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

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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

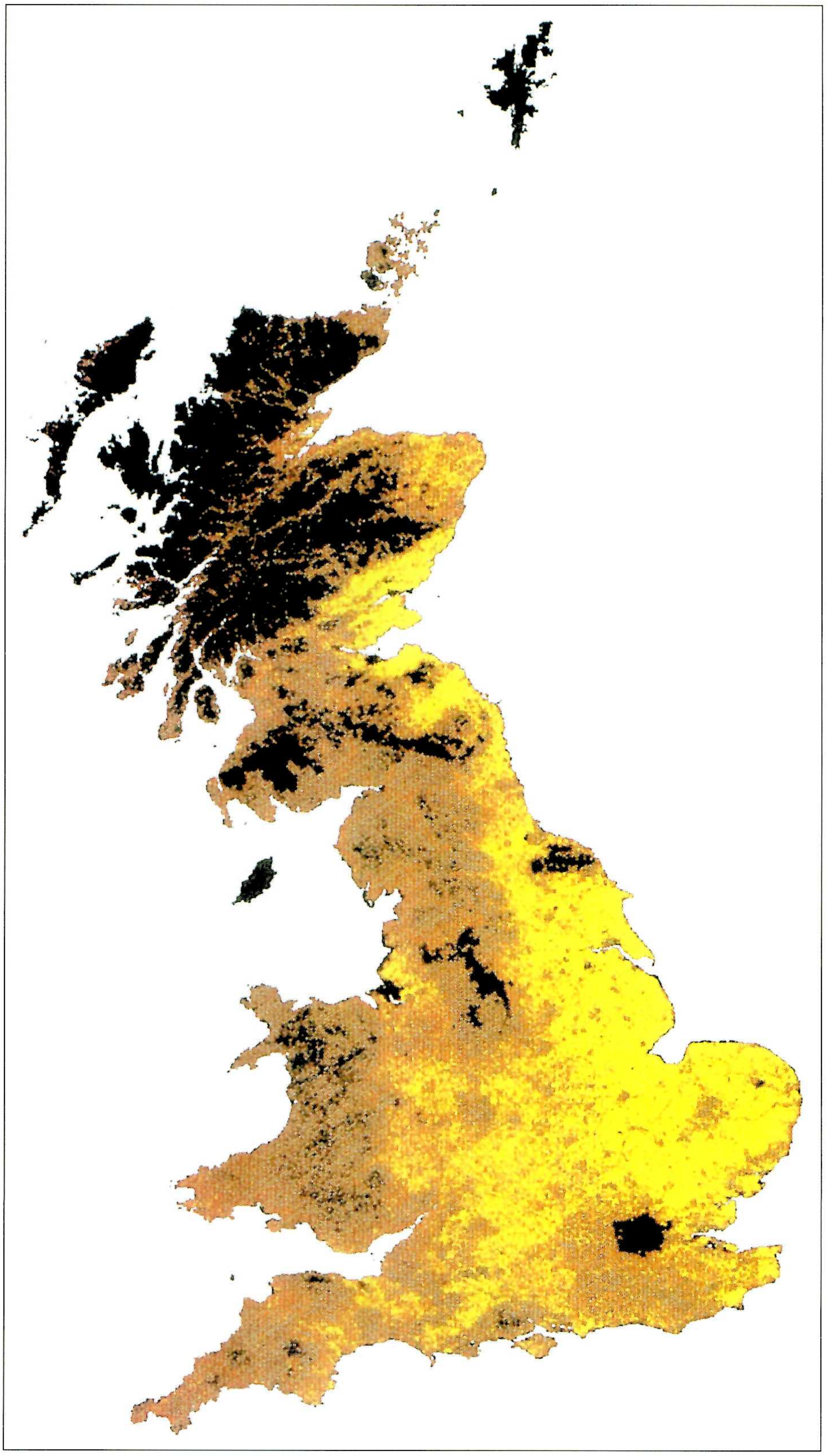

Figure 83. Tilled arable land, derived from the Land Cover Map of Great Britain, plotted from the 1 km summary in the Countryside Information System, showing cover ranging from 0% (black) to >50% (yellow) in five steps

