Bracken (*Pteridium aquilinum* (L.) Kuhn) infestation of rough grazing land in the catchment of the River Tyne, northern England

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ABSTRACT

The distribution of bracken (*Pteridium aquilinum* (L.) Kuhn)within the catchment of the River Tyne, Northern England, was surveyed in the field by stratifying sampling effort within land classes of a national environmental landscape classification developed by the Institute of Terrestrial Ecology (I.T.E.). A total of 182 1-km squares were surveyed in 1991 (equivalent to 6.3% of the catchment). The areas of bracken and rough grazing land differed significantly between land classes. Bracken was estimated to cover 0·7% of the total land surface, and 1·9% of rough grazing land, within the catchment. The results are compared with those of previous surveys of bracken, and it is concluded that a standard survey method is needed if such comparisons are to be statistically reliable. It is proposed that the I.T.E. land classes offer a suitable framework for the organisation of future surveys.

KEYWORDS: ferns, agricultural weed, survey, landscape classification.

INTRODUCTION

Bracken, *Pteridium aquilinum* (L.) Kuhn (Dennstaedtiaceae), is generally regarded as a serious weed of agriculturally marginal land throughout Britain (Smith & Taylor 1986; Taylor 1990). It is an invasive species which thrives in a wide range of habitats (Grime *et al.* 1988). Worldwide it is said to be the most widespread of all vascular plant species (Page 1982). The success of bracken lies in its ability to withstand grazing, burning and chemical control measures through survival of its rhizomes, and the ability of its spores to colonise readily disturbed habitats (Page 1976, 1982; Kirkwood & Archibald 1986; Dyer 1990; Marrs *et al.* 1993; Pakeman & Marrs 1992).

Dense stands of bracken reduce the area of forage available for livestock. Its fronds are poisonous to sheep and cattle (Evans *et al.* 1982; MacLeod 1982; Miller *et al.* 1990). Stands can also act as a reservoir for disease-carrying sheep ticks. They make it difficult to herd and monitor the condition of a flock. Similar problems occur on grouse moors where heather can be replaced by bracken (Hudson 1986). Bracken may also be a source of carcinogens in supplies of water and milk destined for human consumption (Taylor 1990).

The present paper describes the results of a sample-based field survey of the distribution of bracken and other land cover types within the catchment of the River Tyne in northern England, an area of almost 3,000 km^2. An approach used in previous surveys of land cover has been to stratify sampling efforts within zones (or strata) which are perceived to be relatively homogeneous in terms of the variables to be recorded (e.g. Bunce *et al.* 1975). Extrapolation of the results from such sample based surveys requires that the distribution of the sampling strata are well-defined (Cochran 1977). A number of studies have shown that the objective definition of strata can be achieved via

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numerical classification of physical attribute data derived from extant thematic databases, including Ordnance Survey (O.S.), soil, geological and meteorological maps (Bunce *et al.* 1981a; Blankson & Green 1991; Cooper & Murray 1992). Numerical classification techniques have included both agglomerative clustering (e.g. Blankson & Green 1991) and divisive indicator species analysis methods (e.g. Hill *et al.* 1975), but their applications have had the common aim of categorising grid squares into a number of groups. Squares which fall into each group are similar in terms of their measured physical attributes, but different from the squares in other groups. These groups of squares are termed 'land classes'.

The land classification used in the stratification of sampling effort in the present study was that developed by the Institute of Terrestrial Ecology (I.T.E.) (Bunce *et al.* 1981a, 1983). This classification was selected because it has a resolution of 1 km (a suitable areal unit for field survey) and because all 1-km squares within Britain have been assigned to one of 32 land classes. This second feature enables the results of the survey to be placed in a national context (Bunce *et al.* 1981a).

A total of 182 1-km squares, stratified by I.T.E. land classes, were visited in 1991 and areas of bracken were mapped at a scale of 1:10,000. This paper describes the distribution of bracken between land classes, and provides an estimate of the degree of infestation of rough grazing in the catchment.

THE I.T.E. LANDSCAPE CLASSIFICATION

The I.T.E. land classification uses the 1-km cells of the O.S. national grid as its spatial unit. Grid squares are grouped into 32 land classes on the basis of a wide range of map attribute data. The development of the classification was in two phases (Bunce *et al.* 1981a, 1991).

