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Plate 1. The Countryside Surveys have recorded both length and botanical composition of hedgerows using standard procedures. The results show a progressive decline in length, which is matched by a loss of plant species in pastural landscapes between 1978 and 1990

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Land use and vegetation change

Land use research has grown in importance in parallel with intensification of agriculture and pressure on habitats. There has also been a progressive increase in policy interest in land use change reflecting public concern. This paper describes how ITE have developed the application of objective methods of sampling, combined with quantitative analysis, in order to provide the basis for independent estimates of stock and change. Table 1 shows examples of these surveys and how they have been applied in the policy arena.

In 1968 the Research Branch of the former Nature Conservancy (NC) was organised on the basis of habitats. The woodland sections at Merlewood and Monks Wood were responsible for fundamental research and advice to the Conservation Branch on site selection for conservation designation. Following a habitat team meeting at Merlewood, after the appointment of John Jeffers as Director in 1968, it was decided that a National Woodland Classification was required primarily to provide an objective system for the selection of representative sites.

At that time, data were being collected from woodland sites as part of the *Nature Conservation Review,* using cards with a list of 136 plant and tree species from throughout GB. It was decided to use the 2 500 woodlands available from this survey, cartographically defined, as the base data to select sites. Association Analysis (Williams & Lambert 1959) was used in 1970 to produce 103 groups using a standard stopping rule, following a pilot project in 1969 in the Lake District. A representative site was selected from each group using an objective procedure. Therefore, during 1971, a total of 103 woods were surveyed throughout GB, as well as 34 Native Pinewoods in Scotland, using a standard procedure of vegetation survey (Bunce & Shaw 1973). Although this survey was solely concerned with woodlands, the structure of the project provided the basis for future land use research at ITE. In addition, it provided the stimulus for developing a new set of vegetation classification algorithms because, although Association Analysis

Table 1. Examples of policy applications of national and regional surveys between 1968 and 1998

1970–1972	Nature Conservancy (National Woodlands Survey)	Advice on woodland site selection
1970–1978	Nature Conservancy Council (Native Pinewoods Survey)	Advice on conservation of Native Pinewoods
1975–1978	Cumbria County Council (Cumbria Survey)	Contribution to Structure Plan
1978–1985	Energy Technology Support Unit (Ecological Survey of Great Britain)	Potential contribution of wood for biofuels
1984–1997	Department of the Environment (ITE National Land Use Survey /Countryside Survey 1990)	Estimates of hedgerow loss (incl. Rural White Paper and Hedgerow Protection Bill)
1985–1989	Bristol University – Zoology Department (Survey of badgers using the Land Classification)	Estimate of badger numbers (Badger Protection Bill)
1986–present	Ministry of Agriculture, Fisheries and Food/Department of the Environment (now DETR) (Land Use Allocation Model)	Implications of agricultural policy scenarios
1987–present	Ministry of Agriculture, Fisheries and Food (ITE survey of Chernobyl fallout)	Restrictions on human consumption of sheep meat
1987–1991	Highland Regional Council (HRC) (HRC Rural Land Use Information System)	Areas of land use and land cover in the Region
1987–present	Department of the Environment (now DETR) (Countryside Information System)	Accessible information on the British countryside
1990–present	Department of the Environment, Transport and the Regions (DETR)/Scottish Office, Agriculture, Environment and Fisheries Dept (SOAEFD) (Countryside Survey 1990 and Countryside Survey 2000)	Contribution to British obligations under the Rio Convention, Agenda 21 and the UK Convention on biological diversity
1998	European Environment Agency (Models for Integrated Review and Assessment of Biodiversity in European landscapes)	State of the Environment Report

had proved to be a useful technique, it had a high mis-classification rate Mark Hill (ITE) was, therefore, consulted about the improvement of this method as he had become interested in an ordination technique now known as correspondence analysis (previously called reciprocal averaging)

For a multivariate method to be applicable to the analysis of extensive survey data, the crucial requirement is that the computation should not increase excessively in magnitude when the size of the dataset is enlarged Most methods available in the early 1970s had computational requirements rising as the square of the number of plots or even faster Moreover, they were wasteful of computer memory ITE developed an algorithm for correspondence analysis that rises only linearly in proportion to the size of dataset This was the key technical breakthrough, leading to efficient computer programs for ordination (Hill 1973) and classification (Hill *et al* 1975) The programs were subsequently developed into DECORANA (Hill 1979a) and TWINSPAN (Hill 1979b) These programs have now been used widely for vegetation analysis throughout the world