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

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

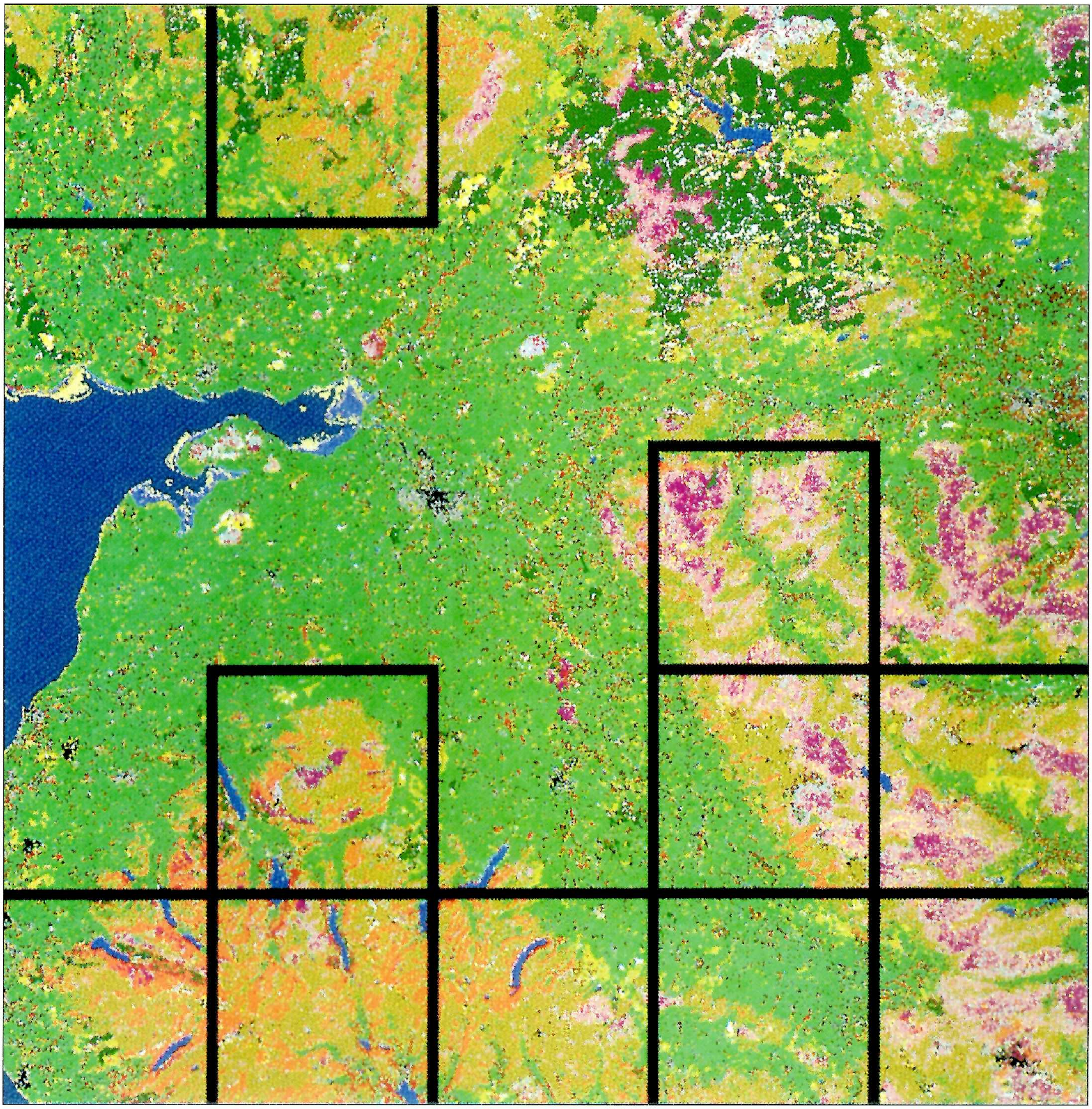

Figure 82. The Land Cover Map for a part of north-west Britain with the boundaries of those 20 km squares where the soil critical load for acidity is exceeded by sulphur deposition, as modelled for a future scenario of sulphur emissions

