Table 3. Results of inverted gaussian modelling

	Plot 0	Plot 50	Plot 200
Shoulder reflectance	65.94	69.32	70.74
Reflectance minimum	4.39	2.80	3.03
Wavelength minimum	686.66	687.31	687.48
Sigma	26.18	26.79	27.16
Inflection wavelength	712.84	714.11	714.64

edge with a minimum of parameters (Bonham-Carter 1988). The results of processing PMI spatial mode data, after radiometric calibration, are presented in Table 3 and Figure 14.

The model demonstrates conclusively the effect of increasing levels of nitrogen on NrIR reflectance. The height of the NrIR plateau (shoulder reflectance) increases progressively with increasing nitrogen. The inflection wavelength, which marks the position of the red edge, shows a slight increase in wavelength with increased application of N. There was no significant shift in the position of the chlorophyll absorption maximum.

display internal variability, especially early in the season when growth is at its most vigorous. Fertiliser is applied in early April, and there is a time lag before the vegetation shows evidence of nutrient uptake. Because of operational circumstances, the campaign was completed before the end of April. It is possible that this timing was too soon after the application of N for the effects to be fully apparent, and that the differences detected by analysis of the PMI data may represent conservative estimates of what might be achieved, given optimal conditions.

B K Wyatt and A R Jones

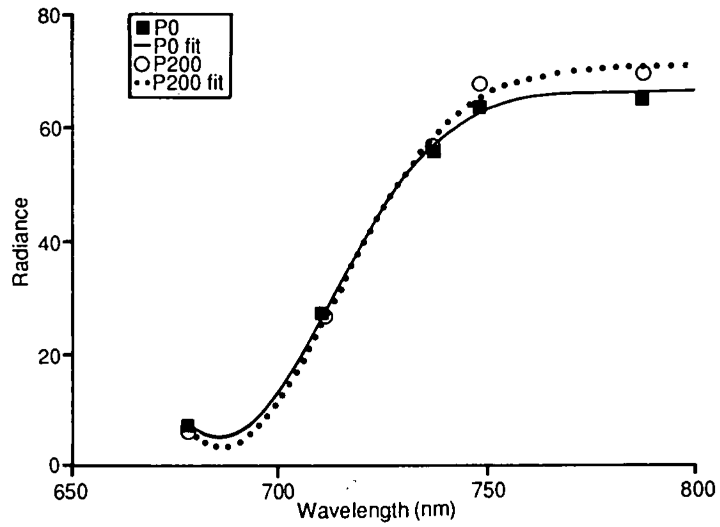

Figure 14. Inverted gaussian curve fitting for PMI spatial mode data

Discussion

Analyses of PMI data in both spatial and spectral mode data reveal similar trends. In either case, individual treatments can be differentiated both in the green spectral region and within the red/NrIR plateau. Modelling the red edge suggests a slight blue shift of the N0 response with respect to that of the N200 of approximately 2 nm. Results of similar experiments on vegetation, in particular coniferous forests, indicate that a 5 nm shift is significant for determining physiological stress. A comparable wavelength shift for the red edge had been expected in this study. Although the experiment has been running for several years, individual treatments still

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Ecological consequences of land use change (ECOLUC)

(This work was funded by the Department of the Environment)

The composition of the lowlands and uplands of Britain has changed dramatically since the war, in response to economic, social and environmental pressures. The distinction must be made between land cover and the use to which the land is put. Land cover defines the type of vegetation, including the crop and the associated habitats which result from management practices within a land use, and harbours the variety of plant and animal species which constitute the visual landscape. Land use defines the main type of management, eg arable or forest. When land use changes, there is a very obvious change in land cover, but land cover can be significantly modified by small changes in management, eg decreased fertiliser use, grazing intensity, or time of cropping. Such small changes are not represented in land use statistics. For land use change, agricultural statistics reveal complicated shifts in the balance of areas of land under different crops. Forestry statistics show an expansion of conifers in the uplands and the conversion of broadleaved woods in the lowlands. Neither set of data contain the ecological information necessary to identify and quantify the consequences for wildlife of such changes in land use. It was for this reason that the Department of Environment (DOE) established the ECOLUC project.

