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Published in:
Landscape and Urban Planning

Publication date:
2002

Document Version
Early version, also known as pre-print

Citation for published version (APA):
Brandt, J., Bunce, R. G. H., Howard, D. C., & Petit, S. (2002). General principles of monitoring land cover change based on two case studies in Britain and Denmark. *Landscape and Urban Planning*, (62), 37-51.

ELSEVIER

Landscape and Urban Planning 62 (2002) 37–51

LANDSCAPE
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URBAN PLANNING

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General principles of monitoring land cover change based on two case studies in Britain and Denmark

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Received 23 May 2002; accepted 23 May 2002

Abstract

There is a well-established need to monitor land use and ecological change so that appropriate policies for the maintenance and enhancement of biodiversity can be developed. By building such exercises around sound scientific principles the reliability of the results can be quantified and policy makers can have confidence that they are genuinely independent. This paper describes two case studies of the development of such systems, the Small Biotope project of Denmark and the Countryside Survey project of Great Britain. These systems illustrate the problems involved in studies at the landscape level and the way satisfactory results can be achieved. Monitoring is considered to be effectively repeated surveillance and needs especially strict protocols to separate real change from the artefacts of sampling. The lessons to be learnt from these studies are summarised as a number of guidelines.

Keywords: Surveillance; Monitoring; Land use; Landscape; Vegetation; Small Biotopes; Denmark; Countryside Survey; Great Britain

1. Introduction

Following the increasing concern over the losses in biodiversity and habitats, it is now widely recognised that it is essential to assess and monitor ecological resources objectively in order to formulate appropriate rural policies (Swanwick and Dunn, 1996). In this context, landscape ecology is a branch of environmental science devoted to the study of environmental problems at the landscape level (Forman, 1995; Burel and Baudry, 1999; Brandt, 1999). Landscape ecologists are expected to have set up monitoring systems for landscapes and their components (Bunce, 2000). However, literature searches of academic journals reveals that landscape monitoring is a little reported subject. In fact, ecological monitoring in general seems to suffer from a lack of a recognised framework for the design of effective systems (Vos et al., 2000). For example, in the "Detecting Environmental Change" Conference held in London in July 2001, only 10 of the some 200 projects presented, referred their studies of change to the wider context. The majority of studies were based on arbitrary selection of sites, rather than ensuring that these were representative of a defined population. Landscape ecologists recognise that landscapes are heterogeneous in nature and complex so that the design of a fully integrated system is difficult to achieve (Bunce and Heal, 1984). The complexity is compounded by an incomplete understanding of the processes responsible for change and their interaction

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0169-2046/02/$20.00 © 2002 Published by Elsevier Science B.V.
PII: S0169-2046(02)00095-6

with landscape elements. The driving forces controlling and influencing change, whether anthropogenic (Whitby, 1996; Jongman, 1996) or natural (Pickett and White, 1985), can be difficult to identify and often operate at different spatial and temporal scales (Brandt et al., 1999; Jongman and Bunce, 2000). Preconceptions may limit the material that may be considered dynamic enough to be worthy of recording or lead to an inadequate frequency of recording that can produce misleading estimates of the rate of change. The situation is further confused by the many different objectives for monitoring which may include elements of ecology, environment, socio-economics and aesthetics. The two case studies described in the present paper demonstrate that surveillance and monitoring, with well-defined objectives, can be successfully undertaken at a strategic level.

Satellite imagery, aerial photography and field survey are the principal ways in which land use data can be collected. Satellite imagery has the advantage of synoptic coverage but usually, at a relatively low level of detail. The new Ikonos images do however contain much greater detail and their increased definition are currently being assessed. Aerial photography is able to provide more detail at a local level, whereas field survey, whilst expensive and time-consuming, provides detailed information which will allow analysis of species composition. Thus, the first two approaches are primarily powerful for estimating the extent, and the latter for estimating the quality of the features concerned. There is therefore a strong synergist effect in combining these approaches. Full integration, whilst possible, has not involved modification of the classes produced by interpretation of satellite imagery, in terms of their more detailed composition (Bunce et al., 1992) but has great potential.

Because of the confusion between the use of the terms "surveillance" and "monitoring", the following paragraph defines their use in the present paper. *Surveillance* is a French word meaning 'to watch over' and generally it is considered to mean the observation of condition, extent and abundance. Scientifically it is the act of systematically observing and recording and it is associated with survey. Survey provides a measure of the extent of a given resource, i.e. stock. Although surveys relevant to landscape ecology can have different objectives, landscape surveillance is usually based on complete records of land cover in the sample units, in order to subsequently derive estimates from the whole domain, e.g. the Countryside Survey of Great Britain (Barr et al., 1993). Other surveys maybe targeted on parts of the land surface such as the German Ecological Areas Study (Hoffman-Kroll et al., 2000). For European cultural landscapes, land use, land cover and vegetation should have priority, since they reflect physical, behavioural and social characteristics. However, it is important that the natural landscape structure is also included although this is often more difficult to record. The disciplines included depend on the detailed objectives and can include soil science, socio-economics, zoology and botany.

Monitoring however, involves surveillance in state over set periods of time and therefore provides information on both stock and change (Hellawell, 1991). A compromise needs to be made between the detail that can be included in surveillance, and the level of change that can be reliably detected. An important principle is the use of repeated measurements at the same sample sites, because then, irrespective of the extent or variability of change, it is always real. By contrast, successive random samples drawn from a population may show differences that cannot be guaranteed to reflect actual change because of the degree of variation between samples.