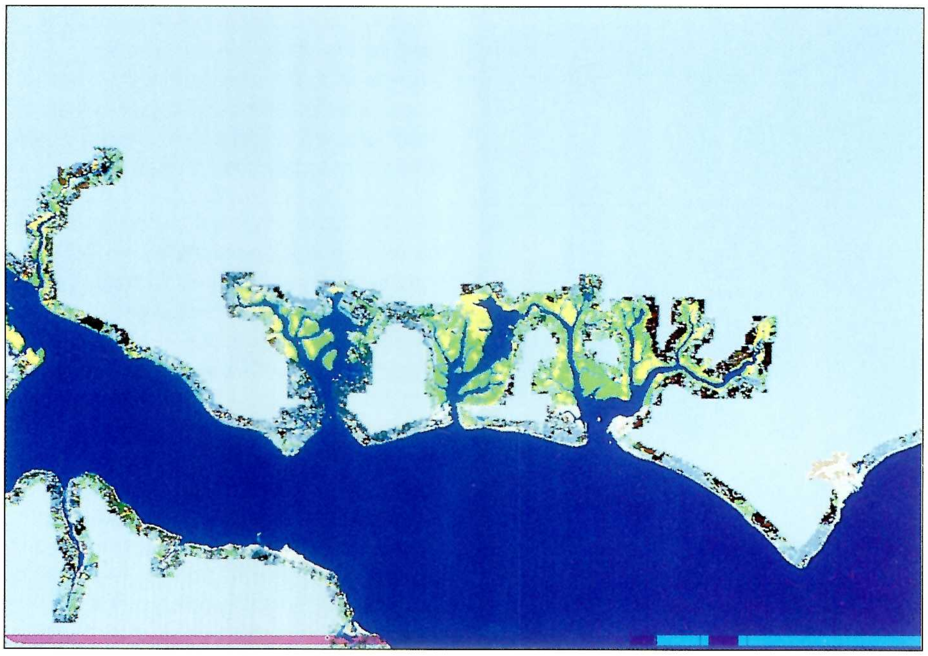

Figure 80. A section of the coastal 'key habitat' near Portsmouth showing land cover: the 'key habitat' was defined by a 0.5 km buffer zone above the high tide line as shown on the Land Cover Map of Great Britain. The coastal 'key habitat' was one of five selected for sample-based field surveys to assess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

