
Robinson, M. 1980. *The effect of pre-afforestation drainage on the streamflow and water quality of a small upland catchment.* (Report no. 73). Wallingford: Institute of Hydrology.

Stevens, P.A. 1981a. *A bulk precipitation sampler for use in a geochemical cycling project.* (Bangor occasional paper no. 7). Bangor: Institute of Terrestrial Ecology.

Stevens, P.A. 1981b. *Modification and operation of ceramic cup soil solution sampler for use in geochemical cycling study.* (Bangor occasional paper no. 8). Bangor: Institute of Terrestrial Ecology.

Studies by ITE on the impact of agriculture on wildlife and semi-natural habitats in the uplands

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This paper considers the following 3 questions.

1. What are the major impacts of agriculture on upland habitats and wildlife?

2. What work relevant to these impacts has been done or is currently in progress in ITE?

3. What are the main needs for research in this field, and how should ITE contribute?

1 Factors influencing upland agriculture

Economic factors arising from EEC and UK agricultural support policies are dominant, but are discussed elsewhere in this volume (eg Marsh 1984). Climatic, geological and physiographic variety, and the consequent diversity in soil types and fertility give contrasting natural environmental characteristics that affect the regional applicability of the economic spurs to, and constraints on, agricultural methods and their potential for profitable change. Historical and social aspects of land ownership, farm tenure and structure, and of regional non-agricultural activities, also create conditions locally which can modify the rate or direction of responses to economic stimuli in similar physical environments. Where climate, land form, soils and farm structure in the uplands combine to give conditions marginally suitable for mixed or even arable farming, current economic policies tilt the balance away from pastoral systems. Changes in land use then involve the conversion of ley grassland to arable cultivation, the decay or removal of superfluous hedgerow or wall boundaries, more use of fertilizers, herbicides and pesticides, increased land drainage, and the removal of unwanted small copses and decline of farm woods. Stock that are retained are transferred to cultivated and re-seeded former rough pastures, and seasonally to remaining fragments of rough grazing and moorland, the latter's vegetation having changed from heather to grass by intensified grazing and burning.

More widely, in areas environmentally only suitable for pastoral farming, the certainty of financial returns from grants and subsidies increases stock numbers within farming systems unchanged in principle. Beyond an expanded zone of improved pastures, this increased grazing intensity again results in heather moorland being transformed into grass moors, with consequent changes in wildlife.

Extensive changes in the uplands also result from taxation policies. It becomes worthwhile to alter current upland farm/moor mosaics by linking agricultural change with zones of forestry planting on rough pastures and moorland. The possibility of agricultural intensification in parts of an upland area may thus be an essential trigger to the more wide-ranging effects on semi-natural habitats caused by associated extensive forestry enterprises.

In summary, these trends, if current support and taxation policies continue, will create uniformity in the more climatically amenable, lower altitude, sectors of the British uplands, through the disappearance of a high proportion of their characteristically varied semi-natural habitats (Plate 7). In the middle altitude ground, surviving semi-natural moorlands will be broken up into separated and declining fragments. The present typical upland landscape contrast, between diverse vegetation on an agricultural fringe, and expanses of uniform open moorland and hill, will persist only where the wishes of local landowners or administrative constraints check the tide of change in temporary museum pieces. Ultimately, only the highest hills, environmentally unsuitable for intensified agriculture or economic forestry, will remain visually rather as they are today, as open mountain and moor. In this fragile environment, even wildlife must compete with increasingly concentrated recreational pressures and now, apparently, also with development demands arising from the compensation principle of the Wildlife and Countryside Act.

2 Relevant research by ITE staff

2.1 Evaluation of upland land and biological resources

In the assessment of national land resources and their use, computer-stored data inventories co-ordinated from a wide range of data are an essential tool. Although the national land data bases set up in ITE were not directly aimed at relating habitats and wild species to agriculture, their availability can assist evaluations of relationships between the physical environment, the distribution of plant and animal species, and current and potential land uses, including those in the uplands. In the Biological Records Centre (BRC), the primary source of information on species distribution in Britain, data sets record the presence of plant, animal and insect species in each 10 km x 10 km grid square of the Ordnance Survey national grid (Heath & Perring 1978). This data bank currently holds more than 2.5M records of over 6000 species (Harding *et al.* 1983). The 10 km x 10 km scale of data collection and storage has also been used for a national land characteristics and classification data set of land physical and use characteristics drawn from map and statistic sources; 126 attributes in groups of physiography, climate, geology, soils, topography, land use, agricultural land classification, and conservation status have been quantitatively recorded and computer-stored for each of the 2858 10 km x 10 km Ordnance Survey grid squares containing land in Great Britain. Analyses of inter-relationships between physical environment factors and land use can be made within the national land characteristics data set, and comparisons between physical land character or broad types of land use, and species occurrence, are possible through the linking of this data set with those of the BRC. Classifications of land strata derived from the 10 km x 10 km land data set are now being generated and tested as one basis for regional and national analyses of land use related to the physical environment, and as a framework for stratified sampling in extrapolation of existing data and for future studies.

