter, to assess the loss of hydrocarbons to drainage waters, the rate of decomposition of hydrocarbons, and the emission of volatile hydrocarbons to the atmosphere A layer of oiled sand has been placed in the lysimeters between layers of dune sand material, and monitoring of emissions and leachates started in early 1994

Standardisation of analytical techniques and quality control

Standardisation of analytical protocols and interlaboratory comparisons are essential in multi-partner studies where analyses are carried out in dispersed laboratories The Section is responsible for co-ordinating analytical methods and for interlaboratory comparison exercises for the Environmental Change Network and for the ENCORE (European Network of Catchments Organised for Research on Ecosystems) project supported by the European Commission These two projects have involved co-operation between 15 laboratories in seven countries

J A Parkinson, A P Rowland and V H Kennedy

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The NERC stable isotope facility

Background

The stable isotope facility (SIF) was established at ITE Merlewood in 1983 to provide a service for the analysis of ^{15}N and ^{13}C at both enriched and natural abundance levels. It is intended for the use of research workers in the Terrestrial and Freshwater Life Sciences of NERC Institutes, and for projects in university departments funded by NERC. The facility is run by two staff and is equipped with two mass spectrometers:

- a SIRA 9 (VG) for natural abundance ^{15}N;
- a Roboprep/Tracermass automated continuous flow system (Europa Scientific) for enriched ^{15}N and for ^{13}C at both enriched and natural abundance levels.

It also has access to means for preparing plant and animal tissues, and soil and water samples not amenable to automated analysis.

The work programmes of the facility are assessed by a small steering committee, currently chaired by Dr H Griffiths of the University of Newcastle. The committee peer reviews applications for analyses. It also acts as a source of advice to anyone wishing to use ^{15}N or ^{13}C but who is unfamiliar with the practical aspects of the technique.

Service analyses

Over the last few years the facility has analysed between 3500 and 4000 samples each year. During 1993–94, 3800 determinations were carried out, predominantly for ^{15}N and made up of 3400 enhanced and 370 natural abundance samples. Material was submitted from three ITE sites and from six universities. Projects currently being supported include:

- assessment of nitrogen demand of conifer and eucalyptus (*Eucalyptus* spp.) plantations using a ^{15}N bioassay;
- investigation of N dynamics in alley cropping systems in Costa Rica;
- assessment of water use efficiency in arctic plants using carbon isotopes;
- determination of critical loads of N for conifer plantations;
- the N nutrition of spruce (*Picea* spp.) in pure and mixed stands;
- assessment of foliar uptake of N by heather (*Calluna vulgaris*);
- understanding the role of vegetation in the hydrological balance of abandoned farmland in Spain;
- assessment of the role of extramatrical hyphae of mycorrhizal associations in nutrient uptake;
- growth strategies of tundra plants related to climate change;
- use of stable C and N isotope ratios in seabird feathers as tests of trophic relationships;
- variation of δ ^{13}C signatures of C_3 and C_4 plants following mutation.

A large percentage of samples for enriched ^{15}N analysis derives from various applications of the N bioassay. This is the most recent development of a more generalised technique which allows determination of soil fertility by actually measuring the amount of N, P and K which is available to a plant. Previously, fertility had to be inferred from foliar analysis or from the use of arbitrary extraction methods; both techniques lacked sensitivity. The SIF was closely involved in the research needed to extend the bioassay technique to include the determination of nitrogen deficiency.

The N bioassay depends on the fact that a plant grown on N-deficient soil will be 'hungry' for nitrogen and that that hunger can be measured in the root by immersing it for a given time in a solution of inorganic N. The greater the deficiency of the soil, the greater the hunger, and the greater the uptake in unit time. However, the uptake is very small compared to the background N content of the root, and its determination is beyond the precision of the conventional analysis for total N but not beyond that of the analysis for ^{15}N which is two to three orders of magnitude greater. Uptake rates are typically 50 ng ^{15}N per mg of root per hour (Jones, Quarmby & Harrison 1991).

The N bioassay has been tested on a wide range of soils from sites in the UK, South Africa, Congo, Uruguay, Portugal, Chile and Costa Rica. It has made use of reference plants ranging from grasses to mature trees, the latter generally in connection with fertilizer trials in forestry. One key feature to emerge from such

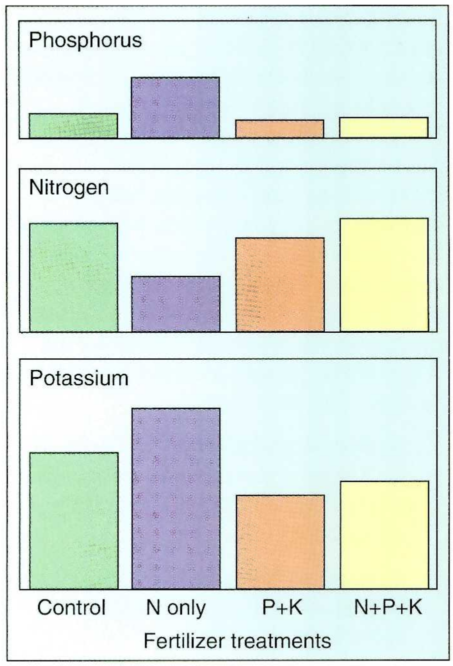

Figure 75. For each bioassay, the height of ech column indicates the relative uptake of N, P or K in excised roots of Sitka spruce grown under four fertilizer regimes

trials was the demonstration of the interdependence of the demand for N upon that for P. Figure 75 shows how adding nitrogen depresses the demand for N, as expected, but at the same time increases the demand for phosphorus. However, in this experiment, adding N, P and K satisfies the demand for P and K only; the increased availability of inorganic phosphate triggers a demand for N over and above that already supplied in the fertilizer, which suggests that in many cases poor uptake of nitrogen by plants is not due to deficiency of N in the soil but rather to a lack of available phosphorus. Such a conclusion can easily be missed by both classical soil and foliar analyses.

Research and development

In addition to providing an analytical service, members of the SIF team are concerned with research projects involving stable isotope analysis in their own right. For example, they are currently collaborating with Dr A F Harrison in NiPHYS (Nitrogen Physiology of Forest Plants and Soils), a European Network project supported by the European Commission. The Merlewood-based subproject aims to test whether or not bulk deposition and throughfall in areas subject to inputs from different sources of pollutant nitrogen have distinct isotopic N signatures. Samples will eventually be collected at all sites participating in NiPHYS, stretching from Umeå in northern Sweden to Montpellier in southern France, and returned to Merlewood for analysis In the current phase, the sampling equipment, methodology, and the underlying concepts of the study are being tested at four sites in the UK They were chosen so that the N input at each location was predominantly from one type of source, but the choice was complicated by the requirement to have a conifer plantation nearby The sites are

- by the M6 on Shap Fell, in Cumbria, with large concentrations of vehicle exhaust fumes but little input from agriculture,
- on a dairy farm in northern Cumbria well isolated from industrial and vehicle exhaust fumes,
- next to an intensive chicken rearing unit in rural southern Scotland,
- downwind of an industrial area east of outer Liverpool, Merseyside, in a large wildlife park

Sampling from the UK sites was started in early 1994, and analysis of samples for $\delta\,^{15}N$ in the ammonium fraction is currently in progress Sampling at the mainland European sites will begin in the autumn of 1994

In connection with the NiPHYS project, the SIF team visited the mass spectrometer laboratory at the University of Bayreuth in July 1993 The aim of the visit was to discuss techniques for measuring ^{15}N in ammonium and nitrate in natural waters and to exchange ideas on ^{15}N analysis in general

Future potential

Much of the work with stable isotopes in ecology concerns identifying the origins of particular substrates and following their progress through the various stages of assimilation or decomposition Initially, artificially enriched starting materials were used, but in field experiments not only is their use prohibitively expensive but apparently simple procedures become unexpectedly difficult For example, how do you apply tracer evenly to 100 m^2 of woodland, and will the application disturb the various equilibria? For such reasons, ecological work with stable isotopes is turning more and more to the manipulation of natural abundance data, because the isotopic tracer is provided free of charge and the equilibria are well established with no further inputs to disturb them Unfortunately, the restricted range of natural fractionation, particularly with regard to nitrogen, frequently makes unequivocal identification of a process difficult when based on the analysis of a single isotope If multiple isotope analysis is possible, however, the position improves dramatically, the ability to discriminate between sources now becomes exponential, with the power of the function related directly to the number of isotopes analysed Scope is clearly very great, and there is no doubt that this will be the major area of development in stable isotope analysis in the immediate future, the elements involved will be hydrogen, carbon, oxygen, nitrogen and sulphur