ECOLUC has been a wide-ranging and exploratory research programme, designed to identify recent and likely future trends in land use, and to quantify the ecological changes that would result from alterations in land management. Much of the information available was fragmented, based on local studies, or, as with national coverage, it related to individual habitats or species. ITE was required to encourage communication and collaboration between various disciplines and research groups, and to recommend techniques for improving the measurement and assessment of change, including both traditional ground survey methods and remote sensing.

At the outset it was recognised that the ITE land classification system and its associated national ecological data bases at Merlewood would form a central element of the programme. However, the wide remit set by DOE was designed to ensure the involvement of appropriate expertise, not only from within NERC – from ITE, the Institute of Freshwater Ecology, and the Unit of Comparative Plant Ecology (UCPE) – but also from many Universities and organisations. The breadth of the involvement is reflected in the 13 major subcontracts of ECOLUC, in addition to the separate DOE contract placed directly with the National Remote Sensing Centre which made a key contribution to the programme.

Change in land use and cover

From the 1940s through the 1960s, the major trend in agricultural land use was the extension of arable farming, at the expense of grassland and moorland (Plate 6). Concurrent with the change in crop/vegetation cover was the loss of hedges in the lowlands and the increase of fences in the uplands. The balance between arable and grassland was consistent over the late 1970s and early 1980s, although the areas of oilseed rape and wheat increased significantly, while that of barley decreased. The major change in the uplands has been caused by afforestation: the forest cover of 8.6% of the land area of GB in 1977 expanded by about 22 000 ha per year between 1975 and 1985.

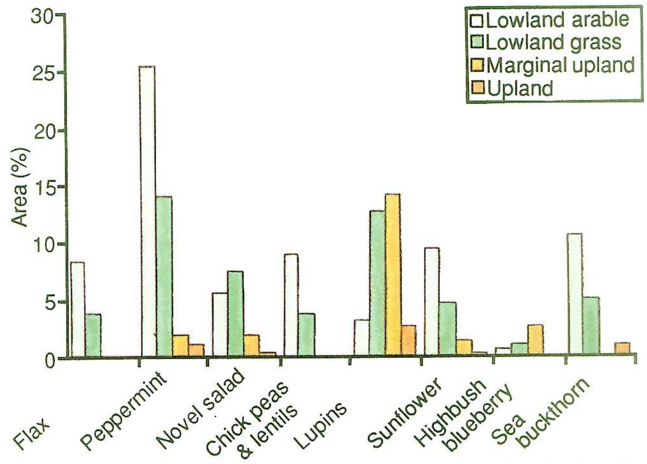

Figure 15. A comparison between four scenarios of change in the countryside, carried out by Lawrence Gould (Consultants). The analysis was caried out on eight 1 km squares from each of the 32 land classes, grouped according to the following sequence:
Land classes dominated by arable land in the lowlands (2,3,4,9,11,12,14,25,26)
Land classes dominated by lowland grasslands (1,5,6,7,8,10,13,15,16,27)
Land classes in marginal areas (17,18,19,20,28,31)
Land classes in the uplands (21,22,23,24,29,30,32)

*Plate 6. Abandoned farm machinery at Diabeg, Highland Region. National trends can mask regional patterns. Within ECOLUC, the national trend is for agricultural intensification leading to the loss of native vegetation. However, locally, as in this photograph in NW Scotland, a decline in the traditional management of hay meadows can lead to colonisation by bracken (*Pteridium aquilinum*) and shrub species, such as willow (*Salix spp.*)*

The basic statistics on land use are provided by the agricultural and forestry agencies. The information has been supplemented by more extensive data on land cover collected in sample surveys during the *Monitoring landscape change* (MLC) project which was sponsored by the Countryside Commission and DOE. The project used air photography, whilst ITE concentrated on field survey and provided detailed information on the species composition of land cover.