Initially, the land classes were identified from a classification of a nationally distributed sample of 1,228 1-km squares, each of which was situated at the intersection of a national 15 km × 15 km grid. For each sample square, 282 attributes were recorded from existing maps. The attributes included environmental variables (such as altitude, slope, geology, drift and climate), semi-natural land cover features (such woodlands and lakes) and anthropogenic features (such as roads and buildings). The sources of these data included 1:50,000 O.S. maps, 1:1,000,000 climatological maps and geological maps. On the basis of these data, the sample squares were classified using Indicator Species Analysis (I.S.A.) (Hill *et al.* 1975). The method is a divisive polythetic method of numerical classification which produces a hierarchical, dichotomous key. At each division in the key, 'indicator species' are identified. This feature enabled grid squares not included in the original I.S.A. classification procedure to be allocated to a land class on the basis of their attributes. Descriptions of the 32 land classes are provided by Bunce *et al.* (1981a) and Benefield & Bunce (1982).

The second phase of development in the I.T.E. land classification system was the assignment of all 230,000 grid squares in Britain to the 32 land classes. In theory this could have simply involved use of the extant key derived from the Indicator Species Analysis. Collation of the necessary 'indicator species' data for every one of the grid squares in Britain, however, was logistically impractical. A reduced set of some 60 attributes was more readily available for all grid squares. These attributes came under eight broad headings; physiography, coastal features, climate, geology, geological drift, land cover/use, offshore island status and distance from coast. These data were used to create a new classification of squares. Correspondence between the two classifications was assessed by comparing the 'new' and 'old' land classes of the original sample of 1,228 grid squares. A range of numerical classifications were tested. That giving the closest agreement between the 'new' and the 'old' land classes involved application of both multivariate discriminant analysis and logistic regression algorithms (Bunce *et al.* 1991). This hybrid approach was therefore used to assign all 230,000 grid squares in Britain to one of 32 land classes.

The hierarchical nature of the I.T.E. land classification allows land classes to be aggregated into broad landscape types. In the present study, the land classes are categorised under three types of landscape, namely: Lowland, Marginal Upland and Upland (after Bunce 1992).

FIGURE 1. The location of the catchment of the River Tyne (shaded).

THE STUDY AREA

The study area was the catchment of the River Tyne in northern England (Fig. 1). The boundary of the catchment was supplied by the Institute of Hydrology (Wallingford). It enclosed an area of 2,903 km^2, comprising 16 I.T.E. land classes. The distributions of the I.T.E. land classes within the catchment were provided by the Institute of Terrestrial Ecology (Merlewood) and are shown in Fig. 2. The composition of the catchment in terms of the proportions of I.T.E. land classes is shown in Table 1. In addition, the table shows the mean altitudes and main land forms within each I.T.E. land class. In the west the catchment is characterised by two upland blocks, separated by the River Tyne-River Solway gap. In the east, lowland landscapes predominate.

METHODS

SELECTION OF GRID SQUARES FOR FIELD SURVEY

The field survey was intended to obtain land cover data from a representative sample of the grid squares within the catchment. There were insufficient resources to survey a representative sample of all 16 land classes in a single summer. The five least frequent land classes, which together represented 0·3% of the total area of the catchment (Table 1), were therefore omitted. In total, 182 squares were selected for survey.

Sample squares were selected from each of the eleven most frequent I.T.E. land classes in approximate proportion to their total areas within the catchment (Table 1). Selection of squares from within ten of these land classes was at random. Within the most frequent I.T.E. land class (i.e. land class 22), however, sampling was further stratified. Equal numbers of squares of land class 22 were selected at random from within each of the upland blocks north and south of O.S. Northing