The results from the National Woodlands Survey were published by ITE in various documents (eg Bunce 1982) and provided the first national classification of a vegetation resource based on stratified random sampling and statistical analysis The initial Association Analysis results were used to assess the nature conservation significance of woodland sites Following the split of NC and the setting up of ITE, the new Chief Scientist's team did not adopt the site classification In Scotland, however, the classification of Native Pinewoods set the conservation agenda following a successful symposium in 1975 (Bunce & Jeffers 1977) The rigorous approach both to sampling and data analysis in the woodlands project formed the basis of the approach developed for land use studies and epitomised the divergence between ITE and the Nature Conservancy Council (NCC) following their separation

In later work, the concept of a woodland site – and subsequently a 1 km square – comprising of mixtures of vegetation sampled at random, proved important and contrasted with most vegetation surveys that have used individual species records within selected areas of vegetation The work on the woodland classification showed the power of the new multivariate techniques to analyse large vegetation data sets, which was to increase as computer technology developed A series of small projects were carried out to assess the application of such methods to environmental data at the 1 km square landscape scale (Bunce, *et al* 1975) Ecological data were collected to test the validity of the land classifications produced However, it was soon realised that they could also be used to stratify samples in order to obtain resource estimates Ecological parameters such as vegetation composition or soil character are related to underlying environmental factors, such as climate and altitude (ie the model is based on regression theory) The difference in the present approach from traditional methods is that the relationships are formalised through statistical analysis

The first major project to test the methodology of land classification and resource accounting was the Cumbria Survey (Bunce & Smith 1978) which was a joint project between ITE, Cumbria County Council and the National Park Special Planning Board A classification was constructed by applying TWINSPAN to environmental data from 1 km squares such as altitude and geology Sixteen classes were constructed for Cumbria and some 7 000 1 km squares were classified The sampling of resources within the squares drew upon the woodland work, in that samples were taken from complex elements, thus allowing the variability within and between sites to be quantified To this end, both the squares themselves, and the position of the vegetation sampling points were selected at random The correlation between the observed vegetation and underlying environment was highly significant with r = 0 75, confirming the validity of the approach The results were used in various planning exercises such as the zonation of nature conservation in the county In addition, linear programming was used to assess policy scenarios for the first time

Although the Cumbria classification was not published until 1978, the then Director of ITE, Martin Holdgate, saw the potential of a national classification and this led to his decision to set up the Ecological Survey of GB in 1975 This coincided with the increased policy interest in land use change and culminated in the formation of the Land Use Section at Merlewood The main objectives were to provide a framework for environmental/ecological monitoring and to provide a computer system for access to the data

The ITE Land Classification produced for this project defined 32 land classes derived from TWINSPAN analysis of environmental attributes from a grid sample of 1212 x 1 km squares This classification was subsequently extended in 1990 to all 234 000 km squares in GB (Bunce, Barr *et al* 1996) The first field survey was carried out in 1978, with John Jeffers and Fred Last providing management support Eleven sample plots were placed in each 1 km square, five at random and six along linear features In addition, soil pits were dug, and the profiles of the soils described, under the guidance of Mike Hornung (ITE) Furthermore, for the first time, the land cover was mapped in the individual 1 km squares, with 79 categories of semi-natural vegetation being recognised

High correlations were shown between the underlying classification and land use (r = 0 82) and as well as

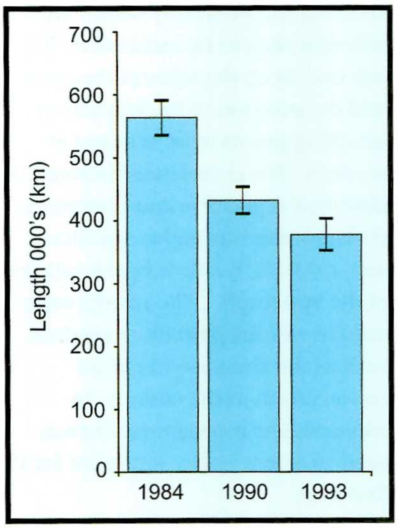

Figure 1. Estimates of length of hedgerows in England and Wales between 1984, 1990 and 1993 (with standard errors) which shows a continuing decline

soils (r = 0.92). The areas of crops and grass also agreed with independent data from the Ministry of Agriculture's agricultural census. The areal extent of the 79 land cover categories also provided, for the first time, complete national estimates for semi-natural vegetation in GB. The Land Classification was also used for other research projects, for example, to estimate badger populations and to assess the representativeness of the Common Bird Census.