Each data set differs in certain respects: the detail provided, the categories surveyed, and the methods used. Despite the differences, the general distribution and type of change in land use are detected by all the surveys. However, only the ITE survey provides a general classification to which all land use and cover types can be related, as well as details of the ecology. For this reason, the ITE ecological data base formed the core of the ECOLUC project; it consists of data collected during surveys in 1978 and 1984 throughout Great Britain, using standardised procedures. The surveys were based on field sampling of 1 km squares, randomly selected within each of the 32 land classes defined using geological, climatic and topographic characteristics. The field survey information provides quantitative data on land cover, vegetation type, and plant species composition. This data base includes details of over 3000 quadrats and linear plots, and can provide information on the distribution of plant species in open land, at its margins and in linear features, such as roadsides, either with their spatial relationships or as summaries by 1 km square or land class.

Future change in land use may differ from those in the past. To assess likely future trends, a number of studies were undertaken by specialists who examined the options for new agricultural and forestry crops and the probable responses to fiscal policy. Lawrence Gould (Consultants) predicted that the greatest change in land use is likely to occur in the lowlands: up to 35% of the land may be subject to reduced intensity of agriculture, but, because of the quality of the land, a range of alternative options are open (Figure 15). This prediction contrasts with that for the uplands, where the range of options is severely limited and where current trends are likely to continue. The scenario was expanded by the Centre for Agricultural Strategy (CAS), who identified alternative crops which are economically viable on different land types. The results (Figure 16) indicate that a range of 'novel' crops may follow the development of oilseed rape on arable and, to a lesser extent, grassland, with lupins the only significant option for marginal land.

As quantified by both Gould and CAS, the upland options considered are mainly limited to forestry, although other recreational scenarios could eventually be considered. A separate analysis of the land availability has shown that up to 15% of the uplands could be used for wood energy plantations, the remaining area being either unsuitable, constrained by designation, or economically viable under agriculture (Figure 17). Although the lowlands have greater growth potential, less expansion of forest for energy is predicted because of the strength of agriculture.

The extent to which options are exploited is strongly influenced by financial forces, eg through the Common Agricultural Policy, and particularly by the economic assumptions made at the outset. In conjunction with the University of Newcastle and ITE, CAS analysed the

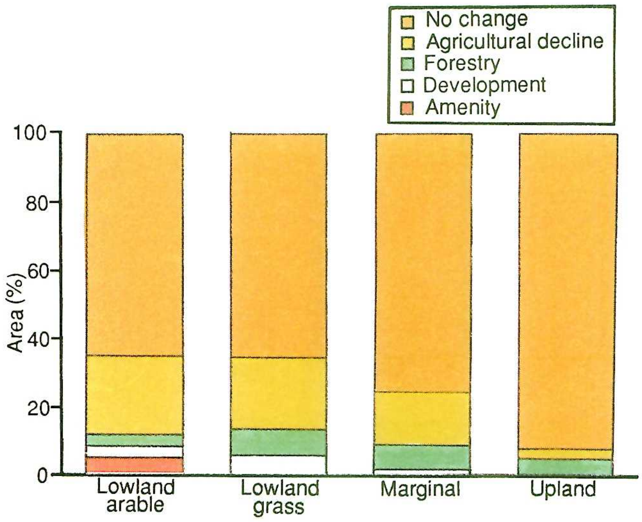

Figure 16. A comparison between estimates of the potential area that could be occupied by novel crops, assuming that all suitable land was included. The analysis was carried out on data from eight 1 km squares from each of the 32 land classes, grouped in the same categories as in Figure 15