Changes in landscapes and their components can occur in a variety of ways and at a variety of rates (Mander and Jongman, 1998). Spatially, they may occur in isolation or unevenly and need to be aggregated, in order to be efficiently interpreted. If early warnings or advice to land managers such as farmers and planning officers is to be given, so that management practices can be modified, it is essential that the design of the surveillance system can be related to the drivers of change. It may be necessary to separate the recording of land management practices and the underlying driving factors of change from the collection of data on land use and land cover. This is in part due to the complexity of the data that need to be recorded, and in part to the fact that different disciplines are involved in gathering the data. The majority of surveillance systems will therefore inevitably be interdisciplinary but must be accurately co-registered or otherwise be integrated using a common framework. A fully integrated survey will cover all required disciplines, but inevitably costs will be high, so the usual procedure is that progressive layers are added according to user requirements.

This paper describes the development of two examples of landscape monitoring systems, one in Denmark and the other in Great Britain (GB), identifying some problems and lessons from these two countries. The GB Countryside Survey includes details of the species composition of vegetation which, up to now, has not been covered in depth by the Danish Small Biotope project. Details are provided in Bunce et al. (1999) who point out that changes in vegetation quality, as can be obtained from vegetation releves, are often greater than changes in the extent of habitats. This has further been confirmed by Countryside Survey 2000 (Haines-Young et al., 2000). The Danish Small Biotope Project includes detailed information on ownership, socio-economic and landscape values among farmers in the sample areas, which have not been covered to the same extent in the GB project (for details, see Agger et al. (1986)).

2. Case studies

2.1. The Small Biotope monitoring system in Denmark

The Small Biotope surveillance in Danish agricultural landscapes was set up in the late 1970s, initially with 13 sites in the eastern part of the country. Gradually, the project developed into a monitoring system covering 32 sites each of 4 km^2, i.e. a total of 128 km^2 (Fig. 1) with sampling campaigns in 1981, 1986, 1991 and 1996.

The Small Biotope project consists of (i) detailed field records of all linear and aerial biotopes less than 2 ha. (ii) Interviews with farmers concerning agricultural practice, including specific management practices for their Small Biotopes, and (iii) additional relevant information on the landscape and geo-related structures and drivers for each site, as far as possible stored in an integrated Geographical Information System (GIS).

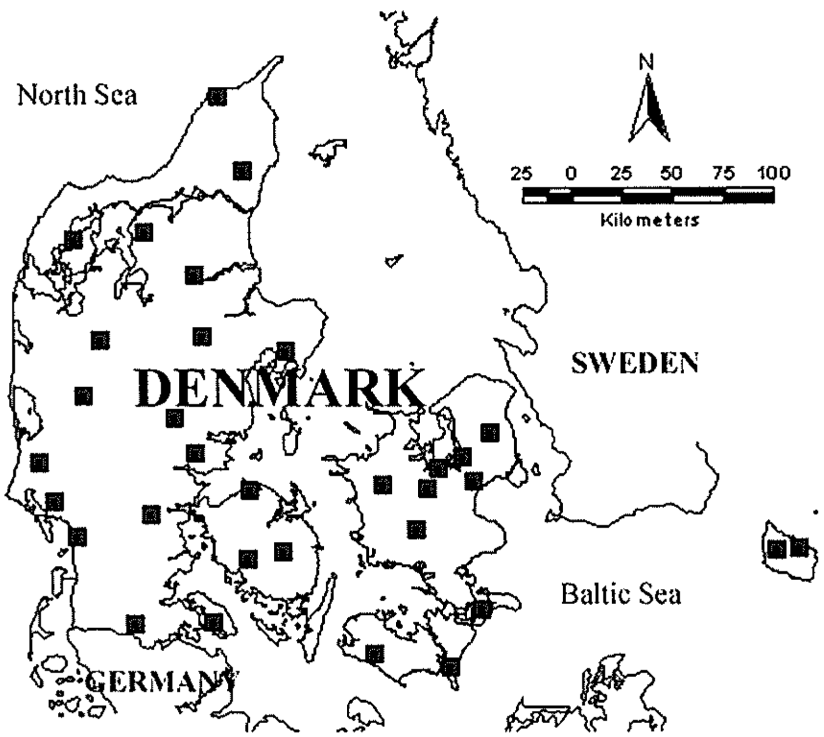

Fig. 1. The 32 test sites of 4 km^2 surveyed in the Danish monitoring programme.

The scope of the surveys has changed over time. The 1981 campaign was organised as a university research project, sponsored by the Danish State Research Foundation for Agricultural Science. The motivation for the 1981 campaign was the general impression of a rapid decrease in the number and quality of Small Biotopes following a period of intensification of Danish agriculture. At that time, Danish nature conservationists were still predominantly concerned with the most threatened natural areas in Denmark and paid little attention to dispersed patches of semi-natural habitats in the wider countryside. However, these occupy about one-third of the total area available for wildlife in the intensively managed agricultural land of Denmark (Agger et al., 1986).

The 1986 survey provided the principal source of information on the status and development of marginal land within the intensively used Weichsel moraine landscapes in Denmark. Here, the dynamics of Small Biotopes were considered to be an indicator for the intensification or extensification processes within agriculture (Agger and Brandt, 1987).

The 1991 survey was carried out in co-operation with the Ministry of Environment as part of the national monitoring programme for wildlife; a monitoring programme not only for Small Biotopes, but also for other larger types of habitat as well as selected animal and plant species. A detailed land use survey of the sample areas was recorded (Brandt et al., 1996).

