Bunce, R. G. H.; Barr, C. J.; Fuller, R. M.. 1992 Integration of methods for detecting land use change, with special reference to Countryside Survey 1990. In: Whitby, M. C. W., (ed.) *Land Use Changes: the causes and consequences.* London, HMSO, 69-78. (ITE Symposium, 27).

Integration of methods for detecting land use change, with special reference to Countryside Survey 1990

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INTRODUCTION

Although Great Britain is not, in European terms, a large country, it has a complex mosaic of different land uses, cover types, and ecological systems. The present rural land use patterns have been determined by the interaction of man with the vegetation cover and in response to the changing climate since the ice age. Initially, the patterns were determined by the natural environment. Since the Industrial Revolution, however, other pressures have modified the basic pattern and, although many of the underlying correlations between land use and the physical environment still exist, they have been highly modified by industrial, technological, and socio-economic factors.

In recent years, with greater control of development and planning, there has been an increasing interest in the composition of the British countryside. This has been partly in response to public perception of environmental matters, but also because of a recognition of the importance of Government policies in determining the patterns and changes taking place in the landscape.

In recent times, a variety of information-gathering projects has been undertaken by Government agencies in response to the perceived increase in rate of change in the countryside.

One basic problem is that the rural land has a wide variety of demands upon it, and there are conflicts between, for example, agriculture, forestry, urban expansion, industrial development, wildlife conservation, and amenity and recreation. To a large extent, rural land use is outside statutory planning procedures, although urban planning does impinge on the countryside. There is, therefore, a requirement not only at a local level, but also nationally, for examining the patterns in the countryside and the likely changes which are taking place. There are four main requirements:

1. resource assessment, which involves an estimation or measurement of the overall resources of the region, or country, concerned;
2. an indication of the broad regional pattern of these resources: a knowledge of their distribution throughout the region is essential for planning;
3. a measure of the changes taking place: many changes in land use may seem small by themselves but together may have incremental effects on the landscape;
4. estimation and prediction of land use potential and scenarios of change, in order to compare policy options which may affect the patterns and land uses present in the countryside.

Whilst there are many independent detailed studies of particular processes and land uses, these are often unco-ordinated. This paper reviews the studies which have been completed at the present time, then goes on to describe the integration which has taken place to date, and finishes with a description of the approach which has been developed within the Natural Environment Research Council (NERC) to describe the countryside and its changing patterns.

The main purpose of this paper is to describe and discuss the approaches used to monitor changes in land use, as a basis for policy implementation.

METHODS FOR DETECTING LAND USE CHANGE

Field survey

The traditional means of obtaining information about the ecological characteristics of land is to carry out field surveys. These vary in methodology and objectives, but are often based upon observing vegetation, and mapping in the field. From this early approach, the associations of species have been recorded in phytosociological units (eg Rodwell 1991), assessing the association between them. In land use terms, until Sir Dudley Stamp set out to obtain a land use statement in England and Wales in the mid-1930s (Stamp 1937-47), there had been no comprehensive recording of these areas since the Domesday Book of 1066. Stamp's land use statistics have been augmented by the mapping activities of the UK Ordnance Survey and by a survey described by Coleman (1961). In addition, there have been extensive and repeated field surveys by the Forestry Commission and by the Ministry of Agriculture, Fisheries and Food and the Department of Agriculture and Fisheries for Scotland. The Soil Surveys of England and Wales, and of Scotland, also completed detailed maps recording the distribution of major soil series in Great Britain.

Aerial photography

Ever since the advent of readily available aerial photography in the early 1950s, it has been realised that it represents an important additional source of land use information. The first national survey using aerial photography was the Monitoring Landscape Change (MLC) project in 1986 (Hunting Surveys and Consultants Ltd1986). This project used a stratified sample, based on the Forestry Commission census strips from soil series, by county, and recorded land cover and landscape features from a series of sites in England and Wales, to obtain national estimates of the nature and extent of these categories. More recently, the National Countryside Monitoring Scheme (NCMS), for the Nature Conservancy Council, has used a comparable approach within counties in Great Britain (Budd 1989). The Macaulay Land Use Research Institute (MLURI), commissioned by the Scottish Office, has also been involved in mapping vegetation throughout the whole of Scotland based on aerial photographic coverage, flown in 1988–89, (Aspinall Miller & Birnie 1991). Over many years, the Ordnance Survey (OS) has been involved with land cover, principally by studying the expansion of urban areas, and has produced quantitative national estimates within GB (eg Department of the Environment (DoE) 1992).

