Integrated monitoring on a landscape scale
lessons from Denmark

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Contents

4. Integrated Monitoring on a Landscape Scale - Lessons from Denmark

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1. Introduction

Landscape monitoring should be seen in a broad context, providing data for many different economic, social and political needs, and operating at a range of geographic scales. Monitoring of biodiversity should not only focus on threatened habitats, but also incorporate general landscape monitoring, since understanding and responding to biodiversity problems must include the effects of processes and changes taking place in the cultural landscapes. Special emphasis should be placed on explaining the landscape consequences of the change from current farming processes to post-productivist agriculture.

The development of the Danish monitoring system for *small biotopes* in the agricultural landscape has shown the need to monitor all components of the landscape, and to ensure that monitoring fully integrates changes over space and time.

2. The broad perspectives of landscape monitoring

Monitoring is a systematically repeated registration of an object, or group of objects, with the purpose of detecting changes. Systematic monitoring means that the registration can be repeated with such precision that any change in the result can only be explained by a change in the object. Mapping may be a one-off activity, but, if repeated in the same way, changes may be detected, and hence may be a form of monitoring.

Monitoring can be divided into *effect-monitoring*, which aims to detect the results of known, often intended, activities, and *trend-monitoring*, which is long-term and oriented towards detecting changes - no-matter what the causes may be.

Monitoring can take place at a wide range of scales, from the particular location of a plant or animal, through to site or the landscape. Often, components of the smaller scale are integrated into the larger scale as part of the process of detecting change.

Landscape monitoring is usually undertaken as part of a biologically based programme to provide information for conservation policy. However, it should be seen in a broader perspective, as there have been important trends in Europe that have led to a growing interest in the monitoring of landscapes (CEC 1992; Council of Europe 1996). These have re-affirmed the need for integration between monitoring programmes established for different purposes - especially as monitoring is often an expensive, time-consuming and organisationally complicated activity. Recent trends include:

- The growing recognition at the political level of the relationship between environmental problems and land use processes at a number of scales from the environment through to individual landscapes. The result has been different types of direct or indirect regulation of land use.
- Landscape-related regional and local differences in population density, intensity of economic activities, and traditional management practices, offer both different opportunities and challenges to solving environmental problems. These differences may give rise to economic, social and political tensions that need to be understood as part of the on-going changes in landscape structure and function.
- Recent changes in agricultural policy have led to shifts in land use strategy in many agricultural landscapes, often described as the post-productivist transition (Bowler & Ilbary 1997, 1999). The productivist phase of intensification, concentration and specialisation, with marked contrasts between the natural structure and dynamics of the landscape, and the development of a mono-functional and homogeneous type of land use appears to be being gradually replaced (Raad voor het Landelijk Gebied 2000; Andersen *et al.* 2000). The trend is now moving towards extensification, diversification and dispersion of land use activities. This is producing less intensive, more multifunctional, land uses, and a more varied landscape. As the balance between the two strategies alters, so the need to study their effects on the landscape grows.
- The technological changes of the productivist phase of modern agriculture were often characterised by labour-saving investments, regardless of environmental and landscape conditions. This 'non-spatial' technology often

led to very similar agricultural landscapes and environments. Developments in information technology have recently led to changes, so that current land use technology reflects both the financial and ecological advantages of adapting the land use processes to local conditions. This will influence the trend towards the post-productivist transition.

- Regional planning in the productivist phase provided economic support for homogenisation of environmental conditions through agricultural improvements, and farm amalgamations