At a 1 km x 1 km grid square scale in the ecological survey of Britain project, map-derived data from a sample of one square in every 225 (1228 squares) were used to give a classification into 32 land classes (Bunce *et al.* 1981a, b). The key from this classification was then applied to allocate a further sample of 4800 squares to classes, in order to strengthen identification of class geographic distribution. Within each class, field data on plant species, habitat type, soils, land use and landscape features have been collected in 8 sample 1 km x 1 km squares. These data have been extrapolated to quantify the characteristics of each class.

These 3 national land data sets, which are being actively maintained and developed, reinforce each other by their different scales and types of information.

In considering geographic data bases, it is possible to argue in favour of digitized computer-stored 'vector' formats which can retrieve the exact location of any desired feature, rather than the cell-based 'raster' format used in these data sets and in other 'local' land data banks mentioned later (2.3), which only locate the feature as present somewhere in the cell. However, practical considerations justify the raster format (see discussions on the national land characteristics data set in Ball 1983; Ball *et al.* 1983).

2.2 Process studies

Early work in Snowdonia had demonstrated the control exerted by geology and climate, through soils, on the vegetation of open grazings in a geologically diverse hill area (Hughes 1958). Quantitative observations followed on the grazing intensities supported by the contrasting vegetation (Hughes *et al.* 1975b). Selective grazing between grass and heather moorland vegetation types has been studied also in Scotland (Welch 1981). To follow botanical changes in the absence of sheep grazing, exclosure plots were set up and maintained on hill grassland types in Snowdonia (Hughes *et al.* 1975a; Hill 1983) and at Moor House in the northern Pennines (Welch & Rawes 1964; Rawes 1981, 1983). The early stages of vegetation responses to grazing removal recorded so far on these plots show generally slow, and probably readily reversible, changes, with an emphasis on an altered balance among plant species already present. The entry of heath species that are less resistant to grazing is limited, often because local seed sources are lacking, but also by the inability of any seed present to germinate in the close grass herbage. Work on the effects of grazing on vegetation was extended to include quantitative detailed measurements of the productivity of flora and fauna during studies under the International Biological Programme (IBP) in the 1970s. Results from these studies, concentrated on grassland on Snowdon and on blanket bog at Moor House, are recorded in an IBP volume (Heal & Perkins 1978) and summarized by Heal and Perkins (1976).

Unfortunately, the intensive studies at Moor House and in Snowdonia in the 1950s to 1970s were not closely integrated in their planning, timing and methods with work in Scotland (eg Miller & Watson 1978), and were not extended to south Wales and south-west England. A co-ordinated study of the effects of soil and climate on the responses of hill heath and grassland communities, and of local ecotypes of key species, to different grazing regimes at a wide range of sites would have given a clearer quantitative picture of regional similarities and differences.

The grazing exclosure plots in Snowdonia and the Pennines allowed direct observation of the locally variable course of vegetation change in the early stages after cessation of agricultural management of hill grazings. An indirect assessment of the longer term response of upland vegetation to a reduction in the intensity of agricultural management was one aspect of a recent study on the ecology of vegetation change in upland landscapes, carried out in England and Wales under contract to the Department of the Environment (Ball *et al.* 1981a, b, 1982). This work took place in 12 parishes designated by the customer, from Alwinton in Northumberland to Widecombe in Devon. The study combined field records of botanical data, and a vegetation classification derived from them, with a land type analysis, an investigation of the history of land use over the past 200 years, and a review, from existing ecological knowledge, of the impact of different management methods which bring about relatively gradual vegetation change.

The historical analysis identified, from map, archive, and air photo interpretation, locations which had been more intensively managed at one time and then allowed to revert to less intensive grazing use only. The sequence of change from improved pastures through rough pasture vegetation types to grassy heaths and ultimately shrubby heaths (heather moorland types) was found to be generally slow. Though some sites had reverted to shrubby heaths within 40 years, others only developed heath vegetation comparable to adjacent undisturbed moorland after more than 130 years. The proportion of shrubby heaths on sites of this age remained lower than in sites on moorland for which there is no evidence of intensified use within the past 200 years. While conversion of moorland to grassland can be achieved virtually overnight, its restoration by natural means, if intensified use is abandoned and only grazing maintained, is very slow. A non-sustainable improvement encouraged by artificial economic inducements can thus have an effect on the landscape and on wildlife habitats that will persist for more than one generation. Predictive interpretations of future vegetation type frequencies in these study areas, a main aim of the work, are considered later (2.3).

