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# Models for predicting changes in rural land use in Great Britain

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## *1 Introduction and review*

In recent years, models have been used increasingly to solve problems which involve interacting factors and where changes in one parameter are linked to a series of events. Such models are necessarily simplifications of reality, yet they provide a means of manipulating large quantities of information and enable the nature and effect of the interacting forces to be more readily understood. This paper presents a review of relevant recent work on modelling changes in rural land use, and describes the experience of the authors in the field.

The first stage in developing such models is to consider the existing structure of land use and the forces maintaining such a structure. The major uses of rural land are agriculture and forestry. Some 78% of the total area of the UK is in agricultural use (Central Statistical Office 1983; MAFF 1983a) and 9% in forestry. Recently, there have been 2 main changes in the land use structure of the UK. First, the total agricultural area has fallen by some 360 000 ha over the last 10 years and, second, the area under grass and herbage has fallen by 811 000 ha over the same period (MAFF 1983a, b). The former losses have been primarily to forestry, which therefore occupies a prominent role in any consideration of future land use change, but also to urban development. To compensate for the reduction in area under grass, there has been an increase in the area of wheat and oilseed rape.

Although the MAFF census data provide detailed information on crops, the data available for GB on semi-natural habitats are fragmented. Information has been co-ordinated for many species, but, apart from specific habitats, eg lowland heaths, there has been no strategic study comparable to that by MAFF. However, the Merlewood land classification system (Bunce *et al.* 1981a) has produced categories of land use for GB which convey more information on habitats, although further subdivision and amplification are required, as exemplified by Table 1.

A further recent trend is the substantial increase in crop productivity since 1971, due, in part, to intensification of agricultural practices. These practices have been criticized by, amongst others, the Countryside

*Table 1.* Categories of land use recorded in the field survey, carried out in 1977–78, in 256 squares based on the 32 land classes of the Merlewood land classification system, and predicted areas for GB ('000 ha)
(For further details of categories, see senior author)

| | | |
|---|---|---|
| 1 | Perennial rye-grass ley | 2244.5 |
| 2 | Italian rye-grass ley | 247.6 |
| 3 | Rye-grass/cock's-foot ley | 205.5 |
| 4 | Cock's-foot ley | 97.2 |
| 5 | Unspecified ley | 530.1 |
| 6 | Cut hay/silage | 258.0 |
| 7 | Perennial rye-grass pasture | 641.6 |
| 8 | Mixed permanent pasture | 953.0 |
| 9 | Improved pasture | 1024.3 |
| 10 | Neglected pasture | 624.8 |
| 11 | Bent/fescue pasture | 453.4 |
| 12 | Mixed upland pasture | 298.5 |
| 13 | Rush infested | 168.5 |
| 14 | Bracken infested | 62.2 |
| 15 | Hair-grass/mat-grass | 42.7 |
| 16 | Heather | 964.0 |
| 17 | Bilberry | 23.6 |
| 18 | Bracken | 316.7 |
| 19 | Rush marshland | 202.6 |
| 20 | Purple moor-grass | 433.0 |
| 21 | Hare's-tail cottongrass | 69.9 |
| 22 | (Unassigned) | — |
| 23 | Herb-rich pasture | 22.1 |
| 23 | Ploughed/fallow | 179.5 |
| 25 | Derelict | 83.6 |
| 26 | Wheat | 1112.0 |
| 27 | Barley | 2169.6 |
| 28 | Oats | 197.2 |
| 29 | Sugar beet | 150.0 |
| 30 | Kale | 47.8 |
| 31 | Roots | 154.1 |
| 32 | Potatoes | 198.4 |
| 33 | Horticulture | 66.2 |
| 34 | Beans/peas | 214.6 |
| 35 | Orchards | 65.7 |
| 36 | Roads | 340.0 |
| 37 | Urban | 1833.2 |
| 38 | (Unassigned) | — |
| 39 | Railway | 54.4 |
| 40 | Cliffs/sand/mud | 166.7 |
| 41 | Canal/stream | 84.6 |
| 42 | Lake | 329.3 |
| 43 | Quarry/pit | 51.2 |
| 44 | Formal recreation areas | 230.5 |
| 45 | (Unassigned) | — |
| 46 | Rock | 143.9 |
| 47 | Hardwood copse | 85.5 |
| 48 | Mixed copse | 9.9 |
| 49 | Conifer copse | 11.6 |
| 50 | Hardwood shelter belt | 21.0 |