In 1984, stimulated by the widely reported losses of many habitats, a further survey was carried out increasing the sample number from 256 to 384 with mainly landscape features being recorded. The results from the 1984 survey showed that there had been a 28 000 km loss of hedgerows since 1978 and provided the basis for more accurate estimates of stock and change in 1990 and 1993 as shown in Figure 1. In addition, other estimates of change were produced that had not previously been available, (eg for new agricultural buildings).

The work was originally funded by the Natural Environment Research Council (NERC), but in 1986 the Department of the Environment (DOE) became interested in the changes of quality that might be taking place within habitats. The vegetation data collected in 1978 provided a unique source of information to measure such changes in quality. John Peters (DOE) and Bill Heal (ITE) therefore instigated the ECOLUC project (Ecological Consequences Of Land Use Change (Bunce *et al.* 1993)) with the following major objectives:

- to examine the ways in which change could be estimated
- to assess the potential of satellite imagery in producing national maps of land cover
- to examine the potential of expert systems as tools for applying ITE's developing information base.

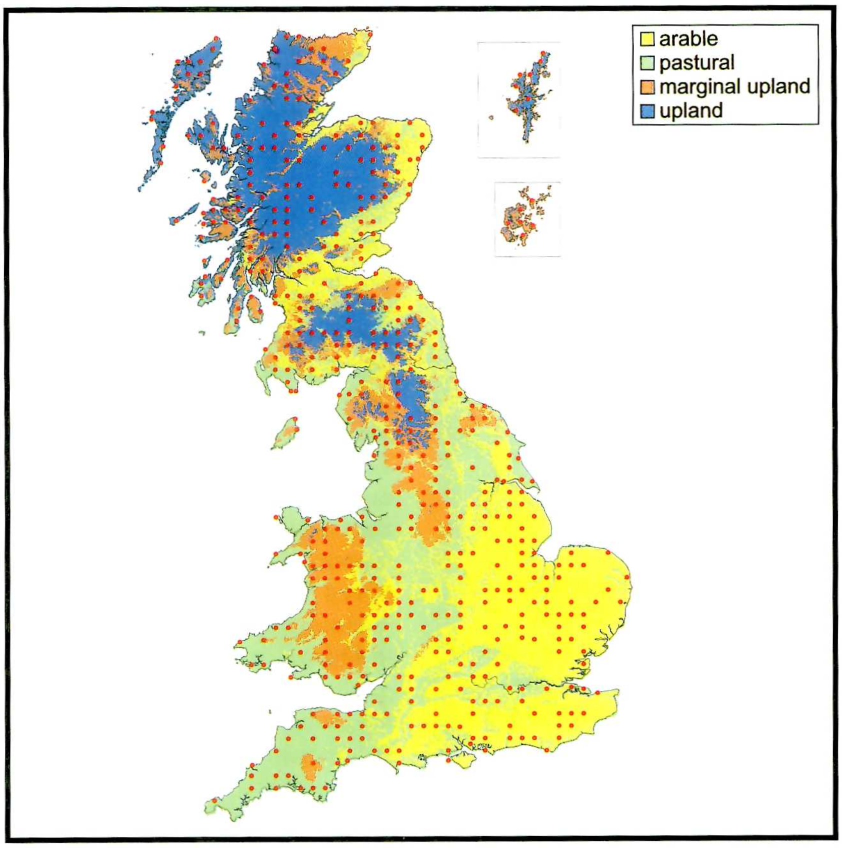

Figure 2. Distribution of the 1 km squares in the four landscape types together with the 1 km squares surveyed in 1990. Arable landscape: land classes 2, 3, 4, 9, 11, 12, 14, 25 and 26; pastural landscape: land classes 1, 5, 6, 7, 8, 10, 13, 15, 16 and 27; marginal upland landscape: land classes 17, 18, 19, 20, 28 and 31; upland landscape: land classes 21, 22, 23, 24, 29, 30 and 32. The derivation of the land classes is described by Bunce *et al.* 1996. The landscapes are used for summarising the results of changes in land cover and land use and for structuring the analysis of changes in species and vegetation

It was concluded that the Land Classification provided the best way of coordinating the disparate ecological information across GB, and that it could be used to integrate surveys of other species groups (eg freshwater invertebrates and moths). It was also shown that the re-recording of the vegetation plots could be used to identify statistically significant change. Much of the botanical variation was found to reside in linear features especially in lowland landscapes, a conclusion that had important policy implications. It was also demonstrated that satellite imagery could produce land cover maps across large areas, as shown by the mapping of heather in England and Wales. However, expert systems were not sufficiently advanced to inform policy decisions. Instead, a pilot information system, based on a project in the Highland Region of Scotland, led to the production of the Countryside Information System for the dissemination of information at the 1 km square scale, from ITE, and from other relevant data sources (Haines-

Young *et al.* 1994). This system of spatially referenced data was marketed in 1994 and has become an important means of delivery of environmental information.