Less certain is what can be achieved in reducing the size of sample needed for the analysis of biological material The mass spectrometers in the facility are typical of those used worldwide for this type of work, but the design is such that of, say, 100 000 molecules entering the system only 1–5 would be expected to be analysed, the rest are lost Cryogenic trapping might raise the overall efficiency to 0 1% but even this requires a *continuous* flow through the source of 3×10^{14} molecules per second which, in turn, dictates that sample preparation of the analyte is in the range of hundreds of micrograms By contrast, analysis by Fourier transform ion cyclotron needs only the *single* injection of 10^4 molecules for a comparable analysis with attendant, if theoretical, reduction in sample size by many orders of magnitude An equally important feature of this instrument is that the resolution is at least 10^6, ie it can distinguish ions of mass 100 0000 from those of 100 0001 Thus, molecules of similar mass, eg $^{14}N^{14}N$ and $^{12}C^{16}O$, or $^{15}N^{15}N$ and $^{14}N^{16}O$, mutually interfere in conventional mass spectrometers as they cannot be resolved, and they must therefore be separated prior to measurement The ion cyclotron, on the other hand, could determine all such components in the one sample without prior separation, thereby simplifying the initial preparation Further work has yet to be done but, provided that analytical precision can match the present requirement of around 0 2%, then the predicted huge reduction in sample size could enable us to measure the pollution input from a single rain shower, which is currently very difficult, or to determine the signature of soil air in a microcosm, which is currently impossible

C Quarmby

Reference

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Aquatic vegetation zones of Loch Davan mapped with a global positioning system

The Dinnet Lochs (Kinord and Davan) on Royal Deeside are a National Nature Reserve and are proposed as one of the first freshwater Environmental Change Network sites in Scotland For the past 15 years or so they have been a focus of research on otter (*Lutra lutra*) ecology by ITE Banchory The present collaborative project on fish and fish predators at the Dinnet Lochs involves colleagues from the Institute of Freshwater Ecology, the North East River Purification Board and the University of Aberdeen in assessing the productivity, nutrient status and the invertebrate food web ITE Banchory staff are studying the fish and their predators, mainly otters and ospreys (*Pandion haliaetus*) The project involves the manipulation of fish populations to test the effects of fish density on the foraging behaviour of their predators (otters and ospreys), and also to see if altered fish densities affect numbers of the fishes' invertebrate prey

As different animals live and feed in different habitats, it is important to know the extent of the habitats within the lochs The aquatic vegetation of the lochs is a major determinant of these zones, and we need to know the exact position of the main macrophyte and emergent plant zones Previous information, apart from species lists, amounted to maps of 'vegetation zones' (not identified to species) by Lucas in 1989 and a detailed species survey of a scattering of sites in Loch Kinord only by Sauter in 1984 Neither gave a comprehensive picture, and Sauter reported she had wasted much time trying to locate her sample positions. We wished to establish if quick and accurate surveys could now be done using global positioning systems (GPS) technology, because the positions of macrophyte zones can sometimes change markedly between years. We concentrated our initial efforts on Davan, the smaller loch.

We solved the problem of locating our sampling positions in a flat and featureless terrain by using a sophisticated global positioning system on loan from NERC's Geophysical Equipment Pool at the British Geological Survey in Edinburgh. We used a pair of Ashtech XII-GPS receivers recording in synchrony. One of these, the base station, is left in position for the entire recording session, and the other, the 'rover', is carried around in the field. Before the roving receiver is used for surveying, the two receivers record together, with their aerials swapped back and forth, for a few minutes. Data signals received from the orbiting satellites during this critical period allow phase differences in the synchronised radio pulses from the orbiting satellites to be used to estimate the relative locations between the receivers to within 10 cm. Thereafter, so long as both receivers maintain contact with at least four of the same satellites, their relative positions can be measured to within 10 cm as the roving receiver is carried around.

Accordingly, we were able to digitise the boundaries of emergent and floating vegetation by mounting the roving aerial in the bows of a small dinghy, and rowing it carefully around the margins

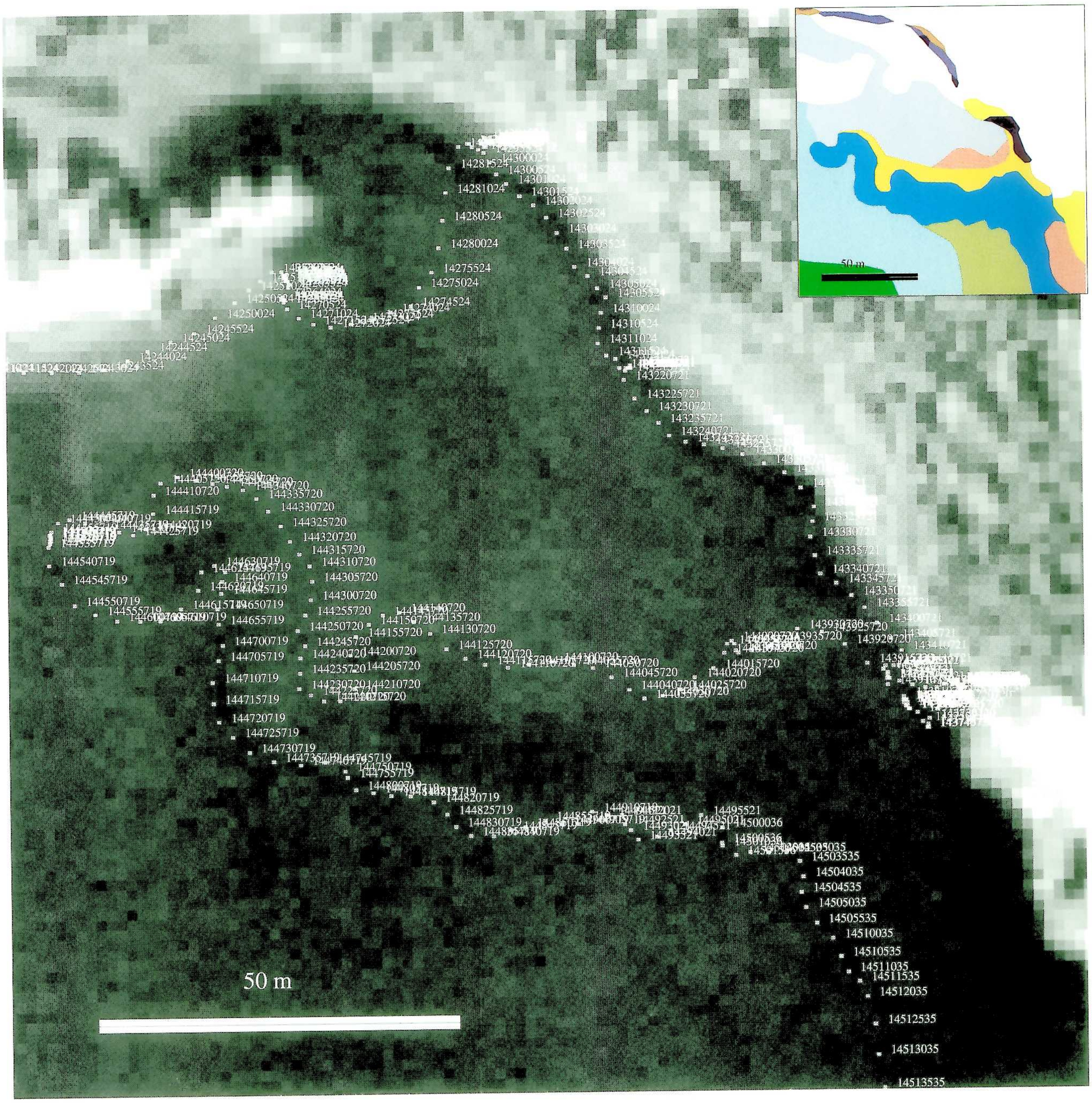

Figure 76. White dots superimposed on the background aerial photograph show a single path of the boat, representing a vegetation boundary, as recorded by the GPS system. The coloured inset shows the edited and interpreted vegetation zones: see legend of Figure 77 and its lower inset for details (Computer cartography at ITE Banchory by P J Bacon & F Diers)