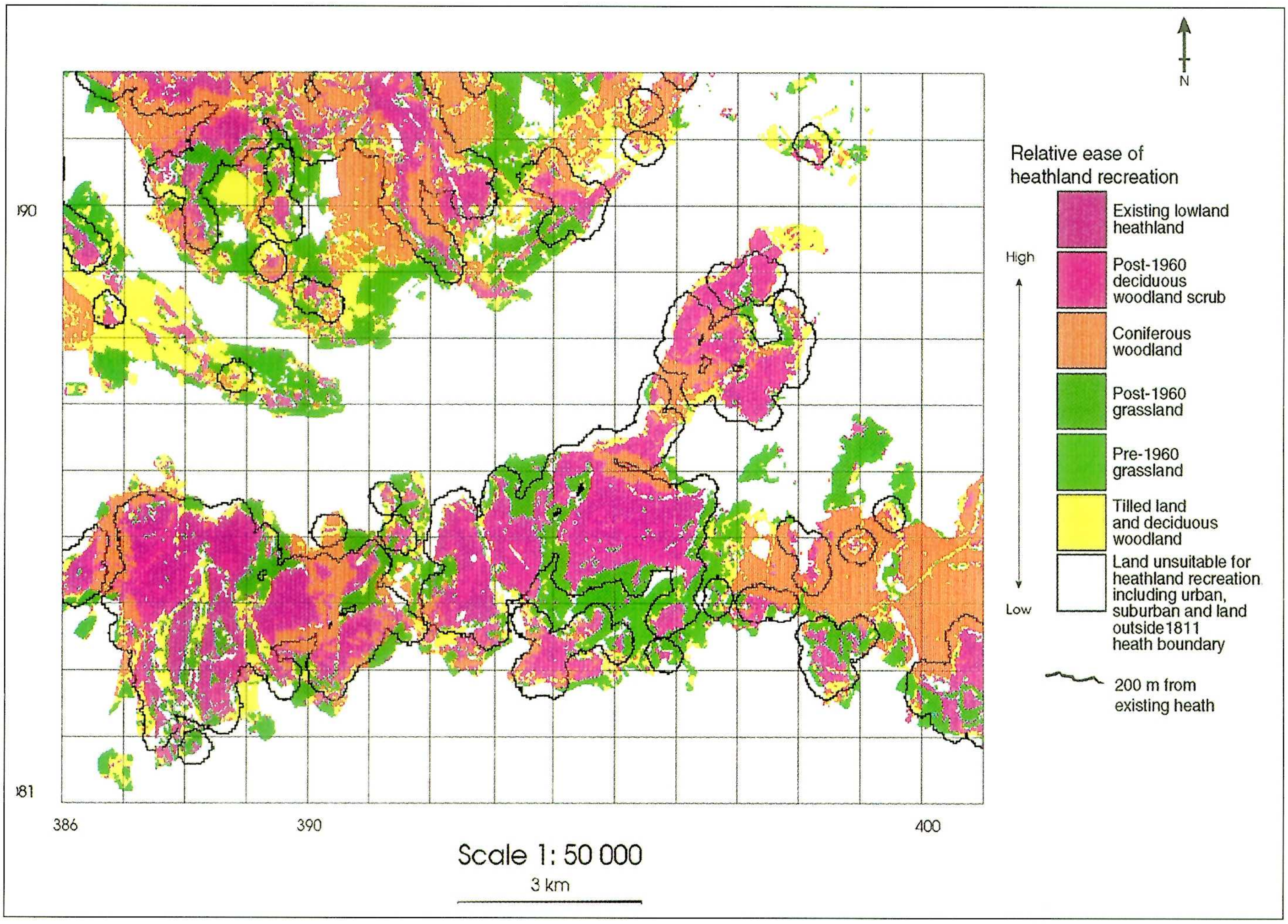

Figure 81. Part of a lowland heathland recreation map of Dorset produced for English Nature, which made use of land cover information from the Land Cover Map of Great Britain and historical data to assess potential areas for heathland recreation

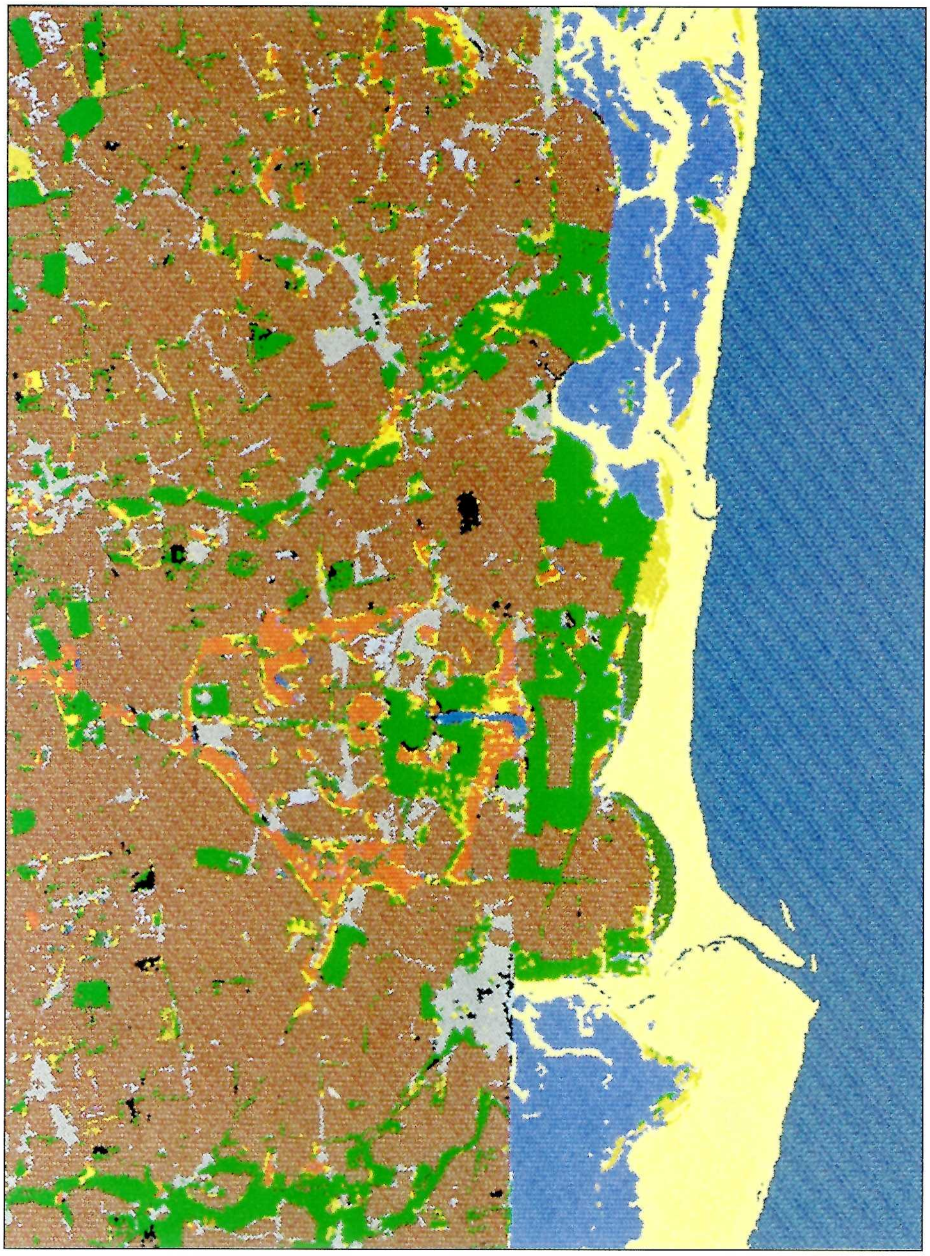

Figure 79. A 15 km × 10 km section of the Land Cover Map of Great Britain, centred on Holkham National Nature Reserve, on the north Norfolk coast (see Figure 78 for key). The historical coastline runs east/west from Brancaster Staithe to Wells-next-the-Sea. Near Brancaster, there has been some reclamation 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