| | | |
|---|---|---|
| 51 | Mixed shelter belt | 15.2 |
| 52 | Conifer shelter belt | 8.5 |
| 53 | Gillside wood | 31.3 |
| 54 | Scrub | 201.3 |
| 55 | Hardwood | 467.5 |
| 56 | Conifer woodland | 1510.2 |
| 57 | Mixed woodland | 145.2 |
| 58 | Timothy | 135.7 |
| 59 | Lucerne | 21.2 |
| 60 | Maize | 40.3 |
| 61 | Mat-grass | 427.4 |
| 62 | Mixed peatland | 331.9 |
| 63 | Subarctic vegetation | 60.4 |
| 64 | Bilberry mixture | 31.9 |
| 65 | Cross-leaved heath | 6.1 |
| 66 | Rye | 6.9 |
| 67 | Heath rush | 6.4 |
| 68 | Mixed upland grassland | 171.8 |
| 69 | Mixed upland moor | 494.0 |
| 70 | Deergrass/heather | 162.7 |
| 71 | Rush mixture | 18.2 |
| 72 | Heather/cottongrass | 390.2 |
| 73 | Heather/bilberry | 202.8 |
| 74 | Burnt | 22.6 |
| 75 | Parkland | 27.9 |
| 76 | Maritime grassland | 19.3 |
| 77 | Oilseed rape | 46.4 |
| 78 | Oats/barley | 30.9 |
| 79 | Salt marsh | 29.2 |
| 80 | New urban | 182.6 |

Review Committee (1978). In addition, the more recent comments by Shoard (1980), Body (1982), and Bowers and Cheshire (1983) suggested that Exchequer and European Community support under the Common Agricultural Policy was largely responsible for the intensification of farming, thus encouraging public interest in the future of British agriculture and its associated impact on wildlife habitats. These concerns have also stimulated the use of models to predict the consequences of developments in agriculture and other land uses in response to macro- and microeconomic change.

The most comprehensive model of British agriculture was developed in the late 1960s to examine the effects of entry into the EC. This large-scale, aggregated linear programming (LP) model is based on more than 40 representative farm types and has proved successful in examining supply in sectors of the industry and the policy measures affecting such supply (Thomson & Buckwell 1979). However, constant revision and updating of the model with sufficiently accurate data to cover the wide range of farm types and practices are proving difficult, and the implications for wildlife have to be inferred.

The effect on British grassland of a variety of economic pressures on livestock producers was examined, using models, by Lazenby and Doyle (1981). Suggestions were made as to how these producers could survive by making better utilization of grassland, more use of clovers, and establishing more preferred grass species. The associated ecological implications were not examined.

The Centre for Agricultural Strategy (1980), when developing a strategy for the UK forest industry, needed to examine the effects on agriculture of increased plantings of forestry. It was considered feasible to replace 1M ha of upland grazings with forestry by the year 2000. The modelling exercise indicated that, if 100 000 ha of hill land were improved, then the loss of 1M ha to forestry would only reduce the breeding ewe population by 160 000, indicating that afforestation also has influences outside the actual land covered by trees.

Although there is no definitive statement on agricultural policy, projections of the future of British agriculture were made by MAFF (1979b) when preparing *Farming and the nation* (MAFF 1979a). It considered projected yields, assumptions about efficiency of resource use, alternative levels of producers' real prices, and developments in the demand for food. However, the projection of areas of crops differs somewhat in comparison with the provisional figures of the 1983 census.