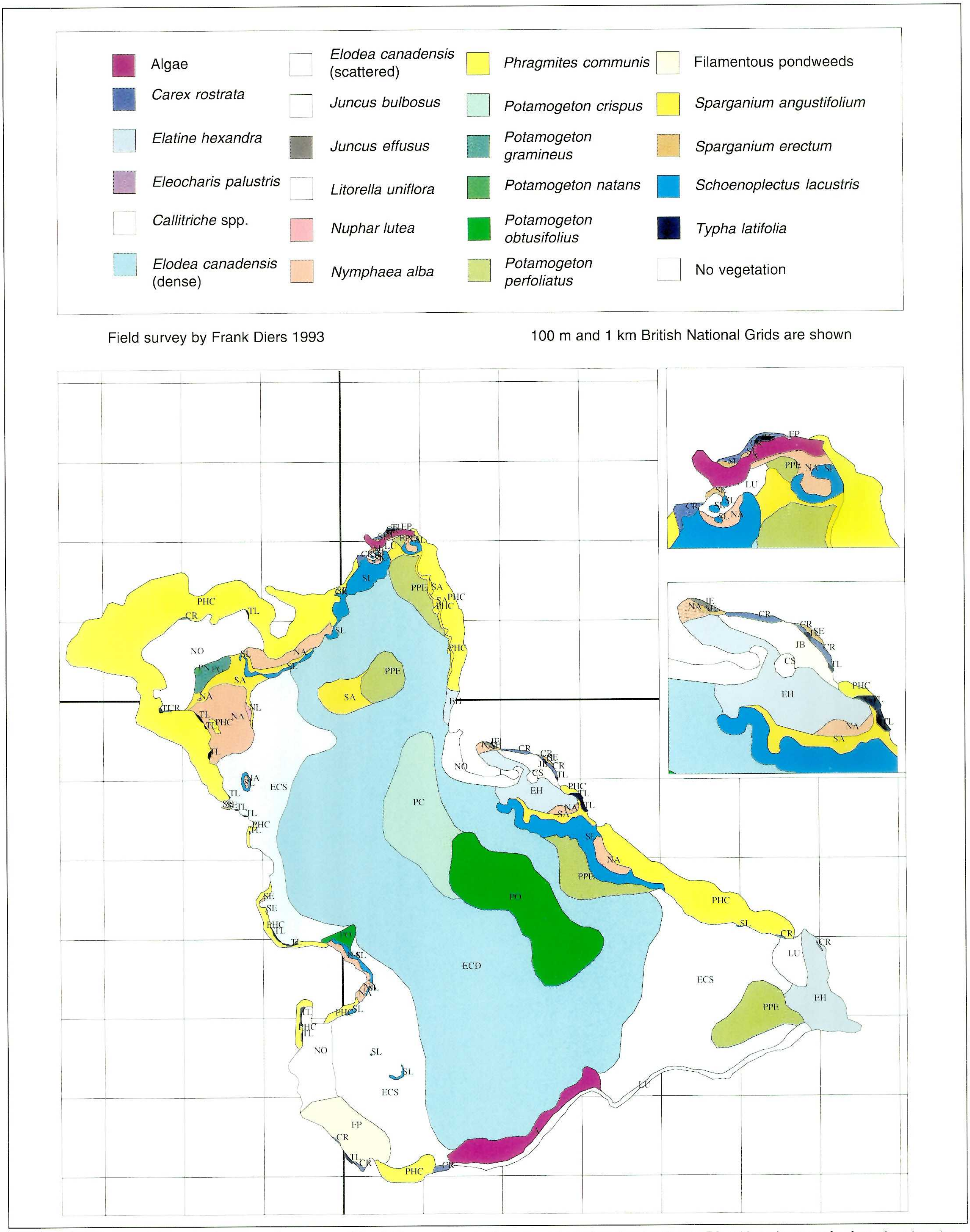

Figure 77. GIS map of the aquatic vegetation zones of Loch Davan. Zones of emergents defined as in Figure 76, with point sample data showing the dominant species in mixed macrophyte stands. The insets show enlarged views of two regions of especially complex mosaics (Computer cartography at ITE Banchory by P J Bacon & F Diers)

of the emergent vegetation in Loch Davan Positions were recorded every 5–10 seconds The data from the two receivers were analysed into latitude, longitude and altitude, then stored in a geographical information system (GIS) (Arc/Info) and transformed into British National Grid co-ordinates These matched the co-ordinates of our GIS data base of the Dinnet Lochs

Figure 76 shows the north-east corner of Loch Davan, with a single path of the boat (as a series of white dots followed by a date and time value) around the outermost margin Handwritten notes of the times when vegetation types changed enabled us to edit this display and map the vegetation zones (inset, Figure 76)

In open water we used the GPS to locate rapidly and accurately points where the abundances of different macrophyte species were assessed The speed of this process allowed us many replicate sampling points, thereby producing a detailed picture of the spatial changes in abundances These data were similarly entered into the GIS, and used to produce both maps of the abundances of single species and an overall assessment of the dominant vegetation zones (Figure 77)

With a little experience, this GPS technique proved reliable, fast and accurate (10 cm instead of some 10 m) indeed, it recorded our positions more accurately than we could determine some of the vegetation boundaries Sharp boundaries were probably mapped about ten times faster and point sampling speeds about doubled compared to conventional survey methods We further utilised its high accuracy in a few days by recording the boundaries of recent management fires on heather (*Calluna vulgaris*) moorland, where the boundaries are very clearly defined The technique works very well in open country, but in woods or forests satellite contact is often lost, and the critical synchrony destroyed In these conditions, simpler GPS instruments, giving an accuracy of a few metres, would be more appropriate, although even they need to get adequate signal reception at sample points

P J Bacon and F Diers*
* University of Heidelberg

The Land Cover Map of Great Britain and its applications

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

The Land Cover Map of Great Britain (Figure 78) was produced by a semi-automated computer classification of images made by the Thematic Mapper sensor on board the Landsat satellite (Fuller 1993, Fuller, Groom & Jones 1994) The Map records the landscape on a 25 m grid, showing 25 land cover types at a field-by-field scale, together with structural patterns within the landscape, such as major roads, rivers, shelterbelts and embankments (Figure 79) The land cover categories include sea and inland water, beaches and bare ground, suburban, urban and arable land, and 18 semi-natural vegetation types subdivided into three woodland classes, four heathland communities, three wetland types, seven grassland habitats and bracken (*Pteridium aquilinum*) This generalised overview has been integrated with the detailed, sample-based field data of Countryside Survey 1990 (see pp20–25) Alone, or in combination, the data sets offer great potential for use in environmental assessment, planning and management

The land cover data allow us to take stock of valuable natural resources and to quantify the extent of Britain's intensively used urban and arable land When compared with existing information, the data may record where changes have occurred in the landscape, giving evidence of how and why areas have changed The Map helps us to understand the patterns or 'biogeography' of the landscape when information on plant distributions or animal movements is added, the Map gives information on how landscape affects the ecology and diversity of wildlife In-depth analyses may provide information about natural processes in the highly managed environment of Britain With a better understanding of past and present landscapes and 'how they work', we are able to see how things change naturally and to determine how our activities influence the ecology We can also better assess the potential for sustainable exploitation of natural resources We may be able to identify practices for enhancing the environment or for restoring degraded areas Thus, policy-makers might build relevant practices into environmental policy and implement management procedures for environmental improvements Finally, the existence of the land cover data allows us to monitor the impacts of policies, to assess their effectiveness, and review their actions in the longer term We examine here some of the areas where the Land Cover Map is already in use or where uses are proposed (Fuller & Groom 1993a)

Social issues

Land cover is highly relevant in a wide variety of social issues Studies where land cover data are in present or planned use include

- public health
- education
- communications
- recreation

Medical statisticians are interested in the coincidence of health problems and land cover types or land uses The data offer the opportunity to examine the spatial patterns of the two to give information about likely effects of land use Examples might include the incidence of tick-borne diseases and the presence of bracken and rough grasslands close to centres of human habitation

In areas of education, the land cover of Britain is so relevant to socio-economic and environmental issues that earlier maps of the 1930s and 1960s were actually produced from the field records of schoolchildren (Fuller, Sheail & Barr 1994) Today's children are now able to learn not only the routine of field recording but also the technologies of remote sensing and computer-based mapping They are able to develop a greater understanding of land use and environment through information systems designed for the classroom and the workplace The Land Cover Map is available for use in schools throughout Britain, and the land cover data are also being made available for educational uses in schools and colleges of further education

A knowledge of land cover is of relevance in the field of telecommunications for example, the design of radio telephone networks requires knowledge of where forests and urban areas may 'clutter' the transmissions, or where open countryside