In 1996, a further survey was carried out, this time to provide an empirical base for a multidisciplinary research programme on possible new techniques for the management of the rural landscapes in Denmark (Holmes et al., 1998).

The sample sites were selected as representative of Danish agricultural landscapes (Agger and Brandt, 1988). They were selected from regions defined by statistical analysis of the relevant agricultural, ecological and socio-economic data at the municipal level. Once defined, the sample sites were then selected, adding samples from less frequent, but typical landscape types, e.g. reclaimed areas.

An important goal for the Small Biotope project has been to influence policy and decision-makers, by changing the focus of conservation interests to incorporate dispersed fragments of semi-natural vegetation. A measure of the success is demonstrated by the widespread use of the term and concept "Small Biotopes" in the Danish environmental debate. It was also used as a basis for a new Nature Protection act from June 1992. The act identifies biotopes under 'general protection' that cannot be altered without permission, even though no compensation is given. The new act extends the list of biotopes regulated by the general protection. In addition, the minimum size of landscape elements regulated by the law has also been lowered to $100\,m^2$ for small lakes and ponds and $2500\,m^2$ for most other biotopes as shown in Table 1.

Ecologically threatened plants and birds found in extensively used agricultural land are protected by legislation, as are almost all recognisable archaeological features. Also, historically more recent cultural elements, such as stone and earth dikes from the 19th century, have been incorporated, (Skov-og Naturstyrelsen, 1992). Comparable agreements are arranged in Sweden (Hasund, 1991), but are rare if not unknown in Britain, although recently Countryside Stewardship agreements can have such arrangements.

It is important to bear in mind that the majority of these newly protected types of nature, as well as almost all other unprotected types of Small Biotopes, are not only historically but also functionally closely related to agriculture, and hence involve agri-economic factors. Up to now, their survival has been linked to agricultural practice, which is also supposed to benefit their future conservation through management. Although other types of non-agricultural land use regulation and practice might be more and more involved in the future development of the countryside, they will in general work through the agricultural system (Primdahl and Brandt, 1997).

A Small Biotope monitoring system must take this dual linkage into account and must enable a continuous evaluation of the effects of legislation. It must also support the development of new methods of regulation by offering flexible tools for the analysis of the drivers causing observed changes.

2.2. The Countryside Survey of Great Britain

In GB, the origin of the Countryside Survey approach is rather different from the Danish programme in that it was developed as a part of a scientific programme of work and, only more recently developed links with policy objectives.

Table 1
The history of general protection—without compensation—of biotopes in the Danish agricultural landscape according to the Nature Conservation Act (1937, 1972, 1978, 1984, Section 43) and the Nature Protection Act (1992, Sections 3, 4 and 12)

	1937	1972	1978	1984	1992
Barrows	All	All	All	All	All including 2 m buffer zones
Other archaeological sites					Most types including 2 m buffer zones
Water courses		>1.5 m	>1.5 m + specially selected	>1.5 m + specially selected	High priority water courses including 2 m buffer zones
Lakes and ponds		All natural lakes	>1000	>500	>100
Bogs			>5000	>5000	>2500
Heaths				>50,000	>2500
Salt meadows				>30,000	>2500
Fresh meadows					>2500
Commons					>2500
Stone and earth walls					All registered dikes including 2 m buffer zones

Minimum sizes in square meters.

The programme developed from methodological studies carried out in 1973, with the first national survey carried out in 1978. The initial studies involved the application of statistical techniques previously used for the classification of vegetation to environmental data at the landscape level. From the outset, it was designed around the principle that the environmental character of the land influenced the vegetation that was growing upon it, with the former acting as the independent variable and the latter as the dependant variable. Bunce et al. (1975) described initial studies in the Lake District in north-west England. The methodology was then extended further to the county of Cumbria, covering 8080 km^2 (Bunce and Smith, 1978) in which a high statistical correlation was shown between strata determined by analysis of data from maps and an independent ground survey of vegetation.

A survey was then planned to describe the stock of natural and semi-natural vegetation for the whole of GB through the assessment of stock and change on the basis of samples. The sample was a set of 1 km^2, stratified according to the ITE Land Classification, which splits GB into 32 environmental strata, termed Land Classes, on the basis of climatic and geographic data (Bunce et al., 1996). This stratification enabled the production of national estimates and associated standard errors derived using standard statistical procedures.

The history of Countryside Surveys is summarised in Table 2. Successive Countryside Surveys in 1978, 1984, 1990 and 2000 have followed changes in the British countryside in terms of land cover and vegetation and to a lesser extent soil and freshwater quality (Table 2). Land cover includes many of the Small Biotopes included in the Danish system. In 1990, the ground survey was coordinated with a land cover map derived from satellite images and since then, emphasis has been placed on data integration (Barr et al., 1996). For the original Countryside Survey, in 1978 256, 1 km^2, were visited (eight squares from each of the 32 Land Classes) recording flora, land cover and soil profiles (Bunce and Heal, 1984). Six years later, the squares were revisited, along with an additional four new squares in each Land Class, a total of 384, 1 km^2 squares. In the second survey, only land cover was recorded (Barr et al.. 1986), but in greater detail than in the original survey using a flexible coding

Table 2
The history of the Countryside Survey of Great Britain with for each survey (1978, 1984, 1990 and 1998/1999) the number of 1 km squares sampled and the information recorded

	Number of squares	Information recorded by field survey			
		Land use	Flora	Soil	Freshwater
1978	256	√	√	√	
1984	384	√			
1990	508	√	√		√
1998/1999	569	√	√	√	√

In addition to the field survey, land cover maps of Britain were derived from satellite imagery in 1990 and in 1998.