Among the sources of data from which the account of the impact of non-cultivation agricultural practices was prepared in the vegetation change study were quantitative investigations of the effects of grazing, burning and nutrient regimes on heather moors in Scotland (Miller 1979). Subsequent work has also identified potential losses of heather moor of landscape importance through fragmentation and inadequate management, losses equivalent to those attributable directly to agricultural improvement, on the moorlands of the Exmoor National Park (Miller *et al.* 1984).

In north-east Scotland, local mosaics of heather moorland and birch woodland occur. Studies have shown the importance of birch, through its more active nutrient cycling and enhanced soil biological activity, in modifying soil conditions from those of heather moorland to ones of higher fertility (Miles 1981). In a low input management system for extensive moors, incorporating in its aims stock grazing, grouse management, maintenance of fertility in the soils, and of conservation and landscape interest through habitat diversity, the potential of successional change between birch woodland and moor in such mosaics has considerable interest.

Reviewing this vegetation distribution and management work as a whole, there would appear to be an adequate general understanding of the directions of upland vegetation change through alternative management. A remaining need is for integrated studies between different upland areas to monitor actual courses and rates of change from control sites and through experiment, so that specific management recommendations can be made with greater certainty for particular situations (cf Hudson 1984). As noted earlier, loss of heather moor through cultivations and liming is easily achieved, but its restoration, if agricultural improvements turn out to have been ill-judged and impossible to sustain, is another matter entirely.

Another gap in past work, which has repercussions now, relates to a failure to follow up the general picture of upland rock/climate/soil/vegetation relationships with adequately sampled soil and plant chemical data from a geographic spread of contrasting soil parent materials and semi-natural vegetation types maintained on sites with long-term security. Had such data been obtained, preferably at different times, then the present conspicuous absence of accurate information applicable to the question of the environmental impact of 'acid rain' might have been alleviated. Although media attention is directed to effects on upland lakes, rivers and plantation forests, if there is a clear 'acid rain' problem it could also be reducing plant nutrient levels in upland grazings with poorly buffered soils below those due to their natural unpolluted environment, thus increasing the costs of sustaining particular fertility and productivity levels.

In association with the Institute of Hydrology (NERC) and the University College of North Wales, ITE is obtaining detailed data on chemical transfers between inputs from rain and rock weathering, cycling in the soils, and outputs in streams (Hornung *et al.* 1983; Hornung 1984). One objective is a comparison of pathways and levels of plant nutrients under agricultural grazing and forestry uses. Contrasts between fertilized and unfertilized grazings also show the long-term residual effects of fertilizers and may help in assessing the long-term economic viability of agricultural improvements that depend on regular lime and fertilizer inputs in similar upland environments.

Turning from upland vegetation to fauna, a large part of ITE work in the uplands has been on grouse and deer. Because there has been less direct interaction with recent agricultural intensification in the types of hill land in which these species occur than in the more agriculturally favourable parts of the British uplands, reference to these studies here is brief. This brevity does not reflect the importance of the work done in long-continuing investigations of management, nutrition, and population dynamics of grouse (eg Jenkins *et al.* 1963; Moss & Miller 1976; Watson & Moss 1978) and of red deer (eg Nicholson 1974; Mitchell *et al.* 1977; Red Deer Commission 1981; Staines *et al.* 1982). Both species play an important economic role in conjunction with, or as an alternative to, agricultural stocking on hill ground. Moorland management for grouse must be reconciled with the demands of grazing livestock, while deer can conflict in winter with agriculture and forestry (Plate 4).

Birds of particular conservation importance, eg merlin, red kite and buzzard (Newton *et al.* 1981a, b, 1982), have been studied in relation to the substantial habitat changes in upland areas that have occurred through modifications of rough grazing and expansion of forestry. Related research, continuing from its prominent role in earlier years, has concerned the effects of agricultural chemicals on birds, including birds of prey in upland areas (Cooke *et al.* 1982).

2.3 Predictions of ecological change

Resource and process studies in ITE, together with data from other sources, have in recent years supplied a means of predicting the results of likely courses of land use change in Britain, and of modelling alternative land use options.