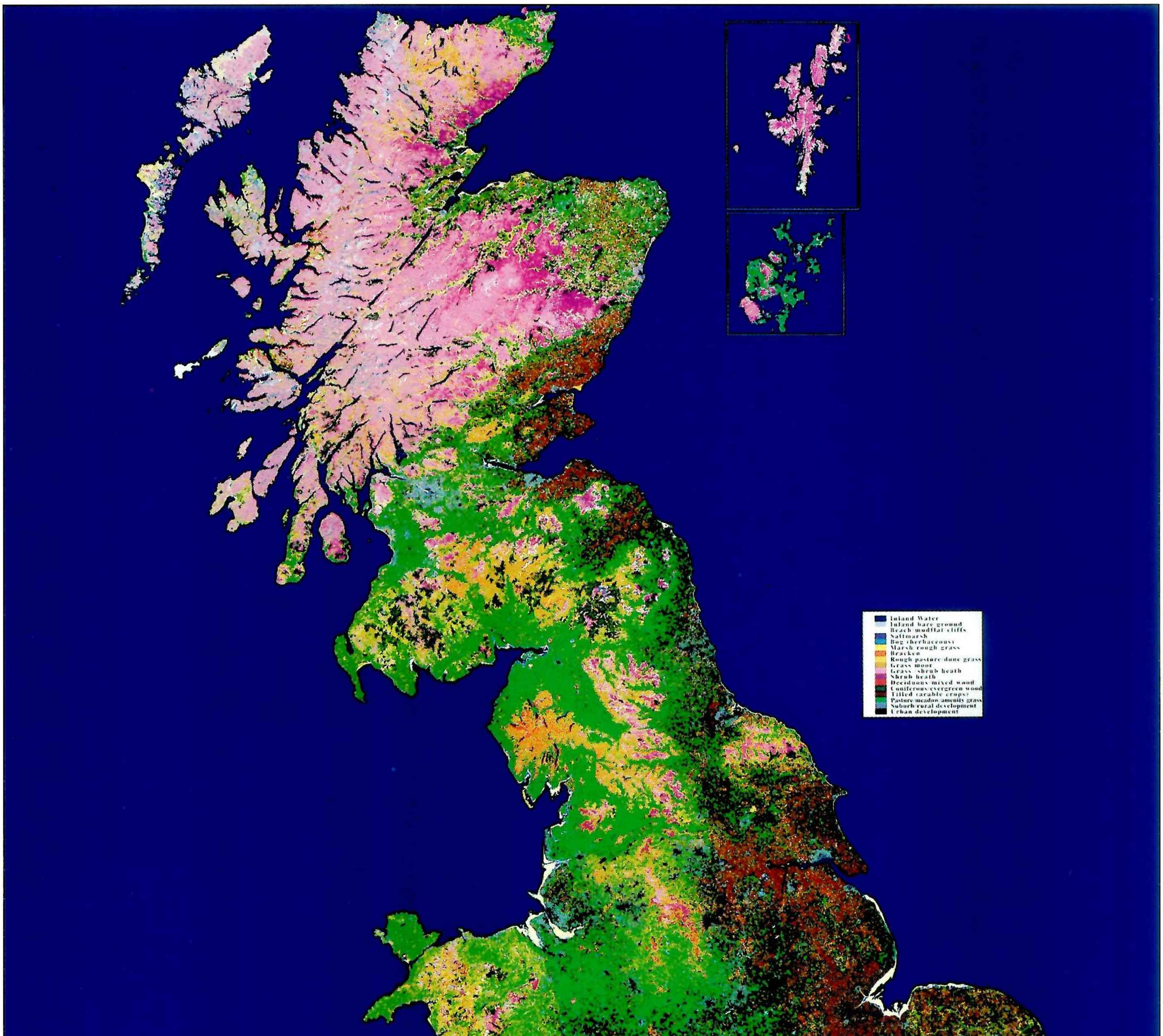

Figure 78. The Land Cover Map of Great Britain: an overview

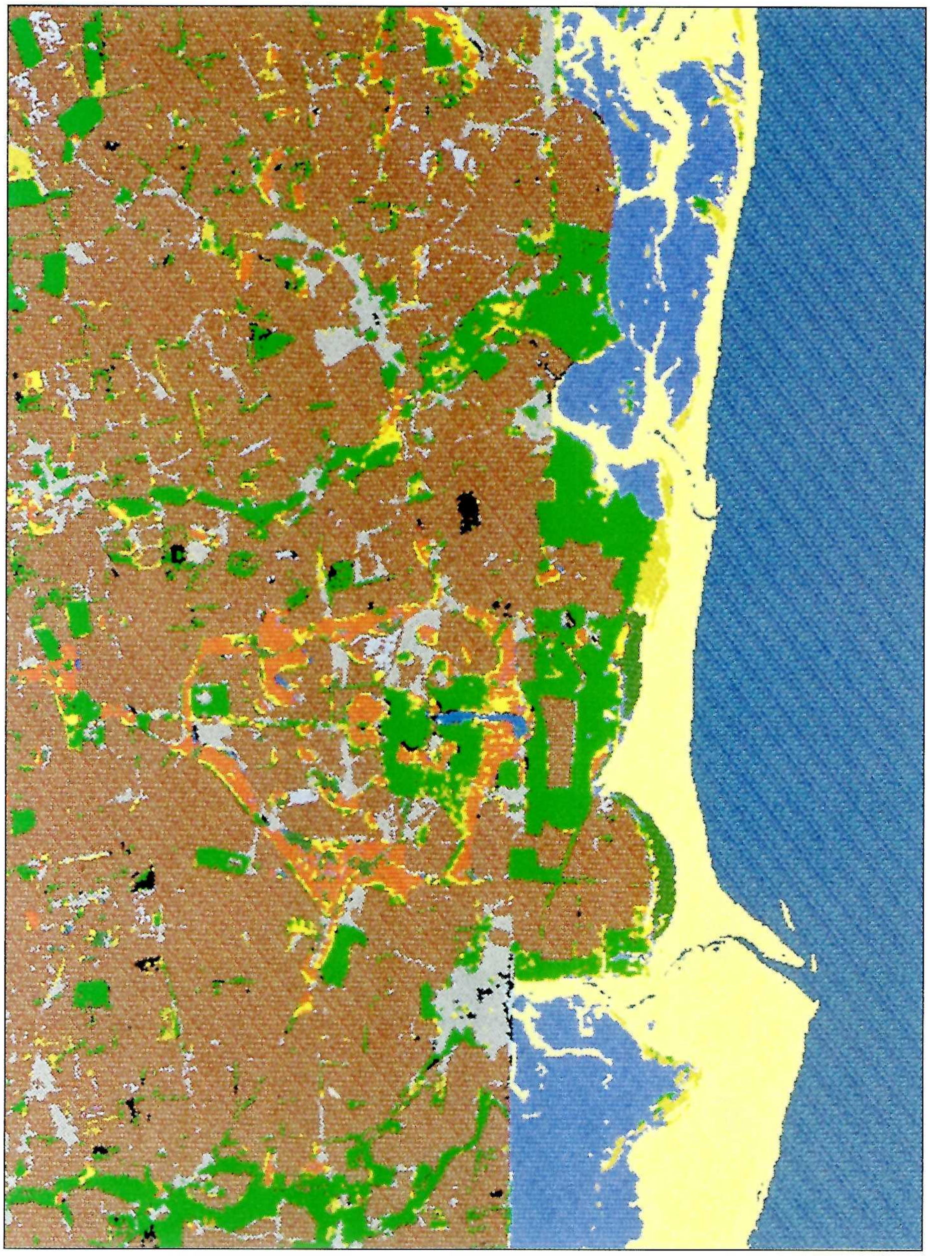

Figure 79. A 15 km × 10 km section of the Land Cover Map of Great Britain, centred on Holkham National Nature Reserve, on the north Norfolk coast (see Figure 78 for key). The historical coastline runs east/west from Brancaster Staithe to Wells-next-the-Sea. Near Brancaster, there has been some reclamation for grass and arable farming; at Holkham (centre) most of the salt marsh has been reclaimed; east of Wells, there has been no reclamation and the town overlooks the marshes

allows easier passage. By modelling radio-wave attenuation using land cover as a key input, it is possible to help build cost-effective and efficient communication networks.

Conservation and wildlife

Land cover is highly relevant for applications in ecology, for example in:

- conservation
- landscape ecology
- biodiversity

Land Cover Map data have been related to wildlife distributions. For example, work with the British Trust for Ornithology has shown a positive correlation between habitat diversity measured from the Land Cover Map and the number of breeding bird species, as recorded by field ecologists. To examine the relationships more closely, ITE's work with the RANGES software combines radio-tracking data with the Land Cover Map: radio-tagged birds have been tracked and their movements recorded digitally on to the Map. From this information, it is possible to establish how the birds use different habitats, for how long, and to relate the success of individuals to the make-up of their home range. We can then predict new areas in which animals might establish, and test the models by experimental releases.

The data have provided statistics for informed policy decisions on wildlife and countryside management. In work for the Department of the Environment, the Land Cover Map has been used to locate areas of key wildlife habitat and to direct intensive field surveys in these areas. The surveys will show the relationships between designation of protected areas and the quality of wildlife habitat. For example, one 'key habitat' under consideration is the coastal zone: this has been defined as a 0.5 km wide strip, above the high water mark. By using the Land Cover Map in a geographical information system (GIS), it was possible to define the tidal limit, using the Map, and to add a 0.5 km buffer zone, using the GIS (Figure 80). Extra context was added by reference to Ordnance Survey maps to determine whether a coastline was 'hard' (ie cliffs), soft (sand and shingle), or estuarine; designated and undesignated examples were also identified. Field surveys then examined a sample of 1 km squares stratified according to hard/soft/estuarine and designated/ undesignated status, to assess habitats and wildlife in those areas.