Satellite imagery

It has taken several years for the technical development of satellite imagery to reach a stage where applications have been encouraged. Recent studies have been successful in producing outputs, in the form of maps and statistics, rather than in detailing technical potential. Fuller, Jones and Wyatt (1989), for example, described the application of imagery to obtain regional estimates of land cover types in Cambridgeshire.

Local and regional surveys

There have been many regional surveys of varying levels of detail. For example, habitat surveys of the type devised by the Nature Conservancy Council (NCC) have been carried out in many counties (eg Moreau 1990). The Countryside Commission has funded detailed interpretations of National Parks in England and Wales (Countryside Commission 1991), and Highland Regional Council also carried out regional studies as a basis for land-use planning (Highland Regional Council 1984).

Thematic surveys

National surveys have been carried out of the individual features which make up the landscape, and estimates of change have been made. Thus, Hooper (1968) described hedgerows, Whitbread (1985) ancient woodlands, Fuller (Fuller, Barr & Marais 1986; Fuller 1987) lowland grasslands, and Bunce (1989) heather in England and Wales.

Socio-economic surveys

A wide range of socio-economic surveys have been carried out, both at individual points and also to follow trends, such as the population census and various recreational studies (eg Lowe, Ward & Munton 1992).

To date, there has not been any true integration of methods or of the data sets which have resulted from these various surveys. They have been determined largely by the individual requirements of the agencies concerned. There is, therefore, a strongly disparate nature of much of the information available for the basic description of the environment and land use in Britain; the wide range of approaches used to analyse the information further complicates the final picture.

DATA INTEGRATION

Full data integration does not depend entirely upon the methods, although these are inextricably linked. It is necessary to produce the final estimates involving and overlaying the various data in order that they are on a consistent basis to improve the accuracy of estimates, and also to show the correlation between the various data streams. The importance of such integration has been recognised for many years, and has its basis in the 'sieve technique' much employed by planners, where sets of different requirements for the countryside are successively overlain using different maps, and their interactions assessed (eg Bunce *et al.* 1984).

With the development of increased computing power and sophistication of mapping procedures, there has been a range of attempts to establish comprehensive data bases. The first and most extensive of these was the Rural Land Use Information System (RLUIS) project based in the Lothian region (Coppock & Gebbett 1978). This study focused on the acquisition of comprehensive sets of information, and was successful in showing that computing systems could enable such data to be stored and manipulated for specific requirements, at the regional level. This approach was extended to other parts of Scotland, but was not successfully followed up elsewhere in Britain because of the difficulties involved in handling such large data bases consistently at the national scale, data bases which were collected for a variety of purposes and at different scales. An early attempt to integrate large numbers of mapped environmental data was made by the Institute of Terrestrial Ecology (ITE) in a project called ECOBASE (Molineux 1978), but, again, lack of computing and data base design technology meant that the approach did not achieve its full potential.

Within the European Community (EC), a further example of integration is provided by the CORINE (Co-ordinated environmental information in the European Community) programme where a variety of data sources have been co-ordinated (Moss *et al.* 1991). Here, again, a major limitation has been the inconsistency of data between countries, but a degree of comparability has been obtained and summaries have been produced for the whole of the EC. In Britain, the agricultural land classification represents a different approach, where data on climate, soil, and potential crops are integrated into a single index to define the potential of land for growing crops. At a regional level, the 'sieve map' approach has been adopted by several regional authorities. Lancashire County Council (1991) and Highland Regional Council (Bunce & Claridge 1985) have both developed systems for identifying areas of conflict within their regions. On the Continent, this approach has proceeded further, and the use of the information is actually fundamental to the planning process, as described by Schaller and Haber (1988) in Bavaria, and by de Veer and de Waal (1988) in The Netherlands. Elsewhere, the ecological land classification projects in Canada (eg Lopoukhine, Prout & Hirvonen 1978) and in Australia (Austin & Margules 1984) have developed comparable approaches, and show the way in which modern computing power can be used in such integrated systems.