In the mid-1970s, a desk study on upland land use in England and Wales, under contract to the Department of the Environment (ITE 1978), reviewed the distribution of different land uses, the factors influencing them, and the changes in land use that were likely. It used a data collection approach linking national, regional and local scales of study that involved Ordnance Survey grid squares of appropriate scales as the unit of measurement (2.1). At the national scale, an upland land classification for England and Wales derived from 10 km x 10 km grid square data (a data set and classification now superseded by the later comprehensive Great Britain set (2.1)) was used to predict sectors in which agricultural activity was likely to expand or contract. At the regional scale, a 1 km x 1 km data set and land classification of Cumbria (Bunce *et al.* 1975; Bunce & Smith 1978) were used to interpret the current use and potential for change of different sectors of the county. At the local scale, 0.25 km x 0.25 km grid squares were employed in analyses of agricultural and forestry potential of a small area in Snowdonia, using data involving progressively greater scales of effort to obtain. Results suggested that land use potential could be effectively assessed from a land classification based on readily available map attributes, with the greater precision of detailed soil and vegetation maps only offering benefit at the site level.

Land classifications in Cumbria have subsequently been applied, with the incorporation of economic data, to resource assessments and land use strategy interpretations at county and district levels in collaboration with staff of Cumbria County Council (Smith 1982). The initial county land classification was expanded through sample field survey to quantify the characteristics of each land class. Combining these data with economic criteria for alternative land uses permitted evaluation of alternative planning strategies in relation to changing economic returns and to social and other constraints on land use. A linear programming model (Bishop 1978) was used to produce land use patterns which maximize particular types of output for the county. The effects of alternative strategies on factors not involved in their formulation could be assessed, for example on wildlife and habitat conservation. At a district level, the same approach was applied to a study of the Sedbergh district. Both scales of analysis suggested that there is potential for significant increases in forestry without detrimental effects on other land uses.

One shortcoming of subsequent ITE work is that the validity of predictions made has not been re-evaluated in the light of data from subsequent actual changes in land use, or altered economic conditions.

From a framework of a land classification in which each class is quantitatively defined by the mean and range of its land characteristics, an assessment can be made of land potential for uses not now practised. An example is the application of current land use and environmental data for the 256 sample squares in the land classes drawn from the ecological survey of Britain data set (2.1) to estimate the area of Great Britain that could be utilized for the production of wood as an energy crop under various constraints (Barr & Bunce 1983). The extreme possibility of 35% of Britain being available for this use, or a more realistically constrained option of 8% being economically applicable, can be suggested from a combination of land, land use priority, and economic data. The model from which these figures are drawn supplies estimates of wood output and its energy capacity for the area of land potentially available under varying constraints. Another potential energy source which might be manageable as an agricultural 'crop' is bracken (Callaghan *et al.* 1982).

The upland land use desk study included a summary of the effects of grazing, burning, and other non-cultivation agricultural management methods on semi-natural grassland and moorland vegetation in the uplands. An expanded analysis has been made in the vegetation change in upland landscapes project (2.2) (Ball *et al.* 1981a, b). The generalized courses of change suggested by this analysis under broad criteria of agricultural expansion or contraction were applied to the present frequencies of the vegetation classes at recorded sites in the 12 upland study areas of England and Wales. If the recent level of agricultural expansion continues over the next 10-20 years, it is estimated, for the study areas combined, that there would be a loss of some 4% of their present total moorland, but a loss of 15% of the current area of 'shrubby heaths' (heather moors in a general sense) (Ball *et al.* 1982). Grassy heath and rough pasture vegetation groups would remain similar in extent to their present situation, but would occur in different locations. Grassy heaths would develop from shrubby heaths, and rough pastures from grassy heaths, as grazing pressures intensify, while improved pastures would be increased by more active change along the moorland fringe. In individual study areas, the effects would vary because of their contrasting land character, farm structure, and non-agricultural constraints. An alternative possibility to the continuance of present trends of change could be a substantial intensification of agriculture (in the order of a 50% livestock increase over 10-20 years). Calculations of the possible changes from present vegetation frequencies under such a 'maximum change' scenario suggest increases in improved pastures by about 60% and rough pastures by 18%, with a reduction of the heather moors to around one third of their present area. The balance of recorded sites, respectively 27%, 17%, 23% and 33% for improved pastures, rough pastures, grassy heaths and shrubby heaths in 1977-78, could change to levels of 44%, 20%, 24% and 12%.

Intensification of agriculture to the maximum scale envisaged would eliminate or severely reduce many vegetation types and the fauna they support. Except where special constraints operate, this intensification would substantially alter the habitats and wildlife of the majority of upland areas of England and Wales and of comparable parts of Scotland. As such agricultural expansion would, for economic reasons, be likely to be accompanied by new forestry plantings so far as land requirements for increased grazing permitted, there could well be additional losses of moorland (Plate 7). On simple assumptions of land type suitability for forestry, this use could occupy some 37% of the study areas as a whole, rather than its present 10% of their area.