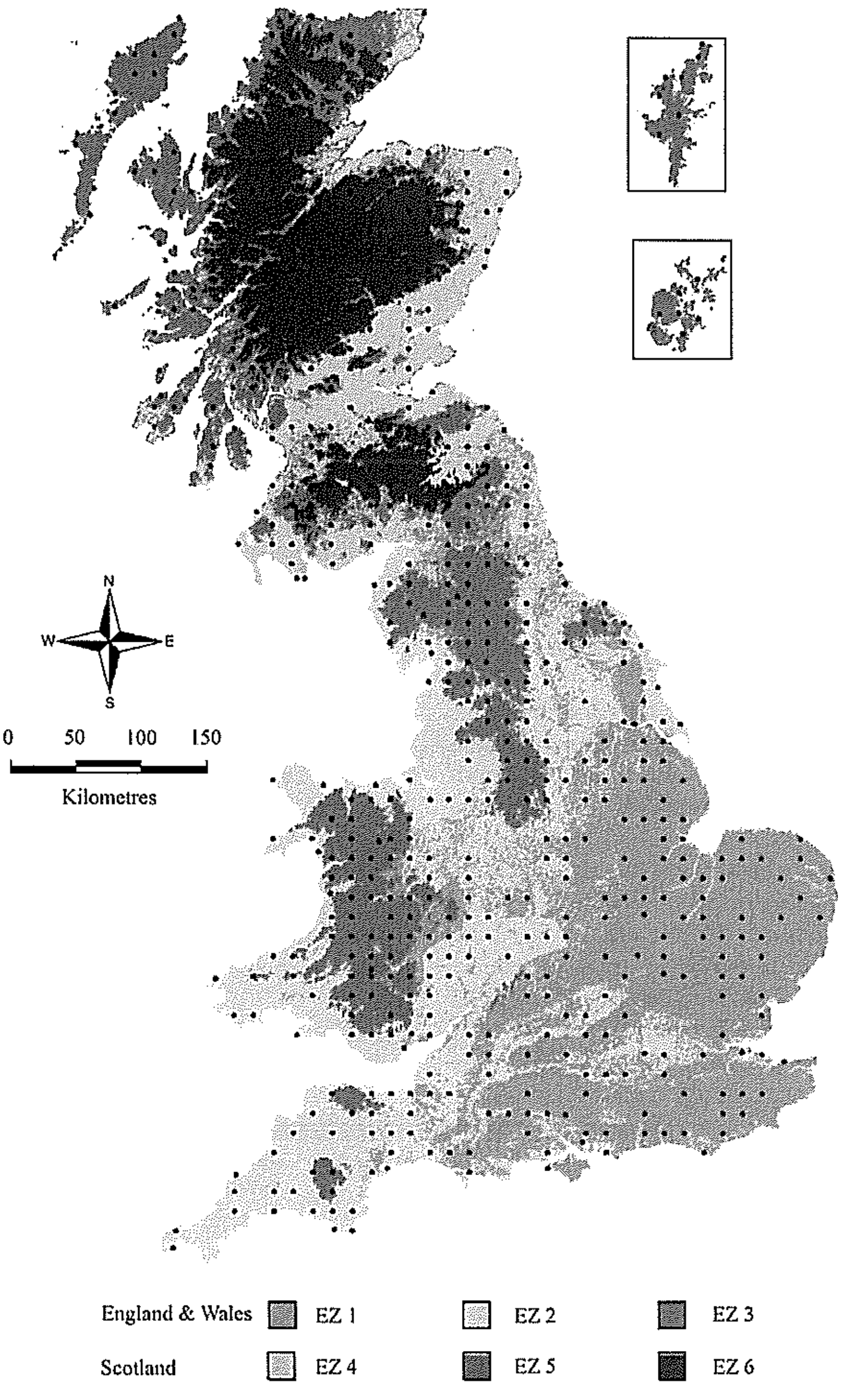

Fig. 2. The location of the 569, 1 km^2 squares surveyed during Countryside Survey 2000 in the six environmental zones: (1) easterly lowland England/Wales; (2) westerly lowlands England/Wales; (3) uplands England/Wales (4); lowlands Scotland; (5) intermediate uplands and islands Scotland; (6) true uplands Scotland.

system (Howard and Barr, 1991). The survey was repeated again in 1990, but extending the sample size to 508, 1 km^2 squares. Wherever possible the same 1 km^2 squares were revisited (381 of those visited in 1984), but because of the private ownership of land and lack of a freedom to roam, a small number of landowners refused permission to survey their land. Countryside Survey 1990 (CS1990) remapped all the squares using the same map coding procedure and repeated all the quadrats (Barr et al., 1993). Countryside Survey 2000 (CS2000) is a slight misnomer as the survey work was carried out in 1998/1999. The same sites were revisited and again the survey was extended by incorporating previously unsurveyed squares. Fig. 2 presents the 569 sites surveyed during CS2000 in their respective Environmental Zone, a unit created for reporting purpose by aggregating Land Classes of the ITE Land Classification.

Data from the original survey have been used in several strategic studies such as the potential for wood energy plantations in GB (Mitchell et al., 1983) and agricultural change (Harvey et al., 1986). It was only after the survey of 1990 that the results became specifically linked to countryside policy objectives (Barr et al., 1993). The results have subsequently been used in the formulation of government policy (Swanwick and Dunn, 1996). Despite the changes in emphasis, throughout the surveys, the methodology was still primarily determined by scientific objectives although government agencies have become progressively involved and have used the results in policy formulation.