True integration provides the basis for planning purposes, and geographical information systems (GIS) provide the tool to enable such data integration to be automated using powerful new computer systems. There are four primary areas in which GIS can be used:

1. to develop a flexible method of mapping, showing the geographical distribution of required features;
2. to enable overlaying of competing land uses or potential land uses;
3. to allow the testing of policy options and scenarios, through modelling, in order to examine the likely outcomes;
4. to analyse pattern and examine the relationships of spatial features to each other and to other elements in the landscape.

PREVIOUS WORK INVOLVING INTEGRATION OF METHODS

Satellite imagery, aerial photography, and field survey are the principal ways in which land use data can be collected. Satellite imagery has the advantage of synoptic coverage but at a relatively low level of detail. Aerial photography is able to provide more detail at a local level, whereas field survey, whilst expensive and time-consuming, provides detailed information which will allow analysis of species composition. Thus, the first two approaches are primarily powerful for estimating quantities, and the latter for estimating the quality of the features concerned. There is a strong synergistic effect in combining these approaches.

Field survey is used routinely in remote sensing studies as 'ground truthing', but rarely feeds back directly to modify the definitions of land classifications determined from satellite images or aerial photography. It is primarily used for ground checking and validating, as in part of the MLC project. In a similar way, soil survey procedures use aerial photography to help in the mapping of soil units; the OS projects use aerial photography to assist the mapping of urban spread.

Some studies have, however, proceeded to develop further the method of full integration. In a study in south Wales, Haines-Young (1992) showed how terrain information and land classification could improve the accuracy of mapping and estimation of features in the countryside, and how they could be used to detect change. Work on Islay (Bignall, Curtis & Matthews 1988) showed how integration could be used to obtain sophisticated estimates of bird populations and to assess their relationship with the environment and with land cover. However, full integration, whilst possible, has not involved modification of the classes produced by interpretation of satellite imagery, in terms of their more detailed composition.

COUNTRYSIDE SURVEY 1990: AN INTEGRATED APPROACH TO LAND USE DATA COLLECTION

The approach described below has been jointly developed by the authors, in association with other staff in NERC and DoE, and others subcontracted to work with ITE. Other organisations, including the Department of Trade and Industry (DTI), the British National Space Centre (BNSC), and NCC, have contributed funding to current work.

The basis of the approach was developed from an ITE project called Ecological Consequences of Land Use Change (ECOLUC) (Bunce & Heal 1990), and was further described by Griffiths and Wooding (1989a). In that study, satellite imagery was used to obtain the distribution and extent of land cover and landscape features, and the incorporation of ground survey data added detail about their ecological characteristics.

The integrated approach pioneered within the ECOLUC project has been fully developed in the Countryside Survey 1990. Five principles, learned from earlier work, were vital in the planning of the Survey.

1. The methods should be objective and reproducible.
2. It should be possible to link data at a variety of scales, eg quadrats at a one metre square level on the one hand, with satellite imagery showing features at perhaps one kilometre or even 10 km levels.

3. Statistical accuracy of the data, both in space and time, should be quantified and expressed.
4. Land cover definitions should be compared, in order to understand the degree of similarity between different approaches and to ensure that the results of the methods are fully understood, in terms of strengths and limitations.
5. It should be possible to modify the outputs from any one part of the project, by reference to those from other components.

Although the Countryside Survey 1990 project is very much an integrated programme, it is simplest to describe the work under its component parts: field survey; mapping land cover from satellite images; data from other sources; and integration.