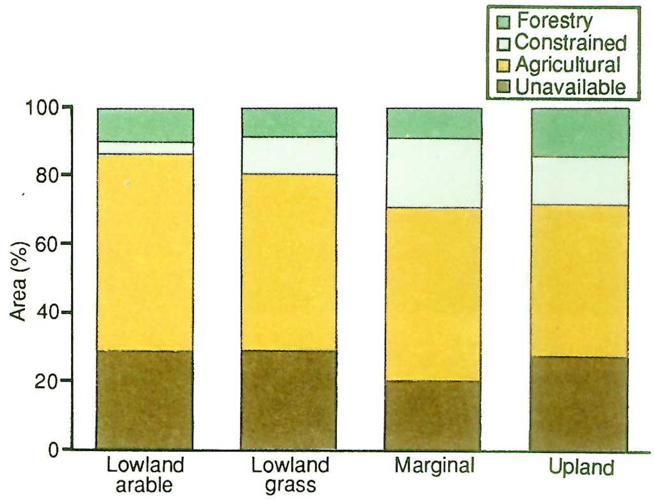

Figure 17. A comparison between estimates of the potential area that could be occupied by wood energy plantations, excluding land which was more economic under agriculture, assuming a 5% discount rate, and land identified as being under defined planning constraints. The analysis was carried out on data from eight 1 km squares from each of the 32 land classes, grouped in the same categories as in Figure 15

likely impact of four policy options in England and Wales. The results emphasised that change in land use is most likely to occur where a particular land use is economically marginal. Thus, core areas of arable or intensive grassland are likely to remain, and even to intensify; the change will occur at the interface between these uses. Geographically, the probability of change between arable and grass is greatest in the Midlands and south-west of England. Marginal uplands are likely to continue to be changeable, as they are at the margins of a number of land uses. The specific mechanisms controlling change in land use may be financial incentives, such as set-aside or farm woodland schemes, designations such as Environmentally Sensitive Areas, or other forms of regulation. The result will be a change either in land use or, through modified management regimes, in land cover and its composition.

Thus, the change may be quantitative, in terms of area of land under a particular use, or qualitative, in terms of the composition of the vegetation and diversity of species.

Ecological consequences of land use change – flora

Whilst census statistics are available for land use, ecological interpretation requires information on species composition. The ITE data base provides comprehensive information on the plant species composition of the major types of land cover, over the range of environmental and land use conditions in Britain. Within ECOLUC, the data base was used to quantify the type and diversity of species and communities in each type of land cover, as a measure of how plant assemblages would be affected by any alteration of land use or management.

Analysis of the data indicates that improving permanent pasture either to short-term ley or to arable would tend to reduce the number of vascular plant species. However, this picture is incomplete. The diversity of vegetation types in the open countryside is lower in the fertile, intensively managed lowlands than in the marginal uplands, where there is often a combination of both lowland and upland habitats, as shown in Figure 18. By contrast, an important feature in the distribution of diversity is that, in the intensively managed lowlands, linear features such as hedges, stream banks and roadside verges (Plates 7 & 8), which constitute only 5–10% of the land area, contain 60–80% of the species present, and about 20–30% of species are found only in the linear features, being absent from the open fields (Figure 19).

In the more extensively managed uplands, linear features are less distinctive in their contribution to the ecology of the landscape. Within a given 1 km square, there are generally more species in the lowlands than in the uplands, whereas the species in the latter form part of the vegetation cover rather than being present in relict patches as

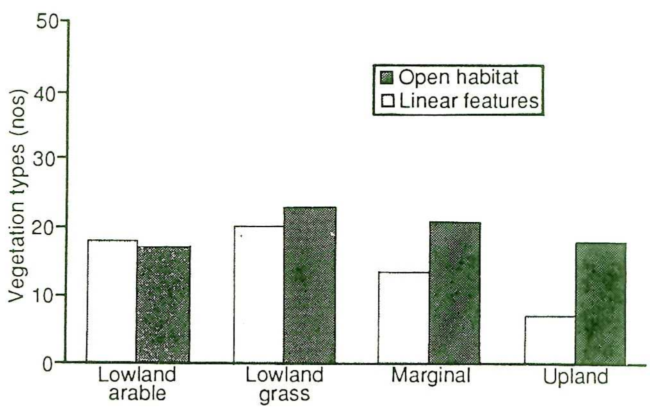

Figure 18. A comparison between the number of vegetation types in open habitats and linear features (hedges, roadside verges and streamsides). Records of all vascular plants and a limited list of bryophytes were collected in 1978 from quadrats in eight 1 km squares in each of the 32 land classes. The data were analysed by TWINSPAN and grouped in the same categories as in Figure 15