If, at the other extreme, upland agriculture were to decline substantially (by a fall in livestock of the order of 50%), the estimates suggest an ultimate possible decline in improved pastures by 25%, in rough pastures by 40%, in grassy heaths by 45%, but an increase in shrubby heaths by 70%. Many of the additional reverted rough grazing and moorland areas would then become scrub woodland, if they were not positively taken into plantation forestry.

The opportunity afforded by the detailed records of plant species at some 1000 sites in these study areas in 1977-78 can be followed up by re-recording sample sites in some areas, to monitor where change has actually occurred in relation to identified stable or changing management, and thus provide comparisons with the generalized predictions.

3 The main needs for research

A pessimistic view is that, if present policies continue, ecological research in all but the least agriculturally suitable hill land would only be able to guide management of the few specially protected 'museum' sites and areas, or record what upland habitats have been like in recent times before the current agricultural changes have taken place. From a more optimistic view point, there is still room for hope that a less narrow attitude towards support for upland communities and environments may develop. This view may be dismissed as a pious platitude that overlooks political realities, but an alternative approach to marginal farming and the welfare of upland communities, biased towards the small unit, traditional methods, and habitat restoration, is having different, and in many ways more environmentally and socially favourable, effects in France (Mills 1983).

Neutrality between conflicting interests is always difficult, and usually unpopular. However, a body such as ITE which aims to gather objective information through research on ecological systems, and to assess independently the ecological effects of actions carried out and policies advocated by agriculturalists, foresters, nature conservationists, recreation interests, water supply bodies, and others concerned in using the uplands, is an essential element in the checks and balances of the diffuse British Governmental system. The Director has stated that 'any future policy must be based on a sound scientific knowledge of the ecology of the uplands, and any policies which are proposed should be fully tested against the best model available to predict the consequences of these policies. Similarly, the results of such policies should be monitored carefully' (J N R Jeffers pers. comm.).

Resource assessment, process investigation, and modelling the effects of actual and potential policies, proceeding in a parallel in a co-ordinated programme, comprise the ITE approach to contributing to such knowledge. In terms of resource inventories and evaluation, more detailed answers are needed to the question: what is present now? These answers will require improvements to the existing land data inventories, and greater integration of national, regional and local physical, management, and economic data to give a co-ordinated base-line of national information on land resources. Expansion of the use of air photography and development of applications of satellite imagery will support or supplant field work in updating information and monitoring change in stratified sample locations. As part of 2 linked research programmes in which ITE work is now involved, *Land resources and land uses* and *Survey and monitoring*, an objective is to produce in 5 years a handbook that will analyse the environmental characteristics of the land resources of Britain, how these resources are now used, and why this land use pattern has developed. It will also include modelling of the ecological impacts of trends in land use change and of alternative options.

Efficient resource evaluation from land data sets depends on understanding the ecosystem processes that link the physical and biological aspects of upland environments to discover why upland habitats are as they are, and how they work. Detailed site studies must be applicable to broader evaluations. A survey census approach based on sound sampling strategies must follow changes in habitats, their soils, and plant and animal populations, on control sites and areas, as well as on sites affected by changes in management in otherwise similar environments. Too many past studies have been concerned only with parts of an ecosystem and have been carried out in isolation from other aspects. The need is for more integrated studies, which should include experimental manipulations of the factors that control soil, plants and fauna in major upland vegetation types, emphasizing both rare and widespread habitats in farmlands, woodlands, moorlands and hill ground.

Long-term geochemical studies, though laborious and expensive, can provide a quantitative nutrient balance assessment for particular land form, climate, soil and land use conditions. Through these data, the costs and benefits can be considered of higher fertility, higher production agricultural systems achieved by increasing the soil nutrient status in inherently unfavourable environments. Is the result of introducing such systems and attempting to sustain them worth the effort? What will the effort cost? What is lost to the upland environment in other ways? What alternative might be preferable? These are among the questions to which answers for particular upland situations would be helpful from an ecological view point.

Although a wide measure of knowledge has been gained on the management of grouse and deer and their interactions with other land uses, if agricultural and forestry encroachment on the hill ground in Scotland increases, conflicts between uses will also increase and their resolution is likely to need further experimental and observational studies. Attention throughout this paper has been concentrated on considering agricultural intensification as the main trend of change in the uplands. However, in a large area of hill land in north-west Scotland, agricultural production will not only never be truly economic under modern conditions, but will remain inefficient even under the criteria of current agricultural support. Alternative options and their ecological implications should be investigated in theory and experimental practice. Could local communities in such areas be as effectively sustained as they are now, if the attempt to maintain any significant level of supported agriculture were withdrawn and replaced by other land uses concentrated on utilization of wild species, and on the economic values in recreation carefully allied to positive conservation?