Intensive land use has led to the degradation of many natural habitats in Britain. As Europe's farming policies have led to overproduction, so extensification has been the new trend. In some cases, this has led to the potential for restoration of lost habitat. Heathland is one example where the damage has been severe. In work funded by English Nature, a GIS has been used to study heathlands in Dorset, where 86% of the heath has been lost. By overlaying the Land Cover Map with a digitised outline of the former heathland boundaries, it has been possible to quantify the losses and to examine the current uses. From these observations, we can then identify areas where heathland can most easily be recreated (Figure 81). The ease of reversal depends on the present use and land cover. For example, grassland would be restored more easily than arable land; we would obviously not expect to restore areas which had been built up.

Management of natural resources

It is necessary to take stock for the sensible management of natural resources. The

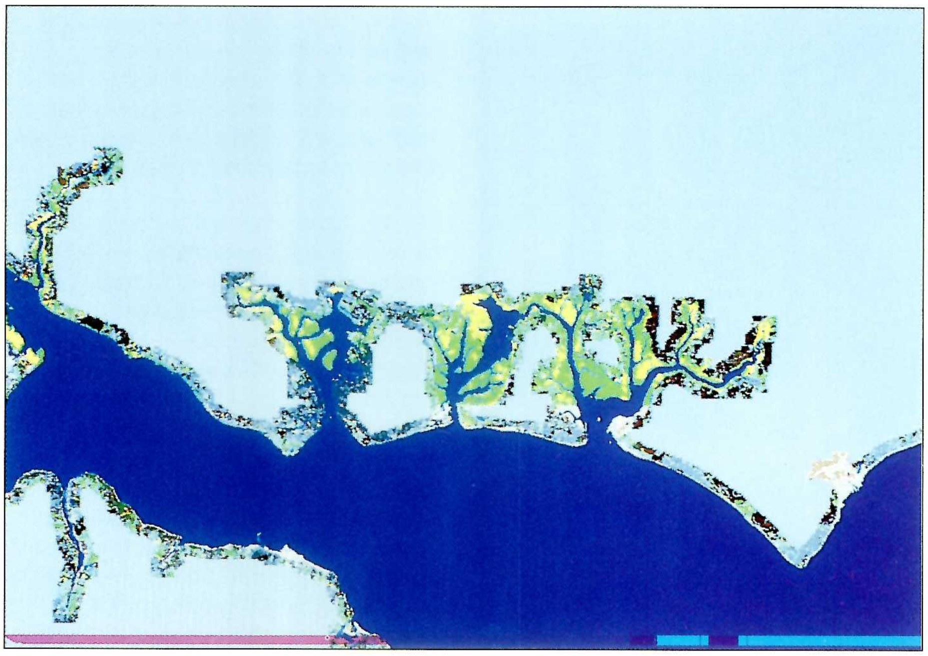

Figure 80. A section of the coastal 'key habitat' near Portsmouth showing land cover: the 'key habitat' was defined by a 0.5 km buffer zone above the high tide line as shown on the Land Cover Map of Great Britain. The coastal 'key habitat' was one of five selected for sample-based field surveys to assess the role of conservation designation in protecting wildlife

Land Cover Map forms an important contribution to our knowledge of the extent, distribution and quality of natural resources, for example in:

- water supply
- forestry
- agriculture
- minerals

Land cover and land use have major impacts on groundwater quality. Land Cover Map data are an optional addition to the Water Information System (WIS) developed by the Institute of Hydrology. WIS is used for storing scientific and technical information about the natural and man-made environments for water resource management, flood estimation, waste management, pollution control and studies of climate change. Land cover data are being used to evaluate the throughput of nitrates and pesticides to groundwater: knowledge of arable and

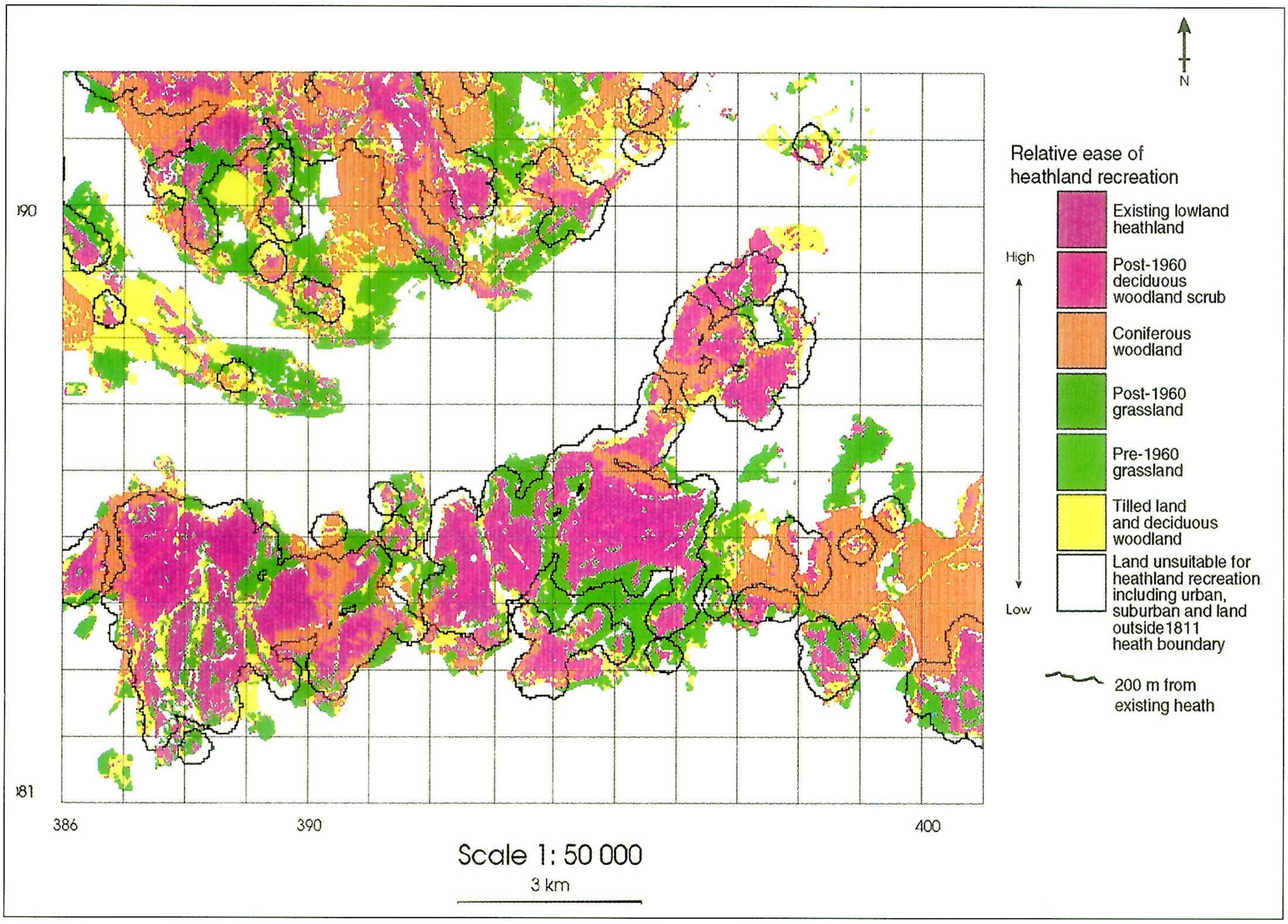

Figure 81. Part of a lowland heathland recreation map of Dorset produced for English Nature, which made use of land cover information from the Land Cover Map of Great Britain and historical data to assess potential areas for heathland recreation

grassland cover, integrated with soil maps and rainwater catchment boundaries, helps us to estimate the applications of chemicals and the rate and extent of leaching to underground aquifers. The data are being used in a similar way to examine the role of land use in affecting the quality of runoff to rivers, estuaries and the sea. The Map data also feed models of runoff which are used in flood prediction and management.