*Plate 7. Many plant species are important as food sources for animals. The wild rose (*Rosa canina*) is common in the hedgerows, but is also able to establish along walls and fences. It provides cover for birds, a food source for insects, and the hips in autumn attract resident and migrating birds*

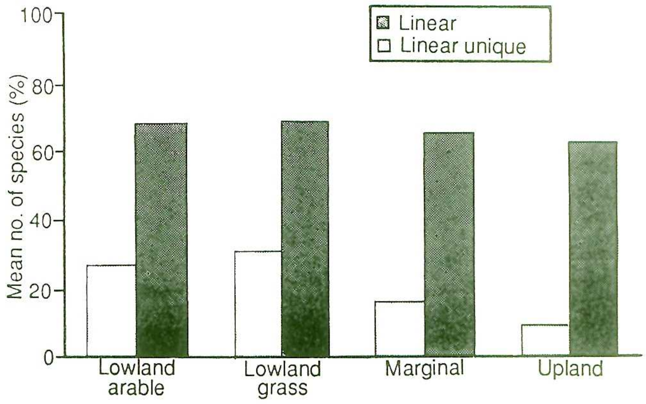

Figure 19. A comparison between the number of species recorded in 1988 from open land and those in linear features, as mean proportions of the total species number and those that were only found in the linear features. All species of vascular plants were recorded from two 1 km squares in each of the 32 land classes, and were grouped in the same categories as in Figure 15

fragmented populations. The implication of such distribution patterns for rural policy is that maximum gain in terms of future maintenance of diversity can be obtained by protecting, expanding or diversifying linear features in the lowlands, whereas in the uplands the whole landscape is involved.

An independent analysis of the data base by UCPE at the University of Sheffield provides a theoretical approach to assessing the likely response of species to an alteration in management. Based on the growth strategy of individual species, the theoretical framework shows the plants' response to environmental stress (eg soil infertility), disturbance (eg trampling or ploughing) and competition (eg in fertile undisturbed habitats) (Figure 20). The analysis defines the composition of the vegetation in different habitats in terms of functional groups.

Thus, arable areas show a high proportion (49%) of ruderal species which are successful in fertile but highly disturbed habitats. In contrast, moorland habitats are dominated by species which are stress-tolerant, reflecting their ability to survive in nutrient-poor, acid soils. Such generalisations are well known, but here they are expressed in quantitative terms which allow interpretation and prediction. For example, in grasslands, an increase in fertiliser use would tend to