Field survey

The field survey element of Countryside Survey 1990 also forms the third in a series of national (GB) sample-based surveys undertaken by ITE, following those of 1977–78 and 1984. In each case, sample units of one km square were drawn from a particular stratification framework, the ITE land classification. With funding from DoE, this system has classified all (approx 250 000) one km squares in GB into 32 environmental strata, termed land classes (Bunce *et al.* 1991); these classes represent an integrated description of the overall environment, and generate a dispersed sample to ensure, as far as possible, that the ecological variability within the country is covered, as well as the principal land cover types. The statistical aspects of this sampling approach are discussed by Brandon *et al.* (1989).

In the 1977–78 survey (Bunce 1979; Bunce & Heal 1984), eight one km squares were visited in each of 32 land classes, giving a sample total of 256. This survey was intended to provide a statement on the ecological resource of the countryside, and included the recording of a number of vegetation quadrats and soil pits at each site. As a secondary activity, land cover was mapped and landscape features were recorded.

In the second survey (Barr *et al.* 1986), the same 256 one km squares were visited and, additionally, four new squares were surveyed in each class, giving a total sample of 384 squares. The main objective of the survey was to provide data on change in land cover and landscape features; no vegetation quadrats were recorded.

In the 1990 survey (Barr 1990), the sample size was increased further, but, having established a statistically viable minimum size in each class, the 124 new squares were allocated to classes in proportion to the overall class fequency in GB. In addition, as part of a separate land use project, 25 one km squares which had been rejected from what is essentially a countryside survey because of their urban character, were surveyed. Thus, the total number of squares visited in 1990 was 533, of which 508 were primarily countryside squares.

In each of the 508 Countryside Survey 1990 squares, two-person survey teams mapped land cover and landscape features throughout the whole square, using OS 1:10 000 base maps. These maps had been updated with information on new and removed boundaries, and with semi-natural vegetation boundaries, interpreted from aerial photographs. Each land cover parcel and landscape feature element was described using a pre-determined list of coded attributes, including details of species and percentage cover, management, and land use. The 313 codes, used in combination, allowed great detail to be attached to each recorded feature. A fuller description of the methods is provided by Barr *et al.* (1985).

The land cover and landscape features were mapped thematically under five headings:

1. physiography – covering the underlying structure of the land and including details of coastal features, rivers, inland cliff, and rock outcrops;
2. agriculture and semi-natural vegetation – to include all agricultural crops, grassland, moorland, and bog;
3. forestry, woodland and trees – including information on species, age, and management;
4. urban, built-up and recreation – including all man-made features in rural and urban areas alike (eg roads, factories, bridges, farmhouses, and recreational facilities);
5. boundaries – including hedges, fences, banks, and walls, together with details of height, management, and species (in the case of hedgerows).

In addition, to provide detailed ecological information (as had been done in the 1977–78 survey when vegetation and soils were recorded in each square), vegetation was recorded in up to 27 quadrats in each square, as follows.

- Five 200 m^2 plots were placed at random throughout the square.
- 1 m x 10 m linear plots were placed along hedgerows (x 2), streamsides (x 5) and roadsides (x 5) (where these features were present).
- A further 1 m x 10 m linear plot was placed at the nearest boundary to each of the five 200 m^2 plots, allowing comparisons to be drawn between 'open' country and linear habitats.
- Five further plots (4 m^2) were located in areas of semi-natural vegetation which was not adequately represented by the large random plots.

Within each quadrat, all species of flowering plants and grasses, and lichens and bryophytes from a restricted list, were recorded, together with a visual estimate of their cover, in 5% classes. The vegetation plots were permanently marked and photographed for relocation.

To complete the above schedule of work in a four-month period between mid-June and mid-October, each square took between two and six days to survey by a trained team of two. All surveyors were selected from ITE staff or were botanists employed for the task. Quality control was rigorous, with a demanding two-week training course for all surveyors, followed by field supervision and frequent mixing of team members. A quality assurance exercise was undertaken whereby a subsample of one km squares was resurveyed.

The mapped land cover data are being converted into computer-readable form (digitised), and all data will be entered into a computer-based GIS allowing automatic calculations of areas, lengths, and numbers of features in the sample squares (Howard & Barr 1991). It will also enable the 1990 maps of the squares to be overlain by those of previous surveys to compute changes. Analyses of the plant data will enable changes to be determined from the records made in 1978, and also detailed comparisons of linear features with the remaining open countryside. In addition, the relationship of boundary features to the surrounding vegetation will be determined.