Environmental chemistry

Land cover data are relevant in studying the wider impacts of land use on environmental chemistry and, conversely, the impacts of environmental chemistry on land cover and use:

- runoff and groundwater
- effluents and emissions
- pesticides and land use
- acid precipitation
- carbon budgets
- climate change

Using a GIS, the land cover data have been combined with maps of 'critical loads' to help assess the impacts of acid deposition. A critical load is defined as the threshold value of acidifying pollutant(s) below which significant harmful effects on sensitive elements of

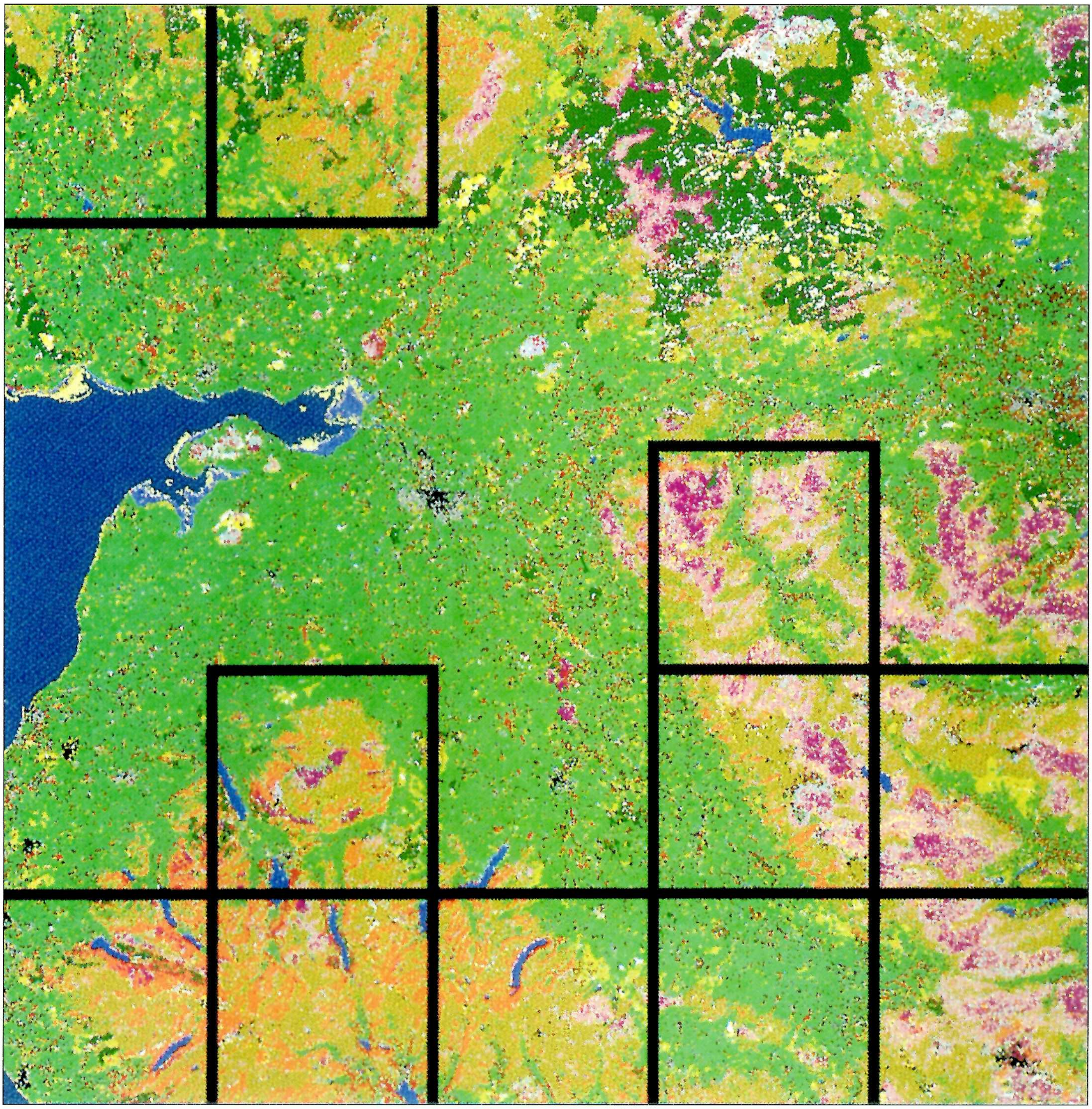

Figure 82. The Land Cover Map for a part of north-west Britain with the boundaries of those 20 km squares where the soil critical load for acidity is exceeded by sulphur deposition, as modelled for a future scenario of sulphur emissions

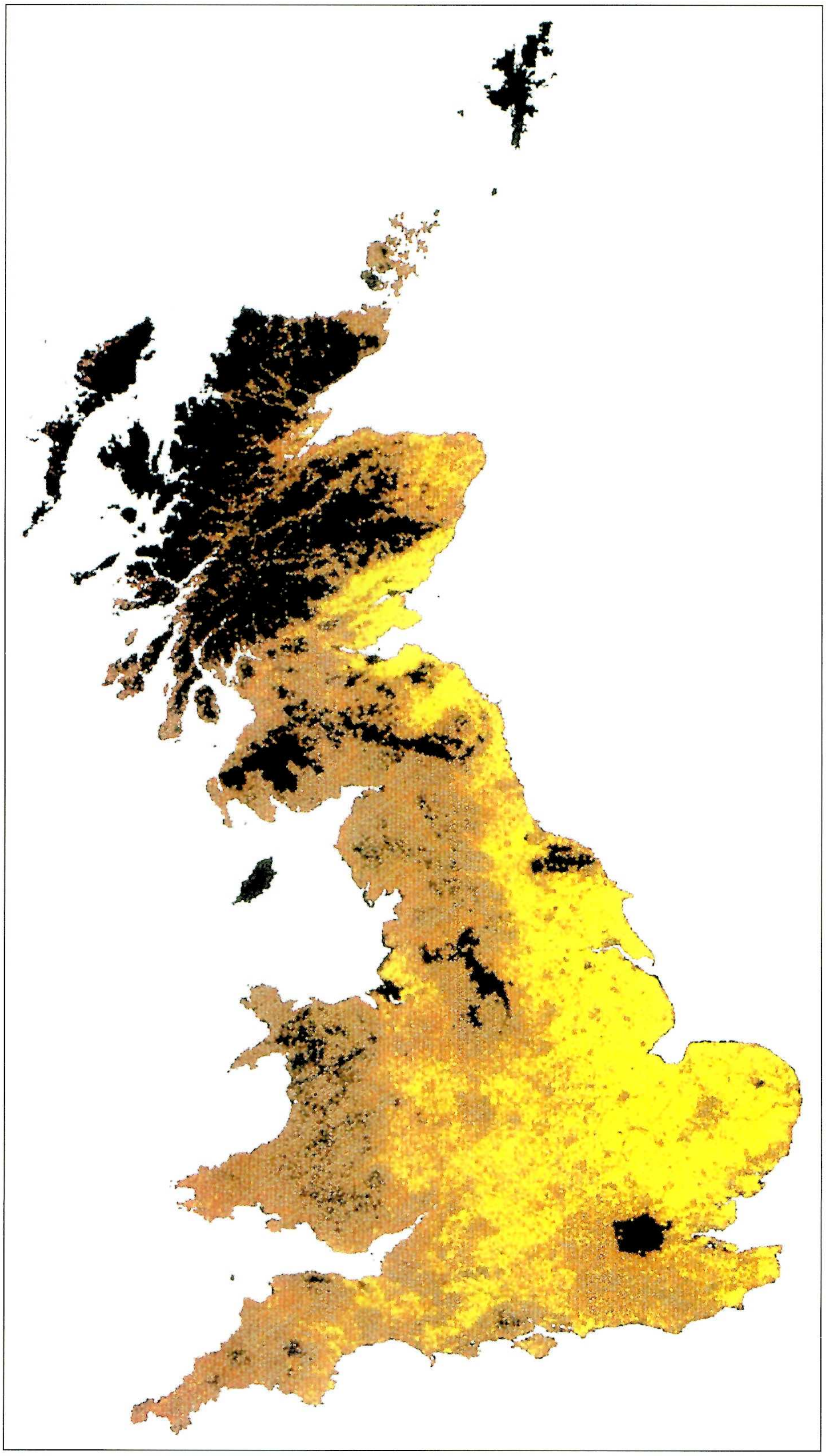

Figure 83. Tilled arable land, derived from the Land Cover Map of Great Britain, plotted from the 1 km summary in the Countryside Information System, showing cover ranging from 0% (black) to >50% (yellow) in five steps

the environment do not occur, according to present knowledge (Critical Loads Advisory Group 1994). The critical load approach has allowed the development of effects-based emission control policies. Critical load maps have been compared with maps of acid deposition to identify where the critical load is exceeded by the deposition. These exceeded areas are combined with the Land Cover Map to examine the types of habitat or ecosystems which may be 'at risk' from acid deposition. Figure 82 shows the Land Cover Map for a part of north-west Britain with the boundaries of those 20 km squares where the soil critical load for acidity is exceeded by sulphur deposition, as modelled for a future scenario of sulphur emissions. Statistics on the land cover classes within the exceeded areas can be derived. Other data such as Sites of Special Scientific Interest can also be incorporated using the GIS.

In studies of climate change, the cover data can help us predict likely changes. Carbon dioxide, an important 'greenhouse' gas, is fixed by vegetation and stored in plant remains such as peat. The Map helps us to evaluate the amounts of carbon locked up in different ecosystems, and so to establish carbon budgets for Britain; changing policies for afforestation or felling could be evaluated in terms of carbon fixation or liberation; the Map may also help evaluate evapotranspiration rates which are relevant to cloud cover and rainfall assessments in climatic prediction.

The data can be used to help assess the impacts of climate change on land cover and land use. Given models of predicted alterations in climate, scientists can assess how such changes might affect land use, or cause shifts in natural patterns of vegetation, and influence processes such as erosion and accretion. Analyses will identify areas where changes are most likely and those areas where current uses are most stable – it is clearly necessary when planning afforestation or siting a nature reserve to be sure that growing conditions will be suitable for the future of the species to be fostered under the scheme.