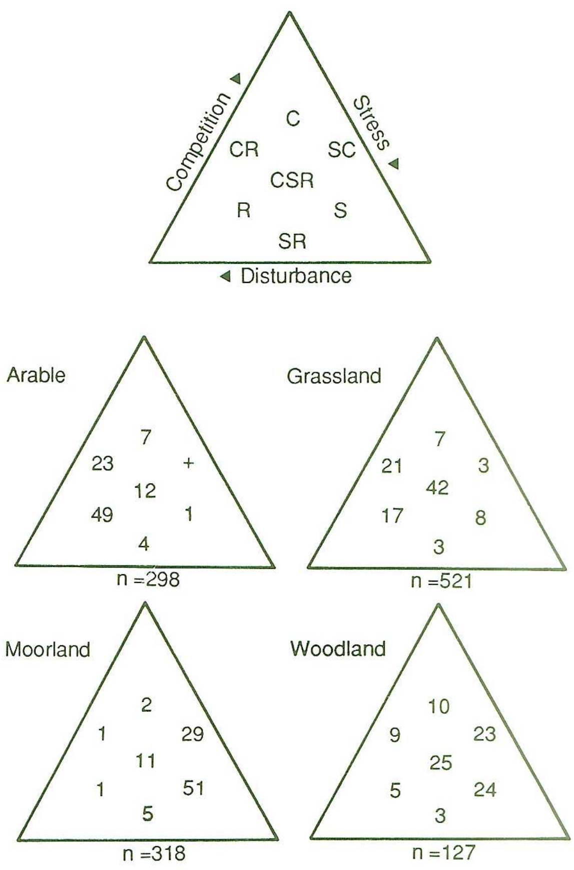

Figure 20. The mean percentage distribution of strategies for four major land use categories, as defined by UCPE. The data were taken from open habitats, as in Figure 18

*Plate 8. Species-rich roadside verge, Earlston, Lothian Region. The studies in ECOLUC have shown the importance of linear features in maintaining species which have disappeared from the open landscape. Management within such features is important, and within ECOLUC it has been demonstrated that, with the decline in roadside cutting, verges will be overtaken by coarse species, such as nettles (*Urtica dioica*)*

increase the proportion of competitive ruderal species from the present 21%, whereas, in moorlands, eutrophication, possibly from pollution sources or agricultural improvement, would tend to reduce the stress-tolerant component of the vegetation from its current dominance (51%). The latter component has been identified by UCPE as the most vulnerable grouping in the UK flora; the resurvey in 1990 of the vegetation sampled in the national survey of 1978 should allow tests of predicted change, as well as interpretation of observed differences.

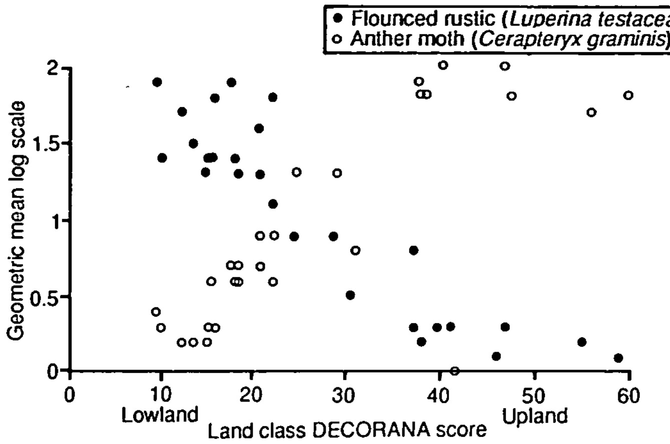

Figure 21. The relationship between two moth species recorded within the Rothamsted Lepidoptera Survey. The data were collected from 313 sites throughout GB, which were subsequently assigned to the 32 land classes. Geometric mean annual catches per land class were converted to a log scale, and correlated with the mean first axis ordination score (DECORANA) for the 32 land classes defined by the analysis of the original environmental attributes of the land classification

Ecological consequences of land use change – fauna

Unlike vegetation, there is no comprehensive information on fauna, although there are many excellent national or local data on individual species or groups, eg those of the British Trust for Ornithology. The challenge in ECOLUC was, therefore, to assess the potential of bringing together different sets of faunal information and relating them to data on land use and land cover. The common base or framework considered was the 32 ITE land classes, strengthened by the field information on land cover. The latter is particularly important because it is the mosaic of land cover to which animal populations respond, as well as the presence or absence of a particular habitat.

Three approaches to the integration of zoological information into the land classification were explored:

1. sampling by land classes,
2. retrospective classification of study sites,
3. assessment of population density based on land class and cover information.