In prediction and modelling studies, in order to answer the question: what will happen if?, data inventories and the type of data provided by process studies will need to be appropriate for a wider range of modelling methods than those previously employed. More use of economic and social science expertise is essential, with greater interaction with other organizations in the formulation of viable models of the ecological, economic and social consequences of action or inaction. The clear definition of land and land use features that are of importance, measurement of their regional and national variation, and appropriate sampling programmes to relate site, region and national assessments, all require the most careful consideration, if observations are to be used to set up models of ecological impacts and changes and then to refine them by monitoring control sites. Modelling should extend to proposing balances of land use in particular regions or upland environments that optimize alternative interests, rather than concentrating on one, however important. The potential practicality of proposals should be examined thoroughly and then, if appropriate land holding structures are available, be tested by co-operation between ecologists, land managers, and administrators.

To some extent, these suggestions could be seen as a continuation of what ITE has done in the past, but they should rather be thought of as an intention to use what has been done as a basis for a more co-ordinated research effort in the future, in line with ITE's current strategy for integrated research in key programme fields. Impacts of agriculture in the uplands are a live political issue and also a live, interesting, and essential field for scientific study.

4 Summary

Past and current work in ITE on impacts of agriculture on upland habitats includes: land resource evaluation, process studies of the interactions of land use with wild species, and the prediction and modelling of the ecological results of alternative land use trends and options. Data banks at national, regional and district scales display and analyse the links between land character, land use, and species and habitat distributions. Process studies have included experimental monitoring of changes in vegetation, as a result of altered grazing and burning regimes, major studies of management and of population dynamics of economically important upland species (grouse and deer), and investigation of the impact of agricultural chemicals on upland birds of prey. Studies involving prediction and modelling of change have included generalized forecasts of the potential trends of vegetation change in upland grasslands and moorlands, applications of land data and classifications to county and district planning strategies under alternative land use options, and the assessment of land potentially available for novel forms of land use, such as the growth of energy crops. Work that should now be undertaken by ITE in this field should look beyond the necessary ecosystem studies in surviving semi-natural habitats to seeking a wider understanding of ecological factors and processes in the general countryside in relation to particular land use systems. Data from such studies, allied to existing material, can be co-ordinated in analysable land resource data sets, to enable predictions of the impact of alternative policies to be made with increased confidence. The current ITE research programmes provide foundations for upland ecosystem process studies linked to regional and national

sampling frameworks, for integrated multiscale land data bases, and for the application of modelling methods combining ecological, technical and economic criteria to assess the acual and potential impacts of policies.

5 References

Ball, D.F. 1983. National land characteristic data bank. *Annu. Rep. Inst. terr. Ecol. 1982,* 103-106.

Ball, D.F., Dale, J., Sheail, J., Dickson, K.E. & Williams, W.M. 1981a. *Ecology of vegetation change in upland landscapes. I: General synthesis.* (Bangor occasional paper no. 2). Bangor: Institute of Terrestrial Ecology.

Ball, D.F., Dale, J., Sheail, J. & Williams, W.M. 1981b. *Ecology of vegetation change in upland landscapes. II. Study areas.* (Bangor occasional paper no. 3). Bangor: Institute of Terrestrial Ecology.

Ball, D.F., Dale, J., Sheail, J. & Heal, O.W. 1982. *Vegetation change in upland landscapes.* Cambridge: Institute of Terrestrial Ecology.

Ball, D.F., Radford, G.L. & Williams, W.M. 1983. *A land characteristic data bank for Great Britain.* (Bangor occasional paper no. 13). Bangor: Institute of Terrestrial Ecology.

Barr, C.J. & Bunce, R.G.H. 1983. The land potentially available for wood energy production in Great Britain. *Annu. Rep. Inst. terr. Ecol. 1982,* 106-109.

Bishop, I. 1978. *Land use in rural Cumbria—a linear programming model.* (Merlewood research and development paper no. 75). Grange-over-Sands: Institute of Terrestrial Ecology.

Bunce, R.G.H. & Smith, R.S. 1978. *An ecological survey of Cumbria.* Kendal: Cumbria County Council and Lake District Special Planning Board.

Bunce, R.G.H., Morrell, S.K. & Stel, H. 1975. The application of multivariate analysis to regional survey. *J. environ. Manage.,* **3,** 151-165.

Bunce, R.G.H., Barr, C.J. & Whittaker, H.A. 1981a. An integrated system of land classification. *Annu. Rep. Inst. terr. Ecol. 1980,* 28-33.

Bunce, R.G.H., Barr, C.J. & Whittaker, H.A. 1981b. *Land classes in Great Britain: preliminary description for users of the Merlewood method of land classification.* (Merlewood research and development paper no. 80). Grange-over-Sands: Institute of Terrestrial Ecology.