The field survey data were appropriate for modelling land use options. One of the first examples started in 1981 to identify the potential for growing wood energy plantations in GB. Maps of the land cover categories from ITE surveys were annotated with financial returns for forestry and agriculture, in order to compare relative performance using a sieve-mapping technique. This technique has been widely applied and is currently being further developed.

ITE also became involved with the development of the Land Use Allocation Model (LUAM), in cooperation with the Centre for Agricultural Strategy at Reading University. This model is based on the structure of the Land Classification and, although primarily directed towards testing the agricultural implications of policy scenarios, it has the potential for being extended into the environmental policy arena. The integration of agriculture and ecological data provides a powerful basis for modelling, which is currently being developed by ITE on the basis of species/landscape relationships.

Following the successful conclusion of the ECOLUC project, it was decided to proceed with the Countryside Survey 1990 (CS1990). This was a joint programme of work between ITE and the DOE with some assistance from the NCC. The number of 1 km squares was increased from 384 to 508 and all the plots surveyed in 1978 were repeated (Figure 2). In addition, further plots were placed along linear features with five additional habitat plots being placed in areas that were considered of nature conservation interest. Although aerial extent of the habitat plots cannot be estimated, they provide a description of additional botanical variation in the landscape.

The results from CS1990 were reported in Barr *et al.* (1993) and showed that the major losses of habitats had slowed, with the exception of hedgerows where a 22% decline was reported. However, the most striking results concerned the general loss of species in many classes of vegetation, as shown in Figure 3. For example, infertile grassland lost up to 20% of species between 1978 and 1990. Of the 65 comparisons in the separate plot types that could be made with adequate sample replication, only eight increased in diversity, whereas 18 declined. CS1990 posed many questions about the causes of landscape change and whether a loss of habitat quality was also involved. A new project called ECOFACT (Ecological Factors controlling biodiversity in the British landscape) was, therefore, set up jointly between DOE; Ministry of Agriculture, Fisheries and Food; Scottish Office of Agriculture, Environment and Fisheries Department; and ITE. The objectives were to extend the analysis of change, to examine the associated causes, to assess pattern in the landscape and to prepare for a possible re-survey.

An important new tool produced in this work was a new single vegetation classification for GB constructed from all the vegetation data available. The results from this classification will be published as *The Countryside Vegetation System* (CVS) (Bunce *et al. in press*). This used a standard stopping rule to group the 100 vegetation classes statistically into eight aggregate classes (Figure 4). The individual classes have subsequently been described in terms of a range of characteristics including soil types, species number and species composition. This classification will be used as the framework for changes in habitat quality. Access to the classification algorithm will be available on the World Wide Web.

This classification has been used to assess botanical diversity at the landscape level. The vegetation in the lowlands is mainly in highly-managed habitats or in linear features and small fragments, whereas in the uplands the vegetation is mainly semi-natural and extensive. Linear habitats make a major contribution to diversity in all landscapes. In lowland landscapes, small patches of semi-natural habitats contain the highest diversity of CVS classes as well as species. This data base will be important in assessing change and will inform policies for the maintenance of botanical diversity at the landscape scale.