At a more local level, Maxwell *et al.* (1979) developed a model to examine the potential for integrating farming and forestry, comparing the effects of different land use distributions on stock densities and economics on a local scale. Unfortunately, this model is only appropriate to conditions operating in the southern uplands of Scotland, as indicated by MacBrayne (1981). Bishop (1978) employed LP techniques to examine the interactions between land uses in Cumbria and to optimize for production. His model indicated that the area of forestry in the county could be increased by 42%, within the constraints governing land use, without having a significant effect upon farming output. Bishop incorporated assessments of conservation interest and showed how the approach could be adapted for wildlife objectives. More recently, Smith and Budd (1982) also used LP for examining forestry/farming strategies in the Sedbergh district of Cumbria. Other comparable studies have been carried out by Dane *et al.* (1977) and Miron (1976).

Apart from the models described above, other techniques such as checklists, matrices, networks and flow diagrams have been widely used in attempts to formalize intuitive assessments of future change. Occasionally, detailed studies of ecological change in particular habitats are available from which future patterns can be inferred, eg those relating to vegetation summarized by Miles (1979). Such an approach was used by Ball *et al.* (1982) to examine potential changes in the vegetation of the uplands of Britain. The rate and direction of change were predicted using explicit criteria, demonstrating the use of informed ecological opinion.

Although not specifically concerned with wildlife, the study by Ball *et al.* contains much information relevant to wildlife habitats associated with land use change.

Similarly, many of the various studies on landscape contain implicit information on habitats, although much of it is in anecdotal form.

It is also possible to transform the information on change into more specific expressions using Markov models. A general discussion of their use is given by Jeffers (1982). From the transition matrix of one state to another and the known area of each parameter, the amount of each type can be predicted over a series of time steps, as well as the expected final composition and rate. Although certain simplistic assumptions are made, eg linearity of change, such models provide an approximation of future states that are likely to be more reliable than direct extrapolation. However, the transition probabilities are critical and it is often difficult to obtain adequate information on their likely values.

There have been several recent applications of such models. Vandeveer and Drummond (1978) demonstrated their use in estimating land use change. Bellefleur (1981) has applied them to study succession and the behaviour of forest types. Markov models have also been applied in agriculture (eg by Buckwell *et al.* 1983), in the Scottish dairy industry, but again have not been directly applied to the present subject. Even from the brief summary above, it will be seen that such models are useful in helping to clarify the consequences of possible changes in rural land use and the associated wildlife habitats.

There is an extensive literature on the use of models in ecology. Roberts *et al.* (1983) and Spain (1982) give useful summaries of the present situation, and provide valuable introductions to the subject.

Although models have been used in associated studies, they have not been applied directl\ to the future of wildlife habitats. This lack of application is in part due to a lack of appreciation of their usefulness by conservationists, and in part to the lack of an adequate data base for developing reliable models.

*2 Detailed examples*

The first example is provided by a systematic model for examining the effects of competing land uses on the current pattern of land use developed during a study commissioned by the Department of Energy. This study, termed the Land Availability Study (LAS), aimed to determine the amount of land which might become available for growing trees for energy under various economic assumptions. The resultant Land Availability Model (LAM) provided a means for predicting change in land use at the site-specific level (Mitchell *et al.* 1983a).

The core of the LAM lay in the Merlewood land classification system (Bunce *et al.* 1981a; 1982). This classification of land is based on an analysis of the environmental attributes derived from maps of some 1228 $km^2$ squares on a grid covering GB. The analysis results in the definition of 32 land classes. Eight randomly selected squares from each land class were used for the field survey of the land use categories given in Table 1. These 256 'fully characterized' squares are used in the analysis with the areas of land under the various categories to obtain estimates for GB (Table 1). Estimates derived in this fashion accord closely with official statistics (Bunce *et al.* 1982). Similarly, potential uses for land in the sample squares can be postulated and the resultant GB figures estimated. This mechanism forms the basis of the LAM, which has the advantage over other models that it provides information on areas of new land use, as well as on the types of land use which would be lost. An assessment of the environmental impact of various practices can therefore be made.