As described above, the field survey is based on a sample of one km squares. By using the known ITE land classification composition of any major region of GB, it is possible to 'gross up' from mean values obtained from the samples, and to make estimates for any surveyed feature within such regions. Further, the statistical accuracy of these estimates can be expressed. The size of any such errors will depend on a variety of factors, including:

- frequency of field samples within strata;
- distributions of features between strata;
- frequency of strata within region of interest;
- spatial characteristics of features, eg small but widespread (small woods); large but relatively uncommon (conifer plantation).

Typically, the statistical errors for the most widespread land cover types in GB, based on a sample of 508, might be 5%. The smaller the geographical region of interest, or the rarer the feature, then the greater will be the error associated with the estimate. However, by linking the detailed information from the sample squares with land cover data for all one km squares, the usefulness of the field data increases.

MAPPING LAND COVER FROM SATELLITE IMAGES

The land cover of Britain is being mapped from Landsat thematic mapper (TM) images. The work of Griffiths and Wooding (1989b) started to develop and demonstrate the strengths of combining the detailed, sample-based approach of the field survey with a generalised census from satellite mapping. A pilot study (Fuller *et al.* 1989; Fuller & Parsell 1990) showed how combined summer and winter Landsat data could be computer-classified to give accurate maps of land cover.

Landsat's TM records digital numbers, representing the scores for reflected light from 30 m cells on the ground. The spectrum is divided into seven wavebands between the blue and thermal wavelengths. By scanning the landscape from side to side, as the satellite makes forward progress, a full array of reflectance data is collected for a 185 km swath. By means of different orbits, full cover of the earth is obtained every 16 days. The data are supplied as digital tapes, representing 185 km-long sections of a path, called scenes.

The procedure of analysis takes three bands (red, near- and middle-infra-red) of a summer scene (May–July), and, by defining ground control points, geographically registers the data to the British National Grid, using 25 m output cells. The same bands of a winter scene (October–March) are registered to the summer image. Thus, six-band, summer/winter composite scenes result, each with oblique 25 m cells.

An image can be displayed on a visual display unit, using any permutation of three out of the six bands (or a mathematical combination thereof). Each 25 m ground cell is represented as a pixel on the display, so the term 'pixel' is usually used to describe such ground cells in analysis.

Sample areas of different cover types are identified in the field, and outlined interactively on the image analysis system. Where a cover type has several subclasses (for example, wheat, barley and potatoes might be subclasses of arable land), the subclasses are defined separately. From the outlines, the system extracts the pixels in each waveband, and calculates the statistical properties of reflectances for each subclass. A maximum likelihood classifier is then made to allocate each pixel to the nearest subclass (in statistical terms), and subclasses can be aggregated into target classes.

In the project to map all of Britain, 25 cover types are targetted (Figure 1), and are believed to represent a classification which can be provided consistently for the whole of Britain. The classes have been made to correspond to those of other surveys, as far as is possible, and have been agreed after consulting other surveyors and end-users of the maps.

Various knowledge-based correction procedures refine the cover maps. For example, a coastline is drawn and any confusion between maritime and terrestrial cover types is corrected; upland masks are fitted around areas of extensive upland cover, and misclassified pockets of lowland are removed; masks of urban cover types are used to remove erroneous arable patches in towns. A filtering procedure removes any isolated pixels in a 3 x 3 pixel region, on the basis that the most unique pixels are errors of classification, hence noise.