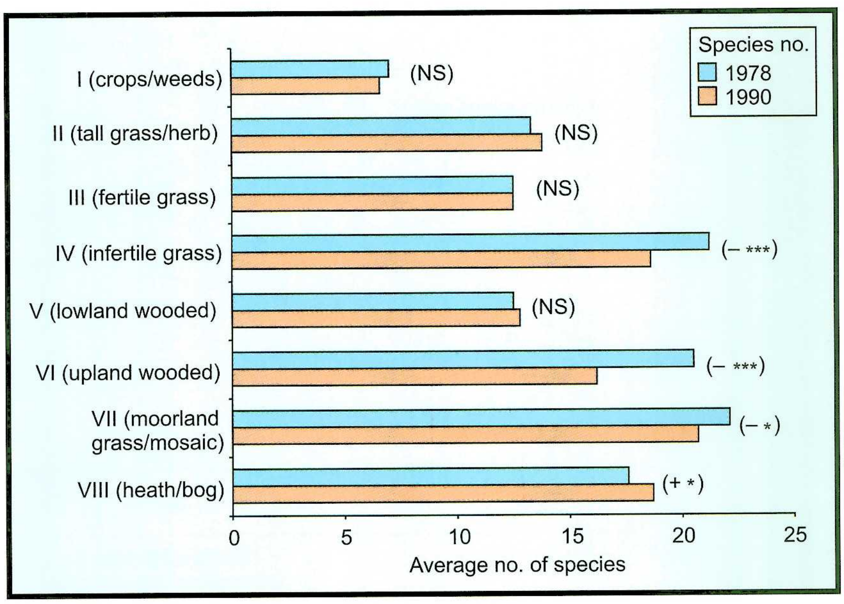

Figure 3. Change in plant diversity within the eight aggregate classes of the Countryside Vegetation System. * = P <0.1; ** = P <0.01; *** = P <0.001; NS = not significant.
The graph shows that botanical diversity declined in the aggregate vegetation classes for infertile grasslands, upland wood and moorland grass/mosaic, but increased in heath/bog. Crops/weeds lost species significantly in arable landscapes only

Plate 2. ITE statistician Tim Sparks with the author Bill Bryson, discussing the ancient hedge at ITE Monks Wood (in the background) which was established to mark the manoral boundary in Norman times

Previous analyses of botanical data have relied upon ecological interpretation for the assessment of the relationships between the principle gradients and environmental factors. Now, however, statistical analysis has shown that the vegetation gradients are highly correlated with environment, the primary gradient with fertility (r = 0.98), the secondary with shade (r = 0.61) and the third with soil wetness (r = 0.82). Shifts between vegetation classes from 1978 to 1990 can, therefore, be interpreted in terms of environmental change. The dominant trend has been shown to be eutrophication, due to a complex of inter-related factors, including aerial deposition of nitrogen, fertiliser and slurry application. Nitrogen was shown to be especially important in neutral grassland systems in reducing plant diversity. By contrast in upland wooded vegetation, the shading effect of increasing conifer canopy was the main cause of species loss.

More subtle changes in vegetation can also affect quality, as considered by the conservation agencies. For example, common assemblages of plant species often form important food resources for many animals. Changes in the distribution and abundance of the groups of these species can, therefore, have consequential impacts on faunal populations. Analyses carried out in the ECOFACT project have explored correlations between the status of a number of butterfly, bird and bumblebee species and their foodplants. The results suggest that the reduction in the food resource, as shown by the 1978 and 1990 vegetation data, may have been an important factor in the recorded decline of these animals.

Following preparatory work in ECOFACT and a scoping study carried out for the Department of the Environment, Transport and the Regions (DETR), it was decided to proceed with Countryside Survey 2000 (CS2000). Field work for this project is currently underway and will be