The criterion for predicting change in land use in the LAS was financial performance, ie that land use which achieved the highest net present value (NPV) over 60 years, at a given discount rate. Economic data for 1977 were used. No judgements were made as to whether the predicted land use change could be accommodated on the farm (see below).

The LAM enabled the comparison of the relative financial performance of different, actual and postulated land uses for individual areas of land in the sample squares, and provided estimates for GB of the areas of new forestry for energy, the potential production and the likely species, thus indicating possible future developments. In addition, the area and nature of displaced land use categories were given, showing that the implications of potential change can be predicted in terms of their associated habitats.

To obtain an estimate of financial performance, a series of some 140 sets of economic values was produced in order to include a range of management systems and yields for forestry. The management systems were conventional forestry for timber, forestry for energy and timber, and single stem and coppice energy plantations. Sets of NPVs were calculated for each model for a range of discount rates, timber values and assumed values of wood for fuel. Current British agricultural practice was described by, and classified into, some 40 production systems. Investigations showed that it was not possible to allocate fixed costs to particular enterprises, so, for purposes of comparison, the NPV of the enterprise gross margin over 60 years was taken. The constraints arising from national planning controls, eg nature reserves, public pressures and legal impediments to change in land use, were included by noting the significance of such constraints on each of the sample squares. Their probability of restricting forestry was used in the model, but could equally be applied to changes in agricultural practice.

The LAM enabled examination of the effects of a wide range of economic assumptions on the areas of land predicted as being available for forestry. One set of assumptions used was: to provide wood for production of pipeline gas, increasing energy prices, constant timber and agricultural costs and revenues, and a 5% discount rate.

With this example, some 4.6M ha of land were predicted to change to forestry (all with an energy component) with a potential production of some 38M dry tonnes per year of wood for energy and 28M $m^3$/yr of timber. However, when constraints were taken into account, some 1.8M ha of land were estimated to change to forestry producing some 16M d t/yr of wood for energy and 11M $m^3$/yr of timber (summarized by Mitchell *et al.* 1983a).

The incorporation of nature conservation constraints in the LAM demonstrates the way in which conflicts between development, in this case forestry, and wildlife can be assessed. The system of comparison of potential and actual uses for units of land can be readily modified to examine the likely future of wildlife habitats such as small woodlands or herb-rich grasslands. Similarly, the effects of possible changes in the countryside, eg canalization of rivers, can be examined at a strategic level. The economic implications of restricting agricultural improvements can also be assessed in comparative terms. Further, the examination of the loss of agricultural land to wood energy plantations demonstrates the way in which impacts can be predicted. Such an approach is already being used by the Highland Regional Council (Bunce *et al.* in press) to examine conflicts between planning constraints, nature conservation, agricultural improvement, and red deer production.

A study designed to supplement a weakness in the LAS provides a second example, in that the estimate of the potential for forestry did not consider the extent to which this was practicable on farms. The LAS was therefore extended to consider the practical and financial implications of incorporating the levels of forestry already predicted into the farm business environment using LP models of 'typical' farms (Mitchell *et al.* 1983b).

LP allocates scarce resources (eg land, labour and capital) amongst competing uses (eg livestock and forestry) so as to maximize or minimize some objective (eg profit or loss). The manager contemplating the introduction of forestry would have to integrate it with his current pattern. The study is therefore analogous to that of Bishop (1978).

Models for 4 'typical' farms were developed, each representative of a land class and each with farm area and fixed costs similar to the MAFF Farm Management Survey group of farms, and with equivalent geographical locations and patterns of land use. Each model selected the combination of current agricultural or possible forestry land uses that maximized farm income, subject to constraints on key resources, such as land, monthly labour and machinery, the cost of forestry contractors, and the availability of working capital.