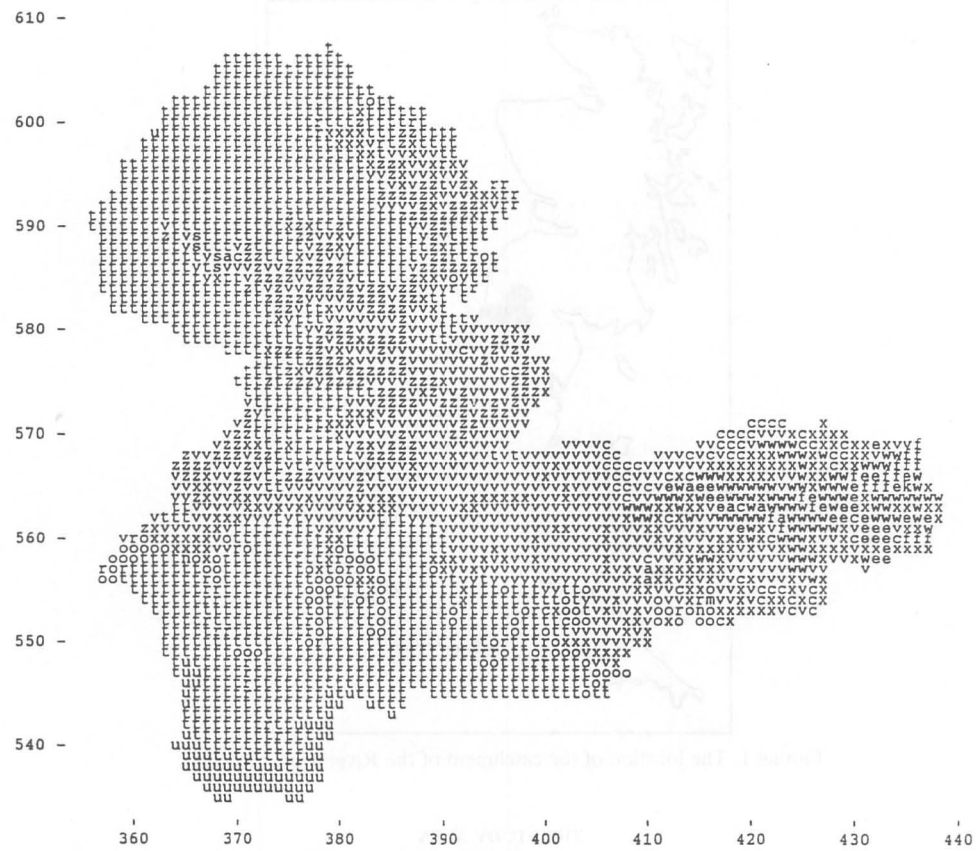

FIGURE 2. The distribution of I.T.E. land classes within the River Tyne catchment: land class 9 – a, 10 – c, 13 – e, 14 – f, 15 – k, 17 – m, 18 – n, 19 – o, 20 – r, 21 – s, 22 – t, 23 – u, 25 – v, 26 – w, 27 – x, 28 – z. Figures at margins are Ordnance Survey coordinates.

564000 (Fig. 2). This was done to allow a more detailed analysis of geographical variation in land cover within I.T.E. land class 22, which represents 43·2% of the total area of the catchment.

FIELD SURVEY METHODS

Field work was undertaken between mid-April and October 1991. Each of the survey squares was visited and the areas of the land cover types defined by the Nature Conservancy Council (N.C.C. 1990) were mapped on to 1:10,000 O.S. maps. Only 20 ha out of the total survey area of 18,200 ha remained unsurveyed due to problems of access. Bracken was mapped as a distinct land cover type where its canopy extended over greater than 25% of the land surface. Dense stands were readily delineated, while the mapping of sparse bracken was more subjective.

PROCESSING AND ANALYSIS OF FIELD DATA

The 182 field survey maps were digitised using the Geographical Information System (G.I.S.) ARC/INFO. The total areas of each of the land cover types within each of the survey squares were calculated from this digital database. The areas of rough grazing were calculated by aggregating the areas of the following cover types: heath, bog, moorland, unimproved grassland and land dominated by bracken. Certain types of unimproved grassland which were not used for livestock grazing (e.g. sand-dunes and maritime grasslands) were excluded, as were small areas of bracken on derelict land in industrial areas.

TABLE 1. LAND CLASSES IN THE CATCHMENT OF THE RIVER TYNE: SELECTED CHARACTERISTICS (FROM BUNCE *ET AL.* 1981B, 1991), FREQUENCY OF OCCURRENCE AND NUMBERS INCLUDED IN THE PRESENT STUDY