Callaghan, T.V., Lawson, G.J. & Scott, R. 1982. Bracken as an energy crop? In: *Solar world forum,* edited by D.O. Hall & J. Morton, vol. 2, 1239-1247. Oxford: Pergamon.

Cooke, A.S., Bell, A.A. & Haas, M.B. 1982. *Predatory birds, pesticides and pollution.* Cambridge: Institute of Terrestrial Ecology.

Harding, P.T., Greene, D.M., Preston, C.D., Arnold, H.R. & Harper, R.J. 1983. Biological Records Centre. *Annu. Rep. Inst. terr. Ecol. 1982,* 44-45.

Heal, O.W. & Perkins, D.F. 1976. IBP studies on montane grassland and moorlands. *Phil. Trans. R. Soc. B,* **274,** 295-314.

Heal, O.W. & Perkins, D.F. 1978. *Production ecology of British moors and montane grasslands.* Berlin: Springer.

Heath, J. & Perring, F.H. 1978. *Biological Records Centre.* Cambridge: Institute of Terrestrial Ecology.

Hill, M.O. 1983. Effects of grazing in Snowdonia. *Annu. Rep. Inst. terr. Ecol. 1982,* 31-32.

Hornung, M. 1984. The impact of upland pasture improvement on solute outputs in surface waters. In: *Agriculture and the environment,* edited by D. Jenkins, 150–154. (ITE symposium no. 13). Cambridge: Institute of Terrestrial Ecology.

Hornung, M., Reynolds, B., Hughes, S., Stevens, P.A. & Hatton, A.A. 1983. Some factors controlling geochemical cycling in an upland grassland. *Annu. Rep. Inst. terr. Ecol. 1982,* 94-98.

Hudson, P.J. 1984. Some effects of sheep management on heather moorlands in northern England. In: *Agriculture and the environment,* edited by D. Jenkins, 143-149. (ITE symposium no. 13). Cambridge: Institute of Terrestrial Ecology.

Hughes, R.E. 1958. Sheep population and environment in Snowdonia (North Wales). *J. Ecol.,* **46,** 169-190.

Hughes, R.E., Dale, J., Lutman, J. & Thomson, A.G. 1975a. Effects of grazing on upland vegetation in Snowdonia. *Annu. Rep. Inst. terr. Ecol. 1974,* 46-50.

Hughes, R.E., Dale, J., Mountford, M.D. & Ellis-Williams, I. 1975b. Studies in sheep populations and environment in the mountains of north-west Wales. II: Contemporary distribution of sheep populations and environment. *J. appl. Ecol.,* **12,** 165-178.

Institute of Terrestrial Ecology. 1978. *Upland land use in England and Wales.* (CCP 111). Cheltenham: Countryside Commission.

Jenkins, D., Watson, A. & Miller, G.R. 1963. Population studies on red grouse *Lagopus lagopus scoticus* (Lath.) in north-east Scotland. *J. Anim. Ecol.,* **32,** 317-376.

Jones, W.D. 1978. A review of some economic aspects of hill and upland farming. In: *The future of upland Britain,* edited by R.B. Tranter, 50-74. (CAS paper no. 2). Reading: Centre for Agricultural Strategy, University of Reading.

Marsh, J. 1984. Recent economic trends in British agriculture. In: *Agriculture and the environment,* edited by D. Jenkins, 28-33. (ITE symposium no. 13). Cambridge: Institute of Terrestrial Ecology.

Miles, J. 1981. *Effect of birch on moorland.* Cambridge: Institute of Terrestrial Ecology.

Miller, G.R. 1979. Quantity and quality of the annual production of shoots and flowers by *Calluna vulgaris* in north-east Scotland. *J. Ecol.,* **67,** 109-129.

Miller, G.R. & Watson, A. 1978. Heather productivity and its relevance to the regulation of red grouse populations. In: *The production ecology of British moorlands and montane grasslands,* edited by O.W. Heal & D.F. Perkins, 277-285. Berlin: Springer.

Miller, G.R., Miles, J. & Heal, O.W. 1984. *Moorland management: a study of Exmoor.* Cambridge: Institute of Terrestrial Ecology.

Mills, S. 1983. French farming: good for people, good for wildlife. *New Scient.,* **100,** 568-571.

Mitchell, B., Staines, B.W. & Welch, D. 1977. *Ecology of red deer: a research review relevant to their management in Scotland.* Cambridge: Institute of Terrestrial Ecology.

Moss, R. & Miller, G.R. 1976. Production, dieback and grazing of heather (*Calluna vulgaris*) in relation to numbers of red grouse (*Lagopus l. scoticus*) and mountain hares (*Lepus timidus*) in north-east Scotland. *J. appl. Ecol.,* **13,** 369-377.