3. Features that should be included in monitoring landscape elements

Originally the term 'Small Biotope' (Danish: *småbiotoper*) was created to enable the analysis of change in the rapid decrease in number and quality of small uncultivated areas within the agricultural landscape of Denmark. 'Small Biotopes' are defined as uncultivated areas that are permanently covered with vegetation, or water, and are situated within or between agricultural holdings. Furthermore, a Small Biotope was defined as less than 2 ha but either larger than 10 m^2 or longer than 10 m with a width of more than 0.1 m (Agger and Brandt, 1984). The latter are linear biotopes, and are mapped as lines, but their area cover is registered through attributes related to their width.

Through this definition the Small Biotopes are regarded as part of the agricultural land use, but contrasting the cultivated areas. Thus, the Small Biotopes are not defined in terms of natural landscape structure (e.g. ecotopes or eco-chores at different levels) in a geo-ecological sense (Neef, 1963; Klijn, 1997). But such structures are seen as important statistical references for the monitoring process, allowing for a systematic analysis of composition, density and change of Small Biotopes within different natural landscape structures, first of all at the detailed landscape level.

The recording system described by Brandt and Jakobsen (1998) involves direct registration of agricultural land use and delineation of all landscape elements on rectified enlarged colour aerial photos (1:5000), and separate sheets for all semi-natural areas for coding of a number of attributes. The system also includes a questionnaire on general agricultural information and land use (also for the part of the holding outside the survey area), specific information on function and management within the survey area and questions concerning attitudes towards environmental management.

All information has been stored in databases that have been developed since the first registration in 1981. A combination of different dedicated GIS systems and an Oracle database has also developed, and, following the 1996 survey, all former spatial information has been converted into Arc-Info format. In 1996, the survey was coordinated with a national land cover map derived from satellite images using same principles as Countryside Survey 1990 (Barr et al., 1993).

There has been a major problem of the Small Biotope definition in Denmark as to whether the Small Biotopes until 1996 should be within, or between, agricultural fields. Hence, potential biotopes within and directly adjacent to farmsteads and urbanised areas were not recorded. Restricting the study to a certain matrix is related to the landscape ecological tradition where biotopes are regarded as patches and corridors embedded within agricultural systems. It does, however, have a major drawback, in particular in connection with the historical analysis, where Small Biotopes can develop or disappear as a result of changes solely in the surrounding matrix. For instance, the dismantling of an agricultural holding might involve the appearance of a ruderal patch such as a set aside-area, thicket, hedgerow or pond, which already existed as biotope but enclosed by the former garden. In a monitoring system, it is also relevant to follow how existing Small Biotopes are embedded in an urban or recreational environment related to the urbanisation process.

Another aspect of this problem has arisen from the maximum area clause of the Small Biotope definition. This clause was introduced to enable the project to concentrate on the smaller biotopes (a2 ha) that are more susceptible to changes in the agricultural matrix. The stability of the larger biotopes is often maintained by the sharing of ownership among several agricultural holdings. The drawback of this maximum area clause is that changes in the Small Biotope population may be wrongly interpreted. Small Biotopes may, for instance, arise from larger biotopes, for example when a bog is drained it often results in several small bogs remaining in the lowest parts of the area, resulting in an increased number and area of Small Biotopes. On the other hand, the amalgamation of two Small Biotopes resulting in the total area passing the 2 ha limit causes a decrease in the number of Small Biotopes. These problems can only be handled by regarding the Small Biotopes as a part of the general land cover, thus supporting the integration of the Small Biotope classification with the general land cover classification. This was incorporated from the beginning, but only since 1991 has there been a consistent integration of the biotope types and the general land cover classification.

In GB, the Countryside Survey covers the entire landscape, with the exception of 1 km^2 that are more than 75% urban—about 1% of the land. Surveyed squares however, include urban areas and villages, where there are often fields in agricultural use mixed with residential dwellings.

The minimum mappable unit is 400 m^2, compared to the 10 m^2 in Denmark. In addition, linear features such as fences, hedgerows and walls that do not have a mappable area are still recorded as lines. As in the Danish case, a coding system is used, so that subsequent database interrogation can extract summary information or more complex mixtures of code combinations. The design of the categories recorded is based on the concept of landscape ecology and the digitised outlines of parcels and linear features can be analysed by GIS to determine pattern and connectivity.

The recording system described by Barr et al. (1993) involves separate sheets for agriculture and semi-natural vegetation, woodland and trees, boundaries, physiographic features and the urban environment. Each parcel or feature is labelled with an alpha code on the map and a string of numeric codes defining its characteristics on the recording sheet. The map data are digitised into Arc-Info GIS from the base map and the codes entered into the Oracle database management system. The thematic maps are combined and the land cover divided into 58 mutually exclusive categories. Overlay of the 1990 and 1984 reporting categories was used to determine change. Following the Rio Convention, Biodiversity Action Plans have been devised in GB for a number of Broad Habitats. The detailed mapping codes used in the Countryside Surveys have allowed the information to be reallocated into "Broad Habitats" and provide estimates of changes in those categories. This is considered to be the minimum information that should be included but other layers can be added as required and the surveys have increased in the range of features recorded. It has not proved possible to simplify the data recorded, rather the opposite has been the case.