An example of the first approach is in the sampling of 2000 1 km squares of known land class in Britain by Dr S Harris (University of Bristol) to assess badger (*Meles meles*) population size. The survey showed that high densities of badgers (0.5–1.0 main sets km^{-2}) were concentrated in five of the 32 land classes with lowland grass cover dominant. In these classes, management is unlikely to intensify significantly towards the lowland arable cover type in which badger main sets had much lower frequency (0.05–0.3 km^{-2}). These data were then used, in conjunction with the scenarios from the CAS study, to assess the most likely effects of land use change on badger populations.

Retrospective classification of areas for which extant faunal data are available can enable these data to be related to independent information of land use or cover. The Rothamsted Lepidoptera Survey is an example of the second approach. It collected data from 313 sites over 25 years, and the analysis by Dr I Woiwod has shown a series of distinctive relationships between individual species and land class characteristics (Figure 21). These relationships provide a mechanism for predicting species composition in areas which have not been sampled.

The third approach uses the habitat information available from the sample of 256 1 km squares to assess population density of particular species. This technique has been explored by the British Trust for Ornithology for birds, by Dr D Macdonald (University of Oxford) for foxes (*Vulpes vulpes*), and by the Game Conservancy for pheasant (*Phasianus colchicus*), grey partridge (*Perdix perdix*) and brown hare (*Lepus capensis*). In the first two cases, expert opinion is used to identify the number of animals likely to occur in particular or general types of landscape. By contrast, the Game Conservancy used formal regression to quantify bird numbers in relation to land cover and, in the case of the grey partridge, to assess the effects of changes in cover and management.

With a few exceptions, information on the distribution and abundance of fauna lacks a comprehensive base from which to assess the consequences of land use change. Most of the data are from localised studies or do not have associated detail of habitat characteristics. Through a variety of invertebrate and vertebrate case studies, ECOLUC has provided a method by which partial or fragmented information can be related to a common framework, within which the effects of land use change can be assessed. The approach has highlighted the need for research to define relationships between abundance of animals and measurable attributes of the landscape, ie the pattern or mosaic of habitats. In a number of cases, eg foxes, game and other birds, abundance could be related to the generalised composition of the landscape, but not to quantified spatial relationships such as heterogeneity or connectivity.

Although the ecological relationships between landscape pattern and ecology are poorly developed, the ability to define pattern and to detect change in pattern by remote sensing has developed rapidly. As part of a joint study with the National Remote Sensing Centre in the use of remote sensing to detect change in land cover, an automatic system was established which defines the size and nearest neighbour of identified cover types or habitats, and calculates a measure of heterogeneity, or 'graininess', of the landscape. The system can be used rapidly to identify areas where the general pattern is changing in repeated images over time, eg in the occurrence of woodlands of different sizes. Such size frequency distributions are potentially useful when information is available about the minimum habitat size requirements of a particular species.

A major element of the remote sensing programme has been to link satellite imagery with ground data. Using a combination of single-date and multi-season imagery, the broad land cover types in Britain can be mapped. A variety of techniques for classifying the image data was compared, including visual interpretation, supervised and unsupervised classification. In practice, the optimal solution is to combine the statistical classification of spectrally separable cover types with visual interpretation of the residual. Change maps were also produced showing the increase or decrease in the area of a particular cover type. The study emphasised that field survey and satellite imagery are complementary techniques, and demonstrated how future surveys can utilise the strengths of both approaches.

Knowledge-based information system

The communication of large amounts of data and the expertise of specialists to those who are concerned with policy decisions is a real problem. The advent of various forms of expert- or knowledge-based systems has provided a powerful set of techniques. In ECOLUC, an exploratory study has produced a knowledge-based information system, built on the framework of the land classification. It holds information on the characteristics of the land classes and the associated land use and land cover features for which census data are available, together with predictions of other features in the ITE data base. The system is compatible with various models predicting potential changes and their consequences. The data are all held by 1 km square, and the system allows the user to select any block of squares for interrogation.

Conclusions

ECOLUC has been a technically far-ranging and exploratory study which has involved many people in the research community. Although concentrating on the terrestrial environment, it extended into freshwater ecology and combined remote sensing with detailed information on plant and animal ecology, both theoretical and practical.