The classification is a hierarchical one, in which users

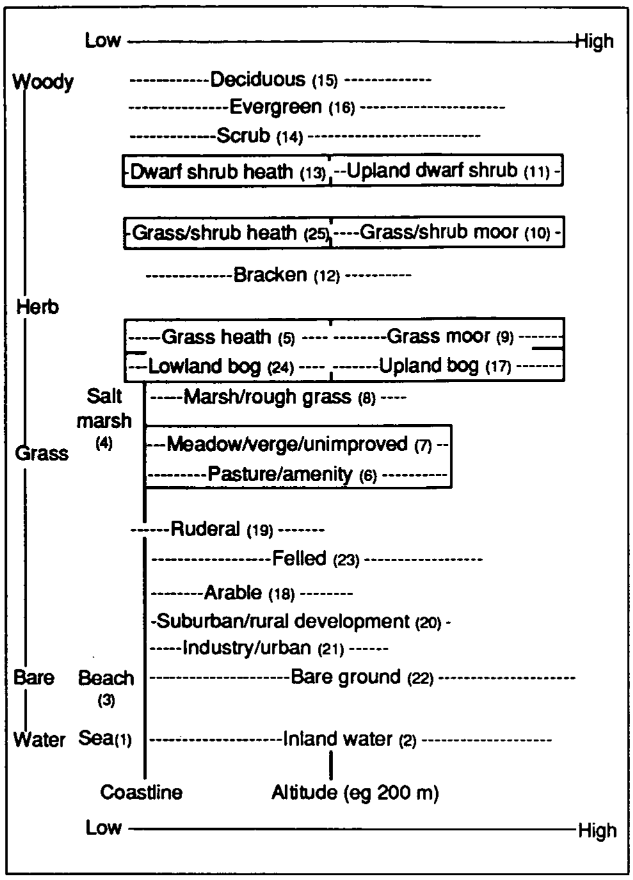

Figure 1. A suggested Landsat classification of Great Britain into land cover classes. Classes which are boxed together are those where spectral separation may be unreliable. In some cases, problems of spectral confusion (eg between beaches and other bare ground) is overcome by knowledge-based correction (eg using digital coastline): in these circumstances, the classes are not boxed. Elsewhere (eg the use of altitude in separating 'lowland grass heath' from 'grass moors') the dividing line is less clear and could present difficulties, at least outside of a GIS environment, so the classes are boxed together

can combine cover types to simplify the classification. Some users may, for example, only want to distinguish between vegetated and bare surfaces. A more simple aggregation might amalgamate the upland and lowland variants of targetted grasslands, and so users can make their own definitions based on altitude, or perhaps an ITE land class. The more detailed subclass data also remain available for specialist consultation, though consistency of subclass interpretation cannot be guaranteed.

Two levels of accuracy assessment are made. First, the cover maps are scored, field-by-field, against a sample of cover data. For 5720 land parcels, results so far show that 85% were correctly identified by the classification. However, the field sample, which was selected to identify unusual features, was not representative of the whole, and the result under-represents the accuracy associated with more common features. A more rigorous procedure will compare the Landsat maps with digitised cover data from the 533 field survey squares. Comparisons will be made pixel-by-pixel, with separate assessments for boundary pixels: summary information at the one km level will also be compared.

The final maps will be available at full 25 m resolution and summarised as one km data. At either level, they can be integrated with the field survey information and the 32 land classes. At one km resolution, there is the obvious potential to examine squares by land class and by cover type. The Landsat map data (corrected for systematic error) will give revised mean cover values for the full population of squares in each land class. It will be possible to use the cover maps to provide information for local and regional studies, where a study population of one km squares may differ from the average.

Data from other sources

Directly associated with Countryside Survey 1990, and the field survey in particular, are surveys of freshwater biota and of soils. Samples of freshwater biota have been collected from each of the ITE field sample one km squares (where present): those from running waters as part of a larger project of the Institute of Freshwater Ecology (Wright *et al.* 1989), and those from static water as part of collaborative work with the University of Newcastle (Luff *et al.* 1992). Integrating data on the occurrence of freshwater animals and plants, and relating these to local land use and environmental factors, will provide useful indices of pollution, especially in the context of eutrophication and acidification.

Soil surveys of the ITE sites are being undertaken by the Soil Survey and Land Research Centre (SSLRC) and by the Macaulay Land Use Research Institute (MLURI). In due course, data and outputs from a wide range of studies which relate to land use change, and which may be geographically referenced or linked to specific habitats, can be integrated into the system. Work being carried out in other NERC Institutes, such as the Institute of Hydrology and the British Geological Survey, which relates to land use issues, can also be integrated in this way.