Landscape	Land class no.	Mean altitude (m)	Main land forms	% of squares in catchment	No. of squares surveyed
Lowland	9	90	Valley floors, flood plains, bluffs, large rivers	0·2	0
	10	95	Valley floors, alluvial plains with scarps on margins	2·1	8
	13	44	Varied: ridges in alluvial plains to river valley	1·1	10
	14	23	Marine or alluvial flood plains of estuaries	0·7	8
	15	138	Varied: dissected plateaus to valley floors	<0·1	0
	25	119	Alluvial flood plains and glacial moraines	24·0	34
	26	53	Valley floors, coastal plains of glacial origin	3·6	12
	27	133	Varied: valley floors and bluffs	9·9	20
Marginal Upland	17	325	Plateau, table lands, dissected scarps, small rivers	<0·1	0
	18	285	Glaciated river valleys with steep scarps	<0·1	0
	19	288	Broad ridges, summits, small rivers	3·2	10
	20	248	River valleys with tributaries and scarps	1·9	10
	28	138	Varied: meandering rivers, peneplains, alluvial plains	7·2	20
Upland	21	295	Peneplain surfaces or broad ridges	0·1	0
	22	358	Slopes of plateaus, glacial valleys, rounded summits	43·2	41
	23	621	Ridges, scarps, corries, mountain summits	2·5	9

The mean areas of rough grazing and bracken were calculated for each land class. Estimation of the total areas of rough grazing and bracken within the catchment as a whole, and within lowland, marginal upland and upland landscapes, followed Cochran (1977), as did estimation of the standard deviations for these figures. Estimation of mean percentage infestation levels of bracken within land classes used the ratios of the means for bracken and rough grazing. Estimation of the variances for mean percentage infestation levels used the approximation given by Colquhoun (1971: p. 41). The same approach was used in the estimation of percentage infestation levels (and associated variance estimates) at the landscape and catchment scales.

Statistical comparison of the areas of bracken and rough grazing between land classes used Duncan's multiple range test within the SAS package (SAS 1989). Prior to these analyses the data were transformed by adding 1·0 to all observations and conversion to $\log_{10}$. Comparison of the mean infestation levels between land classes used Student's two sample t-test for samples of unequal variance (Zar 1984). Bonferroni's correction for multiple comparisons was used to minimise the chance of Type I errors (Miller 1977).

RESULTS

LAND COVER WITHIN THE I.T.E. LAND CLASSES

The land cover composition of each of the I.T.E. land classes is summarised in Table 2. The lowland land classes are dominated by arable crops, sown grassland, woodland and urban development, although the areas of these cover types varied between the land classes. The areas of rough grazing land were also variable, but overall this cover type was a minor component of the lowland landscapes. Rough grazing was most frequently encountered in the form of unimproved grassland.

The marginal upland land classes had markedly smaller areas of arable crops and urban development than the lowland land classes, and were dominated by sown grassland. Woodland and rough grazing were consistent features of these land classes. Rough grazing was composed primarily of unimproved grassland, but areas of heathland and bog were also important (Table 2).

TABLE 2. ESTIMATED MEAN AREAS OF (a) MAJOR LAND COVER TYPES (EXCLUDING ROUGH GRAZING), AND (b) COVER TYPES COMPRISING ROUGH GRAZING, WITHIN EACH I.T.E. LAND CLASS OF THE RIVER TYNE CATCHMENT

	Land Classes											
	Lowland					Marginal Upland				Upland		
	10	13	14	25	26	27	19	20	28	22N[3]	22S	23
(a) Land uses (excluding rough grazing):												
arable	31·2	17·6	17·7	12·9	4·7	15·8	2·7	–	8·2	–	0·6	–
sown grassland[1]	28·6	14·1	17·7	45·3	11·3	22·1	61·6	30·2	47·2	2·0	22·7	–
woodland	9·1	6·2	1·7	12·1	3·5	16·3	11·1	18·9	12·0	42·0	3·4	–
urban[2]	26·7	47·7	49·9	9·8	75·3	27·8	3·2	2·1	3·6	0·5	0·6	0·2
others	3·1	12·6	9·6	1·8	3·1	3·8	0·5	0·7	1·4	1·5	0·3	1·7
(b) Components of rough grazing:												
unimproved grassland	0·9	1·8	3·4	11·8	2·1	9·2	11·1	9·1	16·0	19·9	24·4	27·4
marshy grassland	0·4	+	+	2·6	–	1·3	4·5	0·9	8·5	6·9	2·5	0·4
dry heath/grassland mosaic	–	–	–	–	–	–	0·1	3·0	–	2·7	8·1	0·3
wet heath/grassland mosaic	–	–	–	–	–	–	–	–	–	0·6	–	–
dry heath	–	–	–	2·1	–	0·1	2·5	27·1	0·1	9·2	13·0	3·7
wet heath	–	–	–	0·1	–	2·3	+	1·9	1·2	3·0	0·5	0·3
bog and flush	–	–	–	1·2	–	0·8	1·9	4·1	1·7	10·3	23·1	66·0
bracken	–	+	–	0·3	–	0·5	0·8	2·0	0·1	1·4	0·8	–

[1] Including sown grasslands infested with *Juncus effusus* L.
[2] Including allotments and recreation areas.
[3] 22N and 22S refer to squares of land class 22 in the North and South of the catchment.
+ = <0.1%, – = 0.0%.