In particular, ECOLUC has demonstrated the following points.

1. Land use statistics and ecological information from different sources can be related to a common baseline of the ITE land classes.
2. Major changes in land use result in clearly quantified effects on biological diversity. Adjustments in the type and intensity of management which are not recorded in land use statistics have ecological effects which are of the same order of magnitude.
3. A high proportion of the biological diversity, especially in the lowlands, is concentrated at the margins of fields and in other linear features which comprise less than 10% of the land area.
4. Remote sensing can provide systematic and extensive detection of the major characteristics and change in land cover. Integration with field survey provides detailed ecological interpretation as well as ground truth. Remote sensing with field survey provides a strong combination for detecting change at three inter-related scales of resolution:

   i. major land cover features,
   ii. land cover or habitat characteristics,
   iii. species distribution and abundance.

These conclusions have implications for management policy and for the provision of national statistics. The efforts of many individuals and organisations involved in ECOLUC are fully acknowledged. The next stage is to build on the experience gained to implement the 1990 Countryside Survey.

R G H Bunce and O W Heal

Siting of wind turbines in Britain

(This work was funded by the Department of Energy, Energy Technology Support Unit)

Wind power is currently one of the most promising of the renewable energy technologies for generating electricity in the United Kingdom. If predicted costs can be achieved, it is possible that wind power could be supplying at least 10%, and perhaps as much as 20%, of national requirements by the year 2025. Although the UK appears to be endowed with sufficient wind, is there enough land on which the turbines could be sited?

Much of our land is unsuitable for technical reasons; for example, built-up areas or forest blocks distort wind flow. Such areas are considered to be 'physically constrained'. Other areas are protected by statute, such as the National Nature Reserves and Areas of Outstanding Natural Beauty. Planning controls in these and other specially designated areas may prohibit the construction of wind turbines. Such areas are 'institutionally constrained'.

ITE was commissioned to provide a quantitative estimate of the area of Britain which could not be used for wind energy generation because of physical and institutional constraints.

The areas with physical constraints were obtained from published cartographic sources, and information for this study was supplied, in electronic form, by a company involved in the production and publication of maps. The institutional data were more difficult to access in suitable published form, and were acquired by digitising maps obtained from the agencies that designate protected areas, such as the Nature Conservancy Council and the Countryside Commissions of England and Wales and of Scotland. Initially, the data were stored as Ordnance Survey grid referenced co-ordinates for each designated area. These boundaries were used to allocate the grid referenced 1 km squares fully, or partially, to appropriate designations.

Plate 9 shows the distribution of 1 km squares which are unconstrained by both

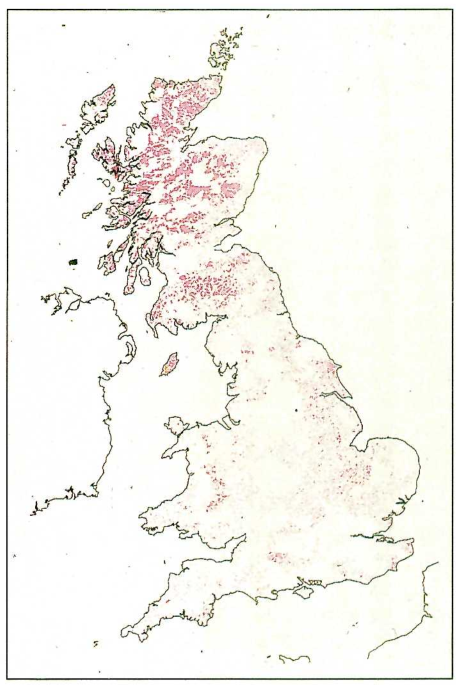

Plate 9. The distribution of 1 km squares in Britain unconstrained by either physical or institutional constraint. This represents 12.5% of the total land area of Britain