Initially, each model reproduced the current pattern of land use on the farm, establishing the *status quo*. Next, the forestry (in terms of area by management system, species and yield) predicted by the LAS was inserted into the farm land use pattern, replacing any existing land use which proved less financially viable. The model was then run to examine the effects of such a change in land use on the on-farm management factors. In broad terms, the exercise confirmed that the area of forestry suggested by the LAS could be accommodated on farms, providing certain 'key' resources such as capital were available. The size of the resource required varies with farm type. If larger areas of forestry than those predicted by the LAS are allowed, then economics of scale start to take effect. In some circumstances, farm income may be increased by increasing the area under forestry. As with the previous model, although being applied for forestry objectives, a comparable approach could be used for conservation, with wildlife habitats being designated as 'key' resources.

Our third example, developed for this symposium, demonstrates the wide application of the Merlewood land classification system by using the land classes to examine the effects of different possible futures (scenarios, Table 2) on patterns of rural land use with regard to agriculture and forestry. The implications of these scenarios (listed below) were applied directly to the categories of land use given in Table 1, as, for the present purpose, it was required to assess the general changes that might result. In more detailed future studies, separate units of land should be examined from individual one km squares and combined into the land classes, as done in the LAS and by Cowie and Williams (1982). The scenarios were developed by the authors working as a multidisciplinary group, and are summarized below.

*Table 2.* Transfers from the land use categories of Table 1 used in the scenarios, with resultant changes over the whole of Great Britain and the proportionate changes in each category

For transfers: low = 1–5%; medium = 5–25%; high = over 26%
For GB area change: low = 0.1–0.5%; medium = 0.6–1.0%; high = over 1.1%
For % change in each land use: low = 1–5%; medium = 5–25%; high = over 26%

*Transfers:*

| | | |
|---|---|---|
| Scenario 1: | high: | 18 to 14, 54 to 8 |
| | medium: | 9/10 to 7/8, 19 to 13, 11 to 10. |
| | low: | 1–9 to 26/27 |
| Scenario 2: | high: | none |
| | medium: | 26–28 to 1–6, 26–28 to 77 |
| | low: | 29–31/33/34 to 1–6 |

Scenario 3: high: 13 to 19, 14 to 18, 16 to 69, 14/18/54 to 56, 68 to 69
medium: 8 to 9, 12/13/15/61/68 to 56, 62 to 20, 61 to 69
low: 11 to 14/54, 11 to 56, 12/15 to 70

Scenario 4: high: 10 to 18, 16 to 69
medium: 7/8 to 1, 9 to 7, 11/14 to 9, 69 to 68, 73 to 68.
low: 1 to 30/31, 18 to 14, 19 to 13, 53/54/61/68 to 9

Scenario 5: high: none
medium: none
low: 10/13 to 47, 53–55 to 56, 11/12/14–21 to 56, 61 to 56, 64/68/69/72/73 to 56

*GB area change in each land use (gains in area = +;* losses in area = −):

Scenario 1: high: −9, −26, −27
medium: none
low: +1, −2, −3, −4, −5, −6, +7, −8, −10, −11, +13, +14, −18, −19, −54

Scenario 2: high: +1, −26, −27
medium: none
low: +2, +3, +4, +5, +6, +29, +30, +31, +33, +34

Scenario 3: high: +16, +56, +69
medium: +9, −61
low: −8, −11, −12, −13, −14, −15, −18, +19, −20, −54, −62, −68

Scenario 4: high: none
medium: −10
low: +1, +7, +8, +9, −11, −12, −13, +14, −16, −18, −19, +30, +31, −53, −54, −61, +68, +69, −73

Scenario 5: high: +56
medium: none
low: −10, −11, −12, −13, −14, −15, −16, −17, −18, −19, −20, −21, +47, −53, −54, −55, −61, −64, −68, −69, −72, −73

*% change in each land use:*

Scenario 1: high: +14, +27, −54
medium: −3, −4, −6, +7, −8, −9, −10, −11, −18, −19, −26
low: +1, +13

Scenario 2: high: +1, +2, +3, +4, −26, −27
medium: +6, +30, +33
low: +29, +31, +34