4. Classifying landscape elements for monitoring purposes

From the very beginning, the Danish project was very aware of the cultural origin of most Small Biotopes; only approximately a quarter of the Small Biotopes of the Danish agricultural landscapes can be considered to be of natural origin, and even these are often highly modified. The origin of the others can be traced to man-made features, primarily related to present or former agricultural land use, e.g. dikes and marl pits. In order to reflect the anthropogenic nature of the Small Biotopes in the latest survey it was decided to use everyday terms for the Small Biotope classification, such as marl pits, ponds, prehistoric barrows, hedges, avenue verge, field margins, small areas of fallow. These were given precise definitions, and fitted into an ecological relevant hierarchical classification.

This classification has proved useful for many purposes. However, in the most recent survey it has been realised, that the mixture of a genetic, functional and ecological based classification is not suitable for a long-termed monitoring process, since it makes change-detection difficult. For example, it would be necessary to define the transition from a marl pit to a pond or a game plantation. Instead a basic physiographic classification was used, adding an internal terrestrial classification involving the re-classification of the former data. Functional characteristics are added to the description as attributes. For instance, a hedge is defined as 20 m of a linear biotope of which at least half is covered with trees or shrubs and where the surface is between 0.25 m under and 0.75 m above the surrounding fields. If the surface had been higher we would have had the Small Biotope type "hedge on dike".

It is interesting to note, that this monitoring-oriented change in classification results in many types that are compatible with the legend-signatures used historically on Danish topographical maps, although in more detail. However, the strict basic physiographic classification also reveals some vernacular types not easily defined, especially among those dependent on type, density and structure of tree cover. For statistical and presentation purposes it has been necessary to use additional attributes for a standard transformation into classifications comparable with historical data and other surveys based on vernacular biotope types.

In the Countryside Surveys, a list of terms is provided which are combined to produce a complete description of a landscape element. Surveyors are provided with a handbook containing the definitions of the terms, and they are allowed to generate new well-defined terms if necessary. All surveyors attend a field training course and there is quality control and assurance throughout the survey. Structured map code sheets are used to encourage all information to be recorded as it is considered to be preferable to make decisions in the field rather than later during the analysis. For example, a hedgerow could be described with a primary code of 'Mixed Hedge', i.e. 'no single species has >50% cover', height code '2–3 m high', code for 'not stockproof', i.e. 'gaps from 1 to 20 m long can be present but represent overall less than 50% of the hedgerow length', a management code 'flailing', i.e. 'if the hedgerow was flailed in the last year, recognisable by smashed and shattered ends to cut branches'.

5. Surveillance reliability

Quality control and assurance is rarely discussed and is often absent from monitoring exercises, although the surveys of crown condition in European forests is an exception. During recent years the reliability of remote-sensing-based surveys has been frequently discussed, especially by the calculation of different landscape-indices. For example, in a commentary on pattern and error in landscape ecology, Hess (1994) states that "landscape ecologists have been using remotely-sensed data to calculate measures of broad scale landscape pattern, but have devoted no effort to quantifying the uncertainty in these measures." However, image classification procedures in remote sensing have considered this problem. Without statistical confidence one cannot use measures of pattern to detect differences in landscapes over space, or changes in a landscape over time. Therefore, for detailed landscape monitoring, it is necessary to be able to express the level of confidence in the results, which at the moment is only commonly done for field surveys. However, field surveys can be just as unreliable as remotely sensed data due to the need for using expert judgement and registration errors, including data-coding. Wyatt et al. (1994) have summarised 17 different land use and land cover surveys in the UK, including mapping from space, from aerial photography and from a stratified ground sampling network, with overall errors of the order of 20–30%. Quality control checks as part of field surveys indicated the recording accuracy of the field surveyors fell in the range 74–83% in the Countryside Survey, but most other projects have no measures of the reliability of the field data.

For landscape monitoring, such errors may have significant consequences but need to be considered in context. An important principle must therefore be that field surveys always should be integrated and validated with other data, e.g. from satellites or aerial photographs. A crucial exercise in setting up a landscape monitoring system is that it should enforce a critical attitude towards the detection and classification of landscape elements.

This can be achieved in a number of ways, closely related to linkage between the experience of the surveyors, the character of the landscapes investigated and the GIS-technique used for the monitoring system.

Two different 'philosophies' closely related both to the GIS-technology used and to the character of monitored landscapes, can be distinguished. The separate-layer model puts emphasis on the independent surveys, where all the reliability checks are related to each survey. Here, a change is registered when differences in spatial position, or attributes, of the single landscape element surpass a given tolerance. This approach is especially relevant when the surveillance is dominated by a continuum of land covers, such as in different grassland types, divided only by weak transition zones. The survey is dependent on the skills of the surveyors in the relevant discipline and their detailed knowledge of the particular land cover classification. Their judgement should probably not be influenced by earlier surveys of the same area, since real changes might be vague and difficult to distinguish. A rather simple GIS-technique is used, where the delineation of a landscape element is represented by reference to a set of line-segments registered independently for each registration year. The second approach, or integrated-layer model, puts emphasis on the registration of changes compared to the previous registration. Information on the previous registration forms the basis for the next field-registration, organised as a check of each landscape element in case of changes in spatial extension or attributes. It pre-supposes that changes are reasonable distinct, which will in general be the case in most intensively used lowland agricultural landscapes of western Europe. It relies on a GIS able to handle vector data in a rather sophisticated way, by attaching the spatial data of all registrations to the same layer. So, a landscape entity, which has never changed its spatial position through a series of surveys, will refer to the same line segments in the GIS in all years. If it changes position, new line segments necessary to describe it will be digitised, added to the system and used for the spatial description of the entity in the relevant years. This conservative way of monitoring has many advantages, especially when seen in the long-term, as it allows checking of the quality of each of the surveys. Each registration of a change generates the question: is it a real change, or is re-evaluation of the earlier registrations required? This permits a higher degree of confidence in the data as the number of surveillance events increases, together with the monitoring process.