Environmental impact assessments

The Land Cover Map has been required as an input for environmental impact assessments in areas of:

- urban planning
- transport routes
- rural development
- industrial impacts
- civil engineering

The Map has been used to predict the impacts of new industrial installations which produce atmospheric pollutants The expected 'footprint' of emissions has been overlaid on to the Map to identify habitats which will be affected The sensitivity and vulnerability of various areas have been evaluated to help locate the plant and design a scheme which minimises deleterious impacts Radford (pp95–100) illustrates an example of such uses in emission control

In designing new roads, the Map has been used to investigate the general impacts of various road options in terms of habitat losses, habitat fragmentation, loss of valuable farmland and proximity to built-up areas Planners can quickly reduce a wide and complex variety of schemes down to a shortlist of possibilities, before in-depth analyses by aerial photogrammetry and field-based impact assessments

Availability of data

The Land Cover Map of Great Britain was completed in April 1993 already some 150 widely different applications are underway It is evident that such data are required by those concerned with environmental policy, planning, management and audit It is perhaps surprising that such users have, until recently, managed without up-to-date information The advent of GIS, with its capabilities to integrate and manipulate multiple spatial data sets, has made the Land Cover Map key data set even more important for so many applications (Fuller & Groom 1993b)

Data are available, under a licence agreement, to users in Government departments, non-governmental organisations, commerce, industry and to the consultants advising those users Data can be provided at the full 25 m resolution, for all 25 classes, and for any region of interest within Great Britain Alternatively, many users require data on different output grids One attractive form of the data is the 1 km summaries which are to be incorporated into the Countryside Information System (CIS) The CIS uses the familiar 'Windows' environment on a personal computer The package is designed for the desk-tops of planners and environmental managers, who can readily access and manipulate quantitative information to assist in the decision-making process educational packages will also become available for use in schools and colleges of further education It incorporates summary data from the Land Cover Map (Figure 83), together with data from the sample-based field survey, recording details about species' distributions, landscape features such as hedges, walls and trees, together with information on land management practices (Barr *et al* 1994) A range of other thematic data, eg summarising administrative regions and environmental attributes, allows simple operation of complex queries on land cover, landscape features, species and environment

R M Fuller, J R B Hall, G B Groom and T W Parr

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Scoping methods of environmental assessment for air pollution

ITE has developed a wide range of applications involving geographical information systems (GIS) since installing its first at the Environmental Information Centre at Monks Wood in the late 1980s One of the fastest-growing application areas has been the combined use of national data bases with other small-scale data sets in scoping studies for environmental assessment There is a clear role for GIS in helping to maximise the value of these data sets as components of policy tools, regional environmental assessments and scoping studies for strategic planning and development control

A hypothetical example has been chosen to illustrate scoping for development control, based on one of the first directly industrial applications of GIS-based scoping methods For British Gas it has proved to be a rapid and cost-effective method of assessing the potential for impacts

An important main nitrogen release to the atmosphere in Britain is nitric oxide (NO), formed by the oxidation of atmospheric nitrogen at high temperatures in combustion processes After emission, the NO becomes oxidised to nitrogen dioxide (NO_2), which is more reactive

Increased levels of nitrogen compounds have an effect on plants in three main ways by direct toxicity, as a fertilizer, and, indirectly, as an agent of soil acidification Direct effects may occur when oxides of nitrogen (NO_x) enter leaves primarily through the stomata and dissolve in the substomatal cavity, forming nitrate and nitrite ions The fertilizer effect causes increases in vegetation biomass and in the concentration of nitrogen in the foliage, which may contribute to such effects as

- increased cuticular permeability, leading to a greater sensitivity to drought,
- prolonged growth periods and reduced cuticle thickness, leading to lower frost-hardiness, and
- a greater susceptibility to pests and pathogens

These effects can lead to changes in plant community structure and composition as a result The formation of acids from the deposition of NO_x may increase existing acidity or tend to offset the buffering capacity of weathering soil In areas where critical loads of acidity for soils are already low (Hornung 1991), increased nitrogen from the atmosphere can help tip the balance towards exceedance

The gas turbines used to maintain pressure in the British Gas National Transmission System are aero-derivatives which operate close to the NO_x consent levels set by Her Majesty's Inspectorate of Pollution (HMIP) Installing control measures to reduce NO_x emissions so that they lie comfortably within these levels at all sites will be a costly process, and outside the principle of BATNEEC (Best Available Technique Not Entailing Excessive Cost), especially in terms of the degree of environmental protection that could potentially be achieved British Gas, therefore, decided to consider the site-specific circumstances of its operations, rather than just adopting a single generic approach

A method was needed to help identify and focus attention upon the receptors and indicators most likely to be sensitive to nitrogen deposition around the source Ideally, a significant proportion of the method needed to be undertaken in the office, so that the limited time available for field activity could be put to best effect The approach taken for the scoping aspect of this work was based upon the availability of four key components

- an industrial model for the prediction of ground concentrations of NO_x,
- the Land Cover Map of Great Britain recently completed by ITE (Fuller, Groom & Jones 1994),
- map data for the critical loads for soil acidification (Critical Loads Advisory Group 1994), and
- GIS for integrating these data and relating them to a topographic base map

The objectives for the GIS scoping were

- to define areas around each site likely to receive maximum deposition from the stacks,
- to mask out from these the extent of land cover types least sensitive to added nitrogen,
- to identify the extent of soils most sensitive to increased acidity within the areas of high ground concentrations of NO_x

The installation considered in the example is a hypothetical one, but it is based on realistic emission data transposed to a location just to the east of Monmouth, Gwent

The first stage was to generate a map of predicted ground concentrations of NO_2 for each site The Industrial Sourced Complex, Short Term (ISCST) model was used, driven by

- hourly meteorological data over the previous year,
- site elevation,
- stack characteristics,
- known levels of NO_x emission

Deposition was calculated for the worst-case operational scenario, assuming all turbines to be in continuous operation, whereas in practice most operate for less than three months of the year All NO was assumed to be converted to NO_2 before deposition The model showed that ground concentrations would be undetectable further than 10 km from the station, and this distance was adopted as a maximum limit of interest

The time available for field survey allowed a search of up to 3 km^2 in total for each site The next stage was, therefore, the selection of a minimum contour value that defined no more than this area The regions at this and higher concentrations were digitised and held in the GIS as a vector coverage for each site This coverage was then geo-referenced to a topographic map based on the British National Grid, to which the Land Cover Map is already registered (Figure 84) All further thematic interest was limited to the areas of predicted high concentration inside the digitised contour of the 'plume' The concentration used in the simulation is 4 0 mg m^{-3}, with a maximum of 4 5 mg m^{-3}, giving a total area of 16 500 ha

The second mask prepared using the GIS was taken from the land cover map Of the 15 mapped terrestrial cover types listed below, six were regarded as unlikely to include plant communities sensitive to added nitrogen, these and the unclassified cells were masked out from the area of interest using GIS grid cell functions (Figure 85) The remaining potentially sensitive cover types included woodland and those with a generally low nutrient turnover The amounts of each cover type within the area of interest were as follows (potentially nitrogen-sensitive categories are marked with an asterisk)

Cover type	Hectares
* Grass heath	1049
* Meadow/Verge/Semi-natural grass	1960
* Marsh/Rough grass	582
* Bracken	219
* Dense shrub heath	76
* Open shrub heath	322
* Deciduous woodland	5365
* Coniferous woodland	1252
* Felled/Cleared vegetation	72
Scrub/Orchard	170
Mown/Grazed turf	1926
Tilled land	2437
Suburban/Rural development	587
Continuous urban	5
Inland bare ground	10
Unclassified	468
Total	16 500

A raster overlay procedure was used to relate this second mask to the first As a result, only those areas of potentially nitrogen-sensitive land cover within the areas of predicted high ground concentrations of NO_2 were left on the map (Figure 86) In this example, in an area with high deciduous woodland cover, the reduction is by 5603 ha, some 34%, in areas of intensive farming, the reduction can be by as much as 80%

A critical load map for soil acidification comprised the final component of this scoping method Because of its coarse scale relative to the other data sets, it was not included in the formal additive masking procedure but was used as a guide to field surveyors when searching for vulnerable sites and information on possible effects

Minor difficulties were experienced with the co-registration of masks, highlighting one of the principal problems associated with GIS operations carried out on data sets of different spatial characteristics An assessment should be made of the minimum number of control points needed to achieve the required level of precision across the full map scene From the field surveyor's viewpoint, maps need to be precise, uncluttered and manageable to be useful in field conditions, given that their accuracy and currency are often open to question when checked against the situation on the ground Attention to detail in the geo-referencing of map data within GIS is an important issue that can have a significant impact on field operations emanating from the scoping studies that use them

Figure 84. Monmouth Compressor Station and modelled plume – Land Cover Map, full resolution 25 class values

This GIS-based procedure enabled ITE to make the best use of available information to meet the customer's requirement for a rapid and cost-effective response. An assessment of the vulnerability of areas around other sources of emissions could be made using the same scoping method. It provides a standard site-specific approach to evaluating air pollution in relation to both general and locally relevant consent levels.