Scenario 3: high: −11, −12, −13, −15, +16, +19, +56, −61, +62, −68, −69
medium: −8, +9, −14, −18, −20
low: −54

Scenario 4: high: +30, +31, −53, −54
medium: +9, −10, −11, −12, −14, −16, −18, +68, +69, −73
low: +1, +7, +8, −13, −19, −61

Scenario 5: high: +47, +56
medium: −10, −11, −12, −13, −14, −15, −16, −17, −19, −20, −21, −61, −64, −68, −69, −72, −73
low: −18, −53, −54, −55

i. *Dairying becomes less profitable*
Grasslands within enclosed land are likely to be mainly affected, as opposed to the hill land in scenarios (iii) and (iv).
(a) Higher grade grassland moves to cereals or other cash crops.
(b) Lower grade grass and herbage are likely to be improved.

ii. *Cereals become less profitable*
These changes are considered to apply mainly to the area of tillage.
(a) Cereals move to grass.
(b) Cereals move to oilseed rape or more profitable crops.

iii. *Hill subsidies are reduced*
This reduction will lead to a decline in agricultural use of the uplands and would involve subtle ecological effects, in addition to the following major changes.
(a) Pasture deteriorates in quality.
(b) Bracken invasion increases.
(c) Area of dwarf shrub vegetation increases.
(d) There is a trend toward forestry.

iv. *Hill and upland sheep become more profitable*
This scenario is the reverse of (iii) and would result in a general increase in the use of upland vegetation, with associated effects on its ecology. The changes would thus be as follows.
(a) Marginal pasture and drainage are improved.
(b) There is a trend away from conversion of agricultural land to forestry.
(c) Dwarf shrub vegetation is converted to pasture.

v. *Confidence in, and support for, forestry increase*
Changes within grassland categories were not considered likely, in comparison with the other scenarios, and thus the probable changes are as follows.
(a) Native vegetation is lost to forest.
(b) There is a general increase in coniferous forest.

The majority of transfers between the land use categories (Table 2) for the different scenarios were in the order of 5-10%. The loss to urban development, although significant in the long term, is below the level of change that can be considered by this model. The results showed some categories changing considerably, because some trends were to one land use, eg coniferous woodland (Table 2). In other examples, feedback mechanisms are operated, buffering change in land use as described by Best (1976). For example, in scenario (i), the loss of high yielding pastures to barley is compensated by the change of poorer pastures into good quality sward. It is only when a major land use category accumulates inputs from other uses that major changes occur. The complexity of feedback and the *ad hoc* nature of the present study indicate that more in-depth studies are required to obtain more reliable information on transfers between land uses. However, it is necessary to consider whether comparable patterns are followed in habitat change as some evidence suggests that change can take place very quickly. Even so, the transfers in the main crops are equivalent to the changes in recent years indicated by MAFF (1983a, b), and the change in forest area is comparable to that which has taken place over the last 10 years, suggesting that the projected changes are reasonable.

The majority of land uses incorporated in the above example were selected to demonstrate the implication for the associated semi-natural habitats, eg the changes in scenario (iii) directly affect the composition of grassland types of importance to conservation. A comparable study could be developed by identifying specific habitats, eg hedgerows and streams, and examining the implications of changes in rural land use for their occurrence, in order to assess potential national changes and critical influences on conservation. For example, the effects of stopping straw burning could be compared with peatland drainage.

As the proportions of the different categories of land use vary through the land classes, the system can be used to examine regional differences. For example, in scenario (iii), the effect on scrub is felt mainly in the downs of south-east England and in the uplands of Wales, Cumbria and Scotland. Markov models (see above) could be used with field data to investigate the implications of transfers. R. Woods (pers. comm.) has already used this method to examine the pattern of urban growth. Further developments could be made by using the technique to compare the potential of individual units of land in a similar manner to that described by Bunce *et al.* (1981b) and Mitchell *et al.* (1983a). Furthermore, the location of areas with identified changes could be examined subsequently in the field. In this way, representative areas could be selected for case studies.