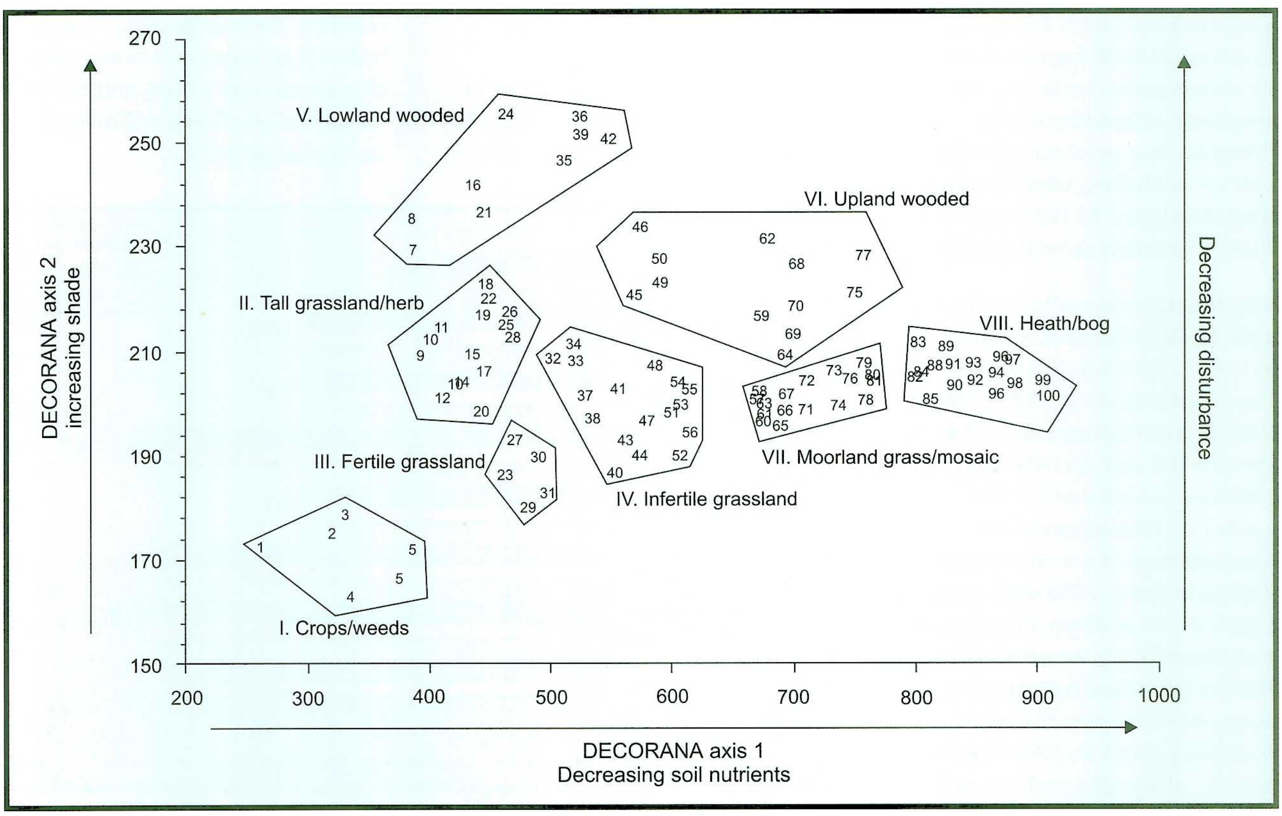

Figure 4. Distribution of the 100 vegetation classes grouped by the eight aggregate classes on the first two axes of the DECORANA ordination. This figure shows that the primary vegetation gradient is correlated with an environmental trend from fertile to infertile soils and the secondary with light and indirectly, disturbance. This graph will be used to show the trajectory of change in vegetation from 1978 to 1990 and 1998

reporting in 2000 The survey will provide a major overview of the habitats, plants, landscape features and land types throughout GB It will provide important information on the current state of the countryside and indicators of the changes that are happening there The survey has two main components

- a field survey of broad habitats, land cover, vegetation, freshwater habitats and linear features including hedges and walls, at over 500 randomly located 1 km squares
- a map and database derived from satellite images showing land cover on a field by field basis across the whole country

The analytical procedures to be used will be those developed in ECOFACT It is intended that further work will be taking place after 2000 to exploit fully the data base for a variety of objectives (eg in assessing the environmental impacts of global warming and detecting the impacts of land use change on biodiversity) The adoption of the Broad Habitats of the UK Biodiversity Steering Group will enable DETR to monitor progress in meeting obligations under the Rio Convention on Biological Diversity New data on the number of woody species in hedgerows will also help to assess the resource of ancient hedgerows (Plate 2) For the first time, reporting will be possible for the whole of the UK, as results from the Northern Ireland Countryside Survey (NICS) will also be coincident with the Broad Habitat categories

ITE's approach to monitoring ecological resources using repeated samples of land, stratified on the basis of environmental variables, will prove increasingly powerful It has now been adopted in several countries (eg Spain, Germany and Austria) and is being developed elsewhere An environmental land classification has now been produced for Europe (Bunce, Watkins *et al* 1996) and has been used to identify ecological regions across the continent These have provided the basis for an ITE-led assessment of pressures on biodiversity, which is being used in the 1998 State of the Environment report by the European Environment Agency A proposal for a European network of land use, land cover and biodiversity monitoring is also under development (EUROLUS), namely *"An integrated monitoring system for strategic assessment of land use, landscape and biodiversity across Europe"*

Countryside Survey now plays a major role in rural policy development, and provides the standard against which new policies can be set It also provides a uniquely rich database for theoretical research and development Whilst ITE has moved a long way from the National Woodland Survey in 1971, that beginning has not been forgotten A pilot for the repeat of this survey has taken place and has confirmed that it provides a valuable baseline for the detection of change in woodland vegetation

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The ITE Countryside Survey now plays a major role in auditing the environmental benefits of land use policies in the UK.