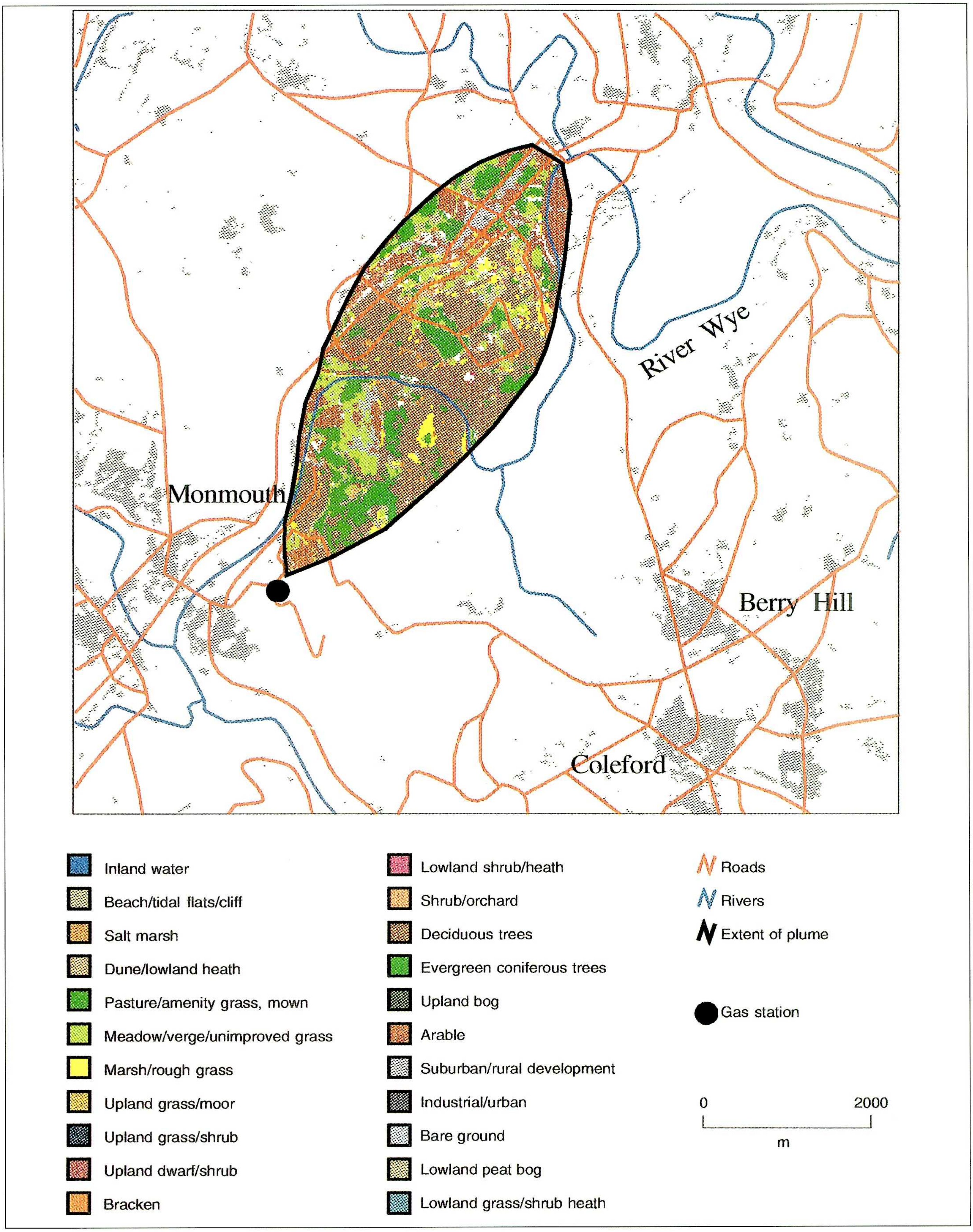

Figure 85. Vegetation affected by modelled plume – Land Cover Map, full resolution 25 class values

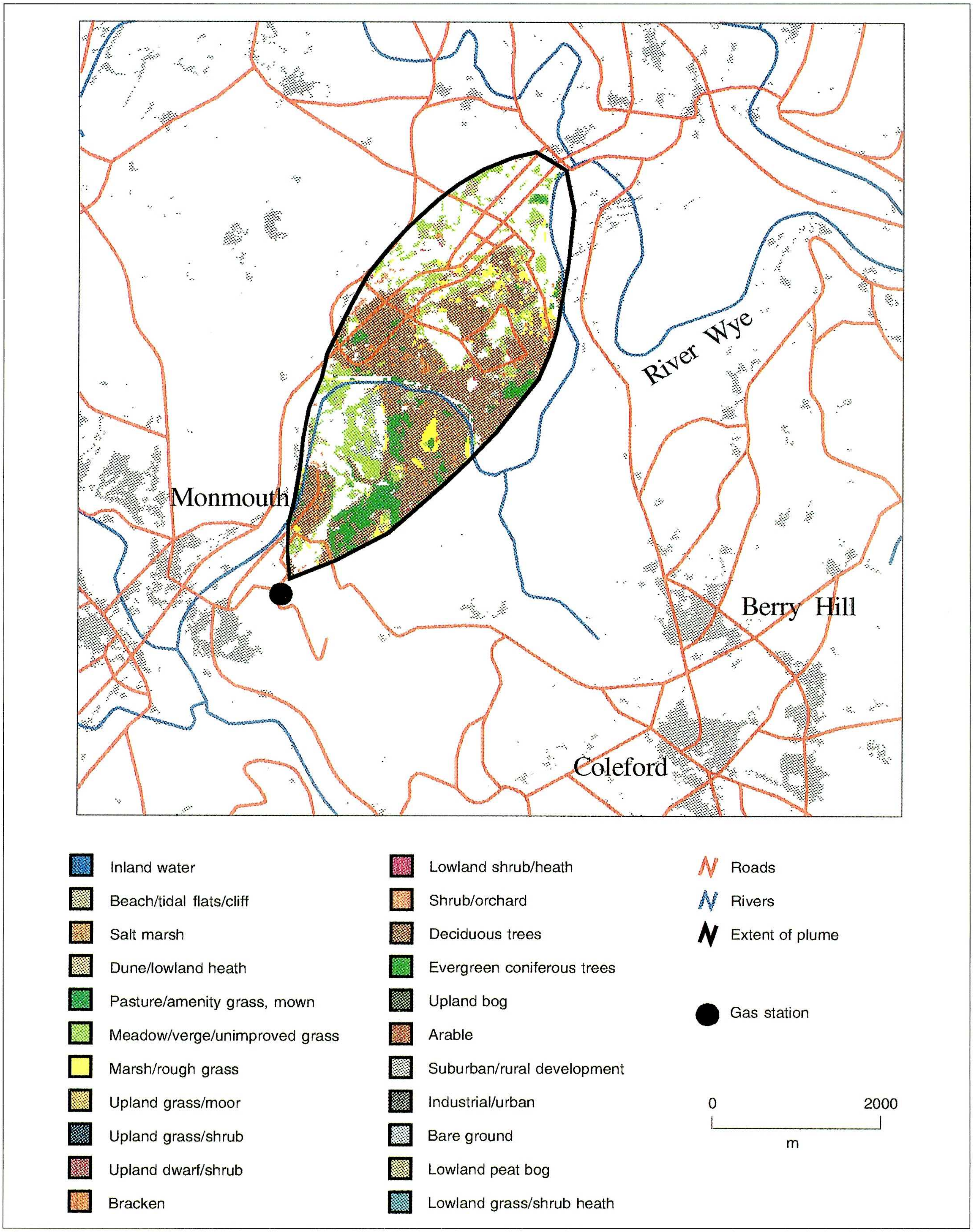

Figure 86. Sensitive vegetation affected by modelled plume – Land Cover Map, full resolution 25 class values

Since the work was undertaken, a studentship has been awarded to develop the interface between atmospheric pollution models and GIS, under the NERC Industry Targeted Studentship Scheme It will allow a more interactive approach, to help guide iterations of the model on the basis of correlations with supporting data sets in the GIS Data transfer between different software modelling packages can be a hindrance and even a barrier to their effective interaction and use Dynamic modelling will often require iterations through chains of computational modules that may not have been designed for linking with other complementary software The design of interface mechanisms to improve the ease and performance of transfers between separate modules involved in these iteration processes can greatly improve the scope, effectiveness and power of predictive modelling

G L Radford

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