### *3 Discussion*

In general, agriculture is likely to have 2 effects on habitats. The first involves changes in practices, eg spraying, whereas the second involves changes in land use structure, eg grassland to barley, and the implications of both may be examined as described above. Forestry, although not considered directly in this symposium, is likely to have the most significant effect on wildlife habitats in the uplands (CAS 1980), and hence discussions of the likely impact of forestry in this paper are particularly relevant. In the lowlands, more diverse influences are involved, which therefore require more careful appraisal.

As stated at the outset, no adequate data base is available for the distribution and extent of semi-natural habitats in GB. Some models, for example the classic Massachusetts Institute of Technology model of economic growth, have shown the severe limitations of inadequate data. It is first necessary to design a conceptual framework and then to develop a suitable data base, as this is a prerequisite for successful prediction. The subsequent proposals follow that essential first stage.

i. Expansion of the existing data base for GB on semi-natural habitats including:
   (a) a detailed assessment of the major semi-natural habitats and land uses in GB, defined on a variety of criteria relating to vegetation and topographic factors;
   (b) a survey of farmer attitudes and beliefs in order to build dynamic elements into the *status quo* position defined in (a);
   (c) definition of past, present and future management practices and the way they are likely to affect semi-natural habitats;
   (d) the correlation of available ground truth information with remote sensing data from aerial photographs and satellites in order to investigate the potential of automation in mapping and as a further basis for modelling;
   (e) the study of key species to conservation, eg badgers and otters, as a basis for modelling threats to their existence (cf Macdonald *et al.* 1981).

   The Merlewood land classification system provides a sampling framework for the above and various studies are planned, or in progress, to meet some of these objectives.

ii. Monitoring of habitats in order to model past development, as a basis for prediction. The essential first stage is to define the objectives of monitoring, eg loss of hedgerows. It is also necessary to record not only the target but also the underlying factors, so that the processes of change can be understood. Three main activities would be involved:
   (a) future monitoring of habitats or attributes for which previous data are available.
   (b) the use of past aerial photographs to determine changes in habitats;
   (c) the use of previous series Ordnance Survey maps to study factors such as urban growth, as a basis for predicting future patterns, as in Markov models.

iii. Identification of representative areas for case studies of particular habitats and also the incorporation of extant detailed local studies.

iv. Post-audit assessments, where checks are made against previous predictions. The land budget model discussed by the CAS (1980) is an example.

v. Simple models, as used in the LAS, can be readily applied by conservationists and have the potential of being developed to examine the effects of agricultural practice on the wildlife habitats of GB. They have the advantage of being readily understood and have been shown to reflect conventional wisdom.

vi. Higher order models, eg Markov models, have a potential which has not yet been realized. The data collection defined above should provide sufficient data for their successful application.

These proposals are concerned with direct habitat recording, but the major force for change is primarily economic. Hence, it is important to incorporate economic factors at some stage in the modelling process, if only as a series of options of progressive severity, as the sensitivity of the systems involved is of major significance.

Models are widely used successfully in many disciplines and the discussion above shows that they have the potential for application to rural land use change. Their use could be a major factor in determining impacts and enabling conservationists to foresee threats to wildlife habitats, and, although they cannot be validated by conventional means, they are useful in exploring options.

## *4 Summary*

The purpose of the paper is to assess the current state of the art and then to examine how appropriate models could be developed. Models, whilst being necessarily simplifications of reality, provide a means whereby the behaviour of complex systems can be understood. A review is provided of recent models used and it is concluded that, although their potential has been demonstrated in associated disciplines, directly applicable examples are not available. Three models based on the Merlewood land classification system are described in some detail, to demonstrate the feasibility and manner in which models could be developed to predict changes in land use and associated habitats in Britain. Six areas for further research were identified: expansion of the existing data base on wildlife habitats in Britain as a basis for modelling; increased monitoring of land use change; definition of representative case studies to assist in understanding the dynamics of change; the conduct of post-audit assessments of predictions; the development of simple models for use by conservationists; and, finally, the development of higher order models for predicting threats to wildlife habitats.