The upland land classes were dominated by rough grazing, with limited areas of arable crops and urban development. In the north, squares of land class 22 had large areas of woodland, whilst in the southern squares of this land class sown grassland was more important. Heathland, bog and unimproved grassland were important components of rough grazing land. Land class 23 was notable for the dominance of bog and unimproved grassland (Table 2).

DISTRIBUTION OF BRACKEN

Bracken was recorded in 10·9% of lowland sample squares, 25·0% of marginal upland squares and 22·0% of upland squares, but contributed a mean area greater than 1% of land cover per square in only two land classes (Table 3). The mean areas of bracken differed significantly ($p < 0.05$) between certain land classes (Table 3). However, although bracken was encountered in a higher proportion of sample squares in the marginal uplands and uplands, there was no clear altitudinal pattern in the variation of the mean areas of bracken by land class (Tables 3 & 4). The mean areas of rough grazing, in contrast, showed a clear increase from the lowlands to the uplands (Tables 3 & 4). Mean infestation of rough grazing land by bracken ranged from 0·0% to 4·23%, but did not differ significantly between any pair of land classes (Table 3).

TABLE 3. MEAN AREAS OF ROUGH GRAZING LAND AND BRACKEN IN SAMPLE SQUARES OF EACH LAND CLASS IN THE RIVER TYNE CATCHMENT AREA

Landscape	Land Class	Rough grazing (ha km^{-2}) $\bar{x}$	Rough grazing (ha km^{-2}) s.d.	Bracken (ha km^{-2}) $\bar{x}$	Bracken (ha km^{-2}) s.d.	% Infestation $\bar{x}$	% Infestation s.d.
Lowland	10	1·27^{d}	1·21	0·0^{g}	–	0·0^{h}	–
	13	1·82^{d}	2·33	0·02^{g}	0·06	1·10^{h}	3·59
	14	3·45^{d}	6·55	0·0^{g}	–	0·0^{h}	–
	25	18·09^{bcd}	29·17	0·25^{fg}	0·58	1·38^{h}	3·90
	26	2·16^{d}	3·04	0·0^{g}	–	0·0^{h}	–
	27	14·19^{cd}	27·46	0·54^{fg}	2·00	3·81^{h}	15·92
Marginal	19	20·82^{abc}	20·04	0·84^{efg}	2·09	4·03^{h}	10·75
	20	48·20^{ab}	39·37	2·04^{e}	4·17	4·23^{h}	9·3
	28	27·60^{ab}	31·44	0·07^{fg}	0·21	0·25^{h}	0·80
Upland	22N	53·81^{ab}	38·51	1·36^{ef}	2·93	2·53^{h}	5·74
	22S	72·22^{a}	33·81	0·82^{fg}	2·59	1·14^{h}	3·64
	23	97·92^{a}	4·90	0·0^{g}	–	0·0^{h}	–

$\bar{x}$ = mean; s.d. = standard deviation.
Means labelled with the same letter are not significantly different at $p < 0.05$.

TABLE 4. ESTIMATED TOTAL AREAS OF ROUGH GRAZING LAND AND BRACKEN, AND MEAN PERCENTAGE INFESTATION OF ROUGH GRAZING LAND, IN LOWLAND, MARGINAL UPLAND AND UPLAND LANDSCAPES, AND IN THE WHOLE CATCHMENT OF THE RIVER TYNE

Landscape[1]	Total area km^2	Rough grazing ha	Rough grazing s.d.	Bracken ha	Bracken s.d.	% Infestation $\bar{x}$	% Infestation s.d.
Lowland	1202	17111	3804	333	141	1·95	0·93
Marginal upland	359	10405	1635	205	89	1·97	0·91
Upland	1327	81530	7952	1500	606	1·84	0·76
Catchment	2888	109046	8966	2038	628	1·87	0·60

[1] Land classes 9, 15, 17, 18 and 21 excluded.
$\bar{x}$ = mean; s.d. = standard deviation.