In the Danish monitoring system, with an average of about 200 Small Biotopes per sample area, even a 1% annual change means changes in only 10 biotopes over a period of 5 years. With very different trends for the many different biotope types, there is little room for error and misinterpretation, if reliable type-differentiated quantitative statistics are to be obtained. Each change needs to be validated, which has been the reason for the choice of the integrated-layer model in the Danish monitoring system. The result is, that the Danish surveillance has not only been more reliable with the time due to better registration techniques, but also the editing of former registrations has added to the quality. This is also necessary, since landscape monitoring in practice relies on the use of detection of rather small changes.

In GB the principle has been to repeat the same 1 km^2 so that the recorded changes are known to have taken place, which follows the same concept as the Danish case, and indeed most other monitoring exercises. The statistical estimates of the areas associated with change are therefore concerned with the reliability of the extent of that change, rather than whether it actually took place. Here also, the recording system has been made more sophisticated in the progressive surveys. These have involved adding further details to the same basic categories to ensure that the reporting categories are consistent. Quality assurance programmes were undertaken for the 1990 and 1998 Countryside Surveys with differences in species recorded, mis-identification, inaccurate recording and imprecise location arising, e.g. because of seasonal variations. These differences were shown not to affect the results, at the landscape level.

6. Monitoring landscape managers and users

In general, landscape changes are caused by changes in society. This was one of the main conclusions of the major Swedish interdisciplinary project on 'The cultural landscape during 6000 years in southern Sweden', called the Ystad-project (Berglund, 1991). Many other studies of the development of our cultural landscapes have come to the same conclusion, e.g. Potter et al. (1996).

In general, human factors also seem to be most important in relation to the short-term landscape changes that are observed in a landscape monitoring system. However, a part of these factors may be only indirectly related to the local landscape system. Many economic and political factors, such as agricultural policy or even international agreements also influence local systems. This is the reason why conservation of cultural landscapes has been a part of the discussion in connection with the World Trade Organisation (WTO) negotiation on agricultural trade (Bohman et al., 1999).

In the Small Biotope monitoring system in Denmark periodic interviews with the farmers have been carried out from the outset in order to get information on the functions of the Small Biotopes and on future plans for their removal, establishment or management. Other more general themes are also of importance in a monitoring system, such as trends in local or regional intensification, concentration and specialisation of agriculture, as well as attitudes towards land use, landscape management and nature conservation, related to changes in farm size, farm type, farm style and land ownership or occupation. So, about 80% of all Small Biotopes in the Danish agricultural landscape are on the borders between holdings. Facing a continuing rapid increase in average farm size the spatial pattern of farm amalgamation and farm fragmentation is certain to influence future biotope patterns. It is of growing importance to distinguish between land-owners and land-users, since long-term decisions related to landscape management seem to be progressively dominated by land ownership interests, often in growing opposition to more short-termed tenancy interests (Primdahl and Brandt, 1997).

In the GB Countryside Surveys, following the publication of CS1990 it was recognised that there was a need to link botanical and land use change to farm processes in order to understand the connections between them. Accordingly a social survey of 504 occupiers within the CS1990 survey squares was carried out as described by Potter and Lobley (1995). A fresh analysis of the data on land cover and botanical change from the CS1990 data was undertaken in order to identify high and low change farms and then link these to the social data (Potter et al., 1996). A complex pattern of extensification and intensification emerged and in many cases land cover change was being brought about by farmers who were developing from a relatively small base. The policy implications of these links were also reported, for example it was considered that attention should especially be paid to the minority of individuals, usually elderly, who were stable in their management. Whilst such studies are undoubtedly important at the strategic level, it is necessary to go down to the field level in order to understand the drivers behind the causes of botanical change because individual parcels may be separate from the whole farm economic strategy. This was demonstrated by Firbank et al. (1999), who showed how drivers can be linked to botanical change and how the pressure-state-response model can be used to make the connections between cause and effect.

7. Planning a monitoring campaign

7.1. *Preparation for a monitoring exercise*

The first question to ask in a monitoring exercise is 'what is being monitored and why?' In general terms it is simple to describe why we need to record changes in ecology and the environment. Increasing public awareness of both the environment and our interaction with it have produced the desire to be 'environmentally friendly'. Information collected through monitoring plays a crucial role in assessing the effectiveness of government strategy and helps plan new policies. The 'what' can be more difficult to answer, especially if the topic of the monitoring exercise is broad (e.g. ecology and environment) and the goal is not well defined. Scope and accuracy must therefore be determined as clearly as possible before starting a monitoring programme. The extent and components of the system being monitored must be explicitly stated. The geographic boundary of the region of interest must be demarcated and the required statistical confidence in any results or descriptions specified. Once all these items have been taken into account, a campaign of data collection can be planned.

7.2. *Terminology and communication*

Whilst the information to be collected and the funds available will determine the methods of data collection, it is important to be aware of the views and needs of different users of the information and knowledge of the disciplines involved, e.g. soil and vegetation classification systems. Unnecessary and irrelevant criticism can be produced by poor communication with different sectors and research fields simply because of differences in procedures and terminology. There should be continuous close collaboration and discussion with different groups who have interest in the production of results, the formulation of reports and presentations to users. A standard terminology with glossaries and dictionaries should be used from the monitoring design to the final publication of the results.