There is interest among socio-economists in collaborative work to find out more about the reasons underlying land use change. It is hoped that work in the ITE field survey squares by Warnock and Bell (1987) and Potter and Gasson (1988) will be further developed, so that the causes and consequences of land use change may be better understood.

Because Countryside Survey 1990 operates at the one km scale, many other data may be integrated through the use of the ITE land classification. The benefits of these links are becoming apparent in a project being carried out by ITE to develop a countryside information system, which operates at the one km square level, and is designed to provide an integrated package of land use information on any one geographical area, for countryside planning and management purposes.

Integration

As part of the principal integration programme, land cover maps of Great Britain will be enhanced by use of field data, through the ITE land classification system. The 25 land cover categories derived from satellite imagery can be broken down by the detailed composition of species from the ground survey samples. For example, coniferous woodland, as defined by the classification of satellite data, can be broken down into its more detailed species composition of pine *(Pinus)*, spruce *(Picea)*, larch *(Larix)* and other species, on a probabilistic basis, from field survey data. In addition, the power of the satellite imagery to display distributions throughout the country will enable categories of the satellite image to be modified by the composition of the field survey squares.

Thus, the cover maps can only give direct information on those cover types which were mapped, but they can give indirect information on other features. For example, the cover of unimproved grassland is not available from the Landsat maps. However, the area of unimproved grassland is clearly related to total grassland cover, and the proportion will have been estimated, by land class, in the field survey. Hence, the Landsat maps can identify the grass cover in a study area, and the land classes can estimate the proportion which is unimproved. The resulting prediction will be much more accurate than would be the case if the user assumed all squares of a land class were identical. The map data can also be used at full resolution; for example, the cover map could show the grassland patterns at a 25 m grid, with probability weightings for unimproved grass cover.

Even the estimates for point and linear features, or plant species distributions, can be improved using the cover map. If the number of ponds, say, is proportionate to the cover of grassland, field-based estimates and Landsat cover can be used to predict pond distribution and density. The number of oak *(Quercus)* trees will relate to the area of woodland and to the land classes of an area; hence, their distribution and density could be estimated. By using other data, such as soil maps, it is possible to further refine estimates, eg of fenland or chalk grassland species. Integration with, say, climatic data would allow development of models which relate cover, land class, species, and climate, and thence the prediction of changes in the event of climate change. A variety of applications is already under development (see later section).

There will be three principal outputs from the integrated approach:

1. the 'stock' of the major land cover categories for every one km square in GB and, from the field survey, estimates of the detailed ecological characteristics of each cover type within each square;
2. by reference to earlier survey data (ITE: 1977–78, 1984; and MLC: 1940, 1970 and 1980), summaries of changes which have taken place over the last three decades, by geographical regions (as far as differences in definitions will allow);
3. a data base, to be used as a definitive statement on the countryside in 1990, with known levels of accuracy and extent, as a baseline for future monitoring.

FUTURE WORK

Countryside Survey 1990 is largely a data collection, integration and comparison project. There is now a need to realise the potential of the investment made, and to initiate further research. Future work might involve the following principal activities.

- Interpretation of the basic information derived from the statistical analyses of the data described above. This will include pattern analysis of spatial features and their relationship with detailed species composition, and an understanding of the processes and structure of changes in the countryside.
- The development of a knowledge-based information system to store the data and enable them to be accessed readily by policy advisers. This work has already proceeded within the Ecological Consequences of Land Use Change project, and has been shown to have considerable potential for further development. In the prototype information system, the characteristics of the land classes and the associated land use and land cover features for which census data were available, together with other predictions described above, were made available within a single computer model. The system is compatible with various other models predicting changes, and any data which are held by one km square can be incorporated. A wide variety of other data, eg on the changes in moth populations or from the MLC project, can be incorporated into this common framework. As it is held within the land classification system on an OS grid, further data can be readily incorporated.
- Further data flows are also involved, eg soils, socio-economics, freshwaters, hydrology, geology, archaeology and phytosociology. It is planned to incorporate these data sets using the same process of integration as described above, in order to demonstrate the interactions between them. For example, archaeological remains can be strongly threatened by changes in land practice.
- The potential for modelling, both in the static and dynamic sense, is considerable. A variety of modelling approaches have been adopted in the past. For example, the land availability study for wood energy plantations (Bunce, Pearce & Mitchell 1981) showed how forestry for energy purposes could be developed in Britain, by overlaying the potential of forestry on to the basic land cover maps. At a more local level, other models have been developed; for example, Maxwell, Sibbald and Eadie (1979) examine the potential for integrating farming and forestry. Smith and Budd (1982) provide an example of a