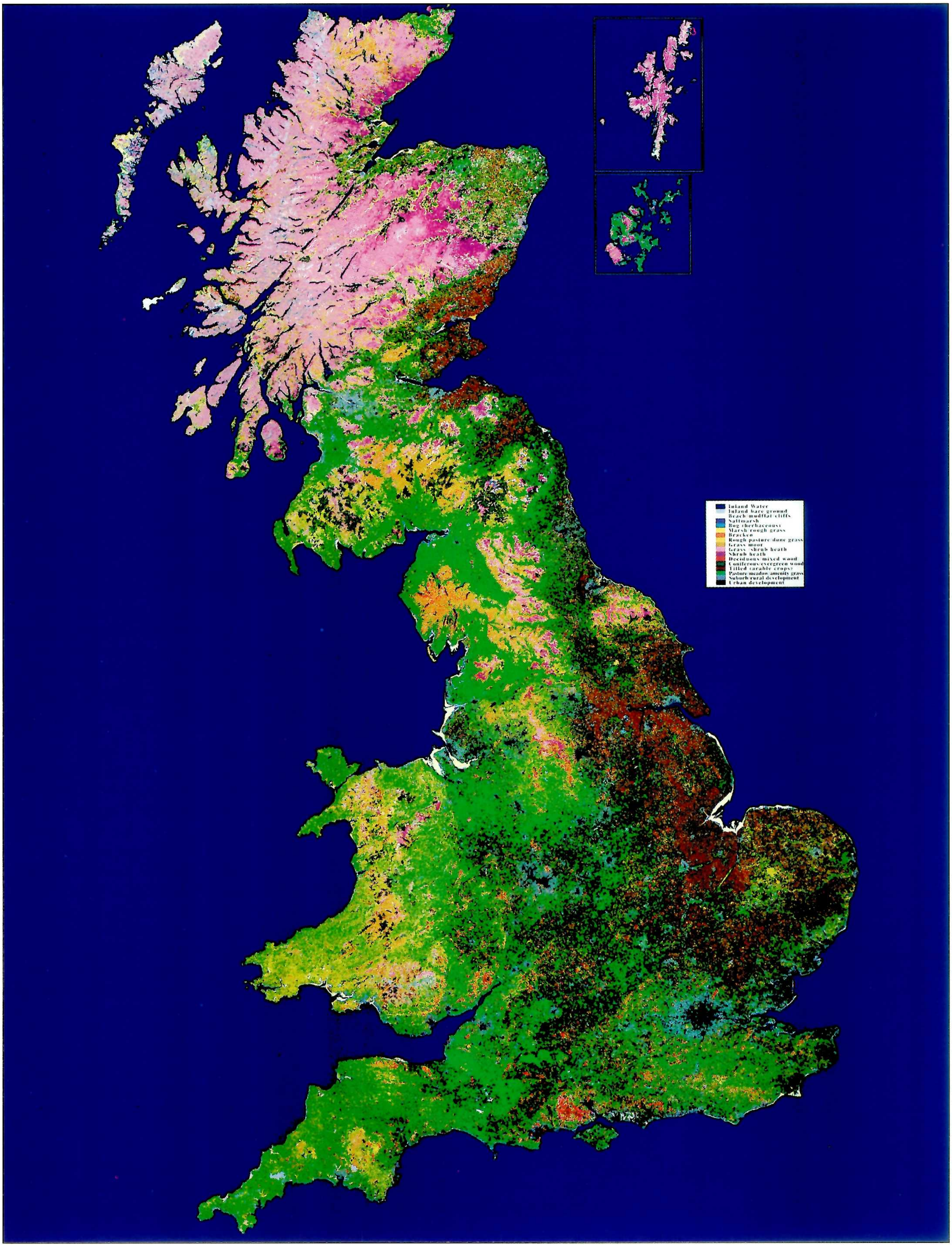

Figure 78. The Land Cover Map of Great Britain: an overview

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

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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