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# Trends in mechanization in the lowlands

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## *1 Introduction*

Large-scale mechanized farming has only developed since the 1930s. Between 1930-58, the number of tractors in UK agriculture increased 33-fold from about 12 000 to over 400 000 (MAFF 1930-82). Over the same period, the number of working horses fell by a factor of 8 to about 100 000 (see Figure 1). From 1958-83, the number of tractors increased only slightly, while the working horse became a museum piece. This dramatic change in sources of energy for agriculture was associated with substantial changes in the countryside, some, but by no means all, caused by this mechanical revolution.

## *2 Energy available on UK farms*

Excluding crop drying, most energy on UK arable farms is consumed in the cultivation of the land. Presumably, therefore, changes in tractor numbers and power available mainly reflect changes in land management. Table 1 classifies wheeled tractor numbers by horse power (HP) and horse power per hectare for the post-War period. Since the initial rise in tractor numbers, there was a substantial increase in tractor power on farms, and this increase is probably continuing. In 1962, only 0.9 HP was available per ha; by 1972, this figure had nearly doubled to 1.5, and in the following decade to 1982 there was yet another

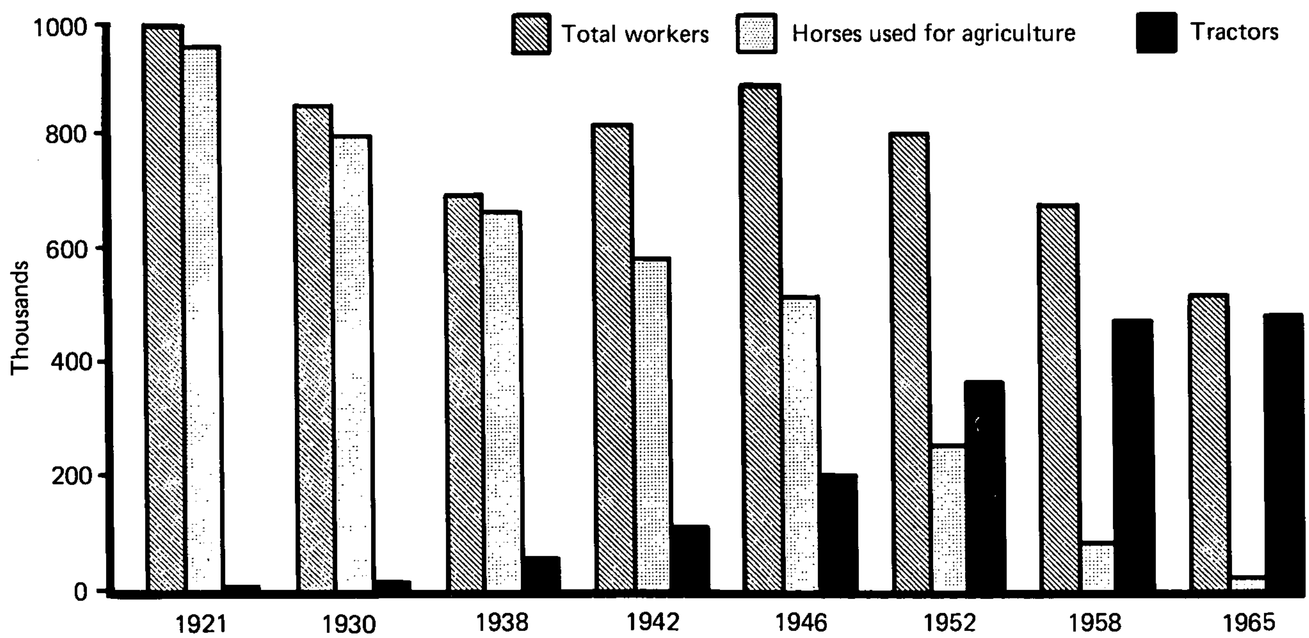


*Figure 1. Labour, horses and tractors in Great Britain, 1921–65*