Newton, I., Robson, J.E. & Yalden, D.W. 1981a. Decline of the merlin in the Peak District. *Bird Study,* **28,** 225-234.

Newton, I., Davis, P.E. & Moss, D. 1981b. Distribution and breeding of red kites in relation to land-use in Wales. *J. appl. Ecol.,* **18,** 173-186.

Newton, I., Davis, P.E. & Davis, J.E. 1982. Ravens and buzzards in relation to sheep-farming and forestry in Wales. *J. appl. Ecol.,* **19,** 681-706.

Nicholson, I.A. 1974. Red deer range and problems of carrying capacity in the Scottish highlands. *Mammal Rev.,* **4,** 103-118.

Rawes, M. 1981. Further results of excluding sheep from high-level grasslands in the North Pennines. *J. Ecol.,* **69,** 651-669.

Rawes, M. 1983. Changes in two high altitude blanket bogs after the cessation of sheep grazing. *J. Ecol.,* **71,** 219-235.

Red Deer Commission. 1981. *Red deer management: a practical book for the management of wild red deer in Scotland.* Edinburgh: HMSO.

Smith, R.S. 1982. *The use of land classification in resource assessment and rural planning.* Cambridge: Institute of Terrestrial Ecology.

Staines, B.W., Catt, D.C., Welch, D. & Scott, D. 1982. Red deer and forestry: current work by the Institute of Terrestrial Ecology. *Deer,* **5,** 400-402.

Watson, A. & Moss, R. 1978. Population ecology of red grouse. *Annu. Rep. Inst. terr. Ecol. 1977,* 18-21.

Welch, D. 1981. Diurnal movements by Scottish blackface sheep between improved grassland and a heather hill in north-east Scotland. *J. Zool.,* **194,** 267-271.

Welch, D. & Rawes, M. 1964. The early effects of excluding sheep from high-level grasslands in the northern Pennines. *J. appl. Ecol.,* **1,** 281-300.

The use of remote sensing for monitoring change in agriculture in the uplands and lowlands

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1 Introduction

In assessing the impacts of agriculture upon wildlife and semi-natural habitats, it is necessary to understand, first, the nature of these impacts, and, second, the location and extent of the areas where the effects are felt. The first requirement (how agricultural practices impact upon ecosystems) is considered elsewhere in this symposium volume. The questions of where such conflicts exist or may arise, their degree, extent and duration are equally important if effective measures are to be found for minimizing them, whether through statutory provisions or by voluntary means.

Specific questions which must be answered include the following.

- Where do vulnerable ecosystems and habitats occur?
- Where are agricultural methods being practised which result in conflict with ecological interests?
- Where are changes occurring in agriculture which may affect the situation?
- What is the extent of the effect, locally and nationally? For example, is there localized pressure on a commonly occurring habitat, or is the threat widespread and the habitat rare?
- What are the dynamics of the problem? For example, what is the rate of encroachment of arable farming on permanent grassland?

The range of information needed to answer these questions is considerable. Identification of habitat types demands a knowledge of the basic topography, vegetation cover, pedology, hydrology, etc. In order to evaluate specific agricultural impacts, it is necessary to distinguish patterns of cultivation, often on a field-by-field basis. Further, much of this information must be collected repetitively in order to provide a monitoring capability.

This information is needed at very local scales (eg in assessing potential impacts of agricultural development on a Site of Special Scientific Interest), at broad national scales to evaluate the overall effects of changes in agricultural practices, and at intermediate scales (eg to monitor agricultural impact in a National Park).

In practice, although elements of such an information base exist (eg Coppock 1976; Coleman 1961; Soil Survey of England and Wales 1983; Heath & Perring 1978) and a number of potentially useful sources is described elsewhere in this volume (Ball 1984; Bunce *et al.* 1984), the available information falls short of the requirements identified above.

On the face of it, remote sensing from satellites or aircraft offers an attractive means of collecting much of the necessary information on land cover that would otherwise be so time-consuming and costly to acquire. This paper is an attempt to evaluate its suitability as a technique for mapping and monitoring rural land cover in the UK, to identify inadequacies in existing techniques, and to suggest research needed to minimize these shortcomings.

2 Methodology for obtaining information

2.1 Terminology

Strictly, the term 'remote sensing' covers all methods of data acquisition in which the sensor is not in physical contact with the object under observation. This paper adopts the narrower, and more useful, definition of Reeves *et al.* (1975): 'Observation of the earth's surface in various parts of the electromagnetic spectrum by sensors carried on aerial or space platforms'. A further restriction has been introduced in that the paper covers only those systems which record in digital form. Aerial photography, whose use in agricultural and ecological survey is now routine, is not considered in this review.

2.2 Survey methods

Survey from aircraft in the UK, until recently, has been confined to photographic methods and to infra-red