7.3. *Sampling strategies*

One of the primary objectives in any survey should be the efficient acquisition of data. One way of optimising data collection is to use a stratification to distribute samples and integrate datasets. This allows the production of regional and national estimates from a limited number of samples and allows the results to be qualified with statistical descriptions of confidence.

7.4. *Methods of data collection*

When monitoring, data need to be consistent between surveys. There is a tendency to improve techniques, alter methods and acquire different information in successive surveys. Methods can be easily altered, but unless changes are carefully planned and conservative, compatibility between different sessions will be lost. It is important that the results can be presented in different styles, so that they remain relevant to contemporary issues. Any modifications or additions must be conservative and not jeopardise comparison with data already collected.

7.5. *Method of recording*

Once the sample unit has been determined, it is necessary to define the precision of data recording. A standard method of recording in the field, usually in the form of a field handbook, is necessary for consistency. Tests were carried out using hand-held computers but these were not sufficiently robust. Recent developments in such machines suggest that they could be used in future to increase reliability of recording the field. This also helps avoiding using vague or ill-defined terms as these take a disproportionate length of time to interpret. Structured map code sheets should be used to encourage all information to be recorded, keeping in mind that it is better to make decisions in the field as they are harder to make and justify during the analysis. In the future, hand-held computers could well increase the efficiency of field recording.

7.6. *Preparation for survey*

Surveys can be seen as snapshots of the 'environmental stock' and comparison of repeated surveys will provide details of change. For a snapshot, the surveys need to be performed within a tight time frame. If a survey for any area covering hundreds of square kilometres is to be completed within a single season, then a number of survey teams must be employed. The start of a survey should be training, to ensure maximum consistency between surveyors. It is important to ensure a standard level of expertise for surveyors/interpreters. After training, survey teams should be monitored by control and quality assurance. No matter how rigorous the supervision, there will always be some noise in the results. However, it is important to avoid directional bias. Repeated use of the same sample plots offers an additional opportunity for quality control, especially when contemporary air photos are available, and if an integrated-layer-model for the GIS is used.

7.7. *Integration of approaches*

Each method of data collection has its own strengths and weaknesses and one should capitalise on the strengths of different approaches. Ideally, methods should be combined in such a way that the strengths complement one another and the weaknesses are minimised. The common approaches range from remote sensing where both satellite imagery and aerial photographs are used, to field survey including interviews and archive searches. Census techniques give excellent broad-brush descriptions and give good geographic distributions, whereas field samples provide greater depth of ecological detail. Every data element has its value, but the key is to recognise and record information in a way that maximises its contribution to the full picture. Barr et al. (1993) discussed the integration of remotely sensed information with ground survey but did not produce a national product. There is currently much work underway in Europe to develop such integration, but no fully worked examples are yet available. There is no doubt that in future, a successful approach will be developed which will represent a major advance.

7.8. Interpretation and time-scale

Once the results have been processed, interpretation can begin. One aspect of multifunctional landscapes that is particularly relevant in interpretation is the different time-scales that different sectors work on. Agriculture tends to have an annual turnover and may use rotational management that is likely to produce change in detailed land cover over 3–5 year periods while for example commercial forestry has a longer span. Urban development is often looked on as simple expansion, but dereliction and abandonment do occur, especially with industrial facilities and extractive industries. The period between surveys and their frequency is of crucial importance in terms of the questions the results can be used to address.

7.9. Consistency

The benefits and drawbacks of using repeat sites as opposed to independent samples are complicated by the magnitude of change recorded. In general, for large changes, statistical estimates are stronger when derived from independent samples, but small changes may be better covered by using repeat samples. The latter approach also allows flows between land cover categories to be identified. Revisiting the same sample locations allows real change to be recorded. Additional sample sites may be added, and rolling programmes can be adopted.

7.10. Communicating the results

It is important to consider the target audience of any results. In multi-functional landscapes, interest is likely to come from different groups with potentially opposing standings. Descriptions of stock can often be treated in a variety of ways, but changes are far more exacting and controversial. Unfortunately, this is the opposite way round to the statistical interpretation where change estimates are more difficult to produce and usually have wider confidence intervals than stock. Although the production of error terms may give an air of validity, the statistics may not cover all aspects of noise in the results and exercises quantifying the repeatability should be carried out.

8. Conclusions

At the European level, a strong need for landscape monitoring has developed during the last 10–15 years due to a growing pressure on the European countryside for environmental and recreational reasons. These pressures become more acute when taken in conjunction with landscape changes due to the restructuring of the agricultural sector as a response to the reform of the Common Agricultural Policy. The development of an appropriate programme for monitoring at the European level needs to consider three major guidelines.

1. The strategic objectives of landscape monitoring must be designed to address relevant policy issues. They must therefore involve institutional co-operation and should use reliable data and consistent methodologies.
2. The principles for landscape monitoring should involve integration, spatial representation, multifunctionality, capability of scenario testing and support for policy.
3. Guidelines for multifunctional landscape monitoring systems urgently need to be produced in a form that can be widely distributed for general application.

Several recent meetings have concluded that a new initiative is required to coordinate the many monitoring exercises that are currently taking place or are being planned in Europe. The International Association for Landscape Ecology (IALE) has formed a working group in response to this gap.

Acknowledgements

The Countryside Surveys of GB have been funded by the Department of the Environment, Transport and the Regions (DETR) and by the Natural Environment Research Council (NERC). The Danish Small Biotopes project has been sponsored by the Danish State Research Foundations for Nature Sciences, Social Sciences, Humanities and Agricultural and Vegetation Sciences, related to the joint research project: Value, Landscape and Biodiversity.

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