complicated linear programming model, developed to examine forestry and farming strategies in the Sedbergh district of Cumbria. Other comparable studies have been carried out by Dane, Meadow and White (1977) and Miron (1976). Apart from the models described above, other techniques such as checklists, matrices, networks, and flow diagrams have been widely used to formalise intuitive assessments of future change.

- More recently, models are being developed to formalise the changes taking place in the countryside, and to quantify them, as in the Reading model (Harvey *et al.* 1986) where the consequences of changes in the Common Agricultural Policy have been modelled in terms of agriculture, socio-economics, and ecology.
- Landscape design and habitat creation are necessary measures to repair past damage to the rural environment. The development of interactive systems based on computer landscapes is becoming readily available. In this way, the average landscapes determined by the Survey can be used as a standard against which observed landscapes in development control areas can be tested and compared. In addition, modern interactive methods enable new features to be drawn on to existing landscapes by use of screen technology.
- Ideas are now being developed towards setting environmental quality objectives for land (Peters 1992). The results from Countryside Survey 1990 provide an objective description of the land surface, against which required and desired prescriptions can be measured. They provide a well-described starting point for the planning process.
- The ability to use the above framework as a way of assessing policy options in the landscape, eg support for maintenance of heather *(Calluna vulgaris)* or for tree planting, is readily available.

Immediate uses of Countryside Survey 1990 data, some of which have already been initiated, are:

Estimation of animal populations
Animal range and habitat evaluation
Island biogeography studies
Ecological change detection
Landscape management planning
Environmental impact assessments
Water quality modelling
Critical loads mapping
Hazard impact assessment
Carbon budget assessment
Predicting impacts of climate change
Potential for alternative energy

CONCLUSIONS

The scientific study of the interactions of land uses, with each other and with other factors, is a relatively new research area (although individual elements have been studied for many years). An essential pre-requisite to such studies is the availability of reliable, representative, current, and accessible land use data. While the relative advantages of field survey, aerial photography and satellite imagery, as sources of such data, have been recognised and debated for a long time, the current trend is towards an integrated approach.

The work by ITE and others, exemplified in Countryside Survey 1990, is designed to optimise between (i) producing a genuine scientific understanding of the processes involved in interaction between land use change and its environment, and (ii) providing a basis for policy-making, as described in the introduction.

Countryside Survey 1990 is the first project of its type, where national land use data sets, from different sources, have been collected at the same time, in a planned and integrated way. The strengths of both remote sensing and field survey have been combined in an integrated system, specifically designed to provide information on land use change. The data are being collected according to a common format, but can be expressed at a variety of scales and can be linked to other data sets. The outputs provide more extensive and comprehensive information than would be practicable using any single method. The approach can be used for regular monitoring of the land, to provide both quantitative and qualitative information.

The ITE approach allows a full comparison of actual and potential land uses (using data which can be regularly updated), and will provide a fundamental understanding of the causes and consequences of land use change.

ACKNOWLEDGEMENTS

Countryside Survey 1990 was funded by the British National Space Centre, Department of the Environment, Department of Trade and Industry, Natural Environment Research Council, and (former) Nature Conservancy Council.

The authors would like to take this opportunity to acknowledge the support and encouragement given to land use integration studies by staff within the funding organisations, and especially to thank Mr John Peters (DoE) who was largely instrumental in setting up the Countryside Survey 1990 project.

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