Extrapolation from the mean areas of bracken and rough grazing in the land classes indicates that bracken accounted for around 1·9% of rough grazing land in each of the lowland, marginal upland and upland landscapes (Table 4). The estimated total area of bracken, 2,038 ha, was equivalent to 0·7% (s.d. ± 0·2%) of the land surface of the catchment (Table 4).

DISCUSSION

A number of surveys of bracken distribution have been conducted in Britain, but each has used a different approach or has focused on a limited geographical region (Lawson *et al.* 1986; Miller *et al.* 1990). This may, in part, explain variation in the estimates of the total extent of bracken in Britain, which range from 1·2% to 2·7% of the land surface (Lawson *et al.* 1986; Taylor 1986). The only study which is directly comparable to that presented here is that of Bunce *et al.* (1981a). In 1978, these authors mapped land cover (including bracken) in a nationally distributed sample of 1-km squares of each of the 32 I.T.E. land classes. They estimated that bracken covered 316,703 ha (1·3%) of the land surface of Britain. Comparison with the present study suggests that bracken is less common in the catchment of the R. Tyne than elsewhere.

Comparison of the results of the present study with those of others conducted in north-east England is difficult. The Countryside Commission (1991) used a visual interpretation of aerial photography to estimate that 4·1% of the Northumberland National Park (which impinges upon the catchment of the R. Tyne) is covered by bracken. Varvarigos & Lawton (1991) conducted a postal survey of farmers, and estimated that 14·7% of rough grazing land within the Less Favoured Areas (L.F.A.) of Northumberland and Durham supported bracken. The L.F.A.s in the catchment of the R. Tyne lie predominantly within land classes 19, 20, 22, 23, 25, 27 and 28. Conversely, 90% of squares of these land classes possess L.F.A. status in the study area (unpublished). Although the catchment does not include all L.F.A. land within either County Durham or Northumberland, the present study suggests that Varvarigos & Lawton (1991) overestimated the extent of bracken infestation. Only around half of farmers targeted in their survey returned questionnaires, but whether the probability of farmers returning the questionnaires was related to the extent of bracken infestation was not addressed. It is possible that farmers with severe infestations would have been more likely to respond. This interpretation is supported by preliminary analyses of LANDSAT data, which suggest that bracken covers around 1·5% of the catchment of the R. Tyne (Cherrill *et al.* in press).

Use of the I.T.E. land classification system in field surveys enables estimates of land cover to be viewed in the context of broad patterns of environmental variation summarised by the land classes (Tables 1 & 2) (Bunce *et al.* 1981a, 1981b, 1983; Benefield & Bunce 1982). Thus, for example, the absence of bracken from land class 23 can be attributed to the effects of altitude and the predominance of waterlogged mires in this land class. Bracken is rarely found above altitudes of 600 m and is known to prefer well drained soils (Thompson *et al.* 1986; Grime *et al.* 1988; Ader 1990). In this context, it is relevant to note that although the nature of the vegetation beneath bracken was not investigated, bracken stands were most frequently associated with areas of dry heath and unimproved grassland (Table 2). It is these ecologically interesting cover types which are likely to be at greatest risk of colonisation and which have probably lost most ground to bracken within the study area.

In conclusion, the present study has followed others in being restricted to a limited geographical region. However, it differs from many of its predecessors in one major respect, namely the use of a national landscape classification system in the stratification of sampling effort. The use of a diversity of methods in previous studies has led to difficulties in the collation of national statistics and a failure to produce consistent regional estimates of the extent of bracken. The need for a standardised method of field survey is clear. Use of the I.T.E. land classes allows the extrapolation of sample based survey data to give regional estimates of land cover. In the future, use of the I.T.E. land classification system would have the additional advantage of permitting comparisons between temporally and spatially separated field surveys. Although remote sensing offers a potential solution to the standardised collection of land cover data (e.g. Miller *et al.* 1990), its capabilities are often overstated and there will be a continuing need for 'ground-truth' data (Price 1986; Townshend 1992). The I.T.E. land class system has recently been used as a framework for the stratification of

sampling effort in field surveys designed to aid the interpretation of satellite data (Cherrill *et al.* in press). The classification, therefore, offers a framework for the organisation of traditional field surveys, but also provides a link with modern remote-sensing technologies (Bunce *et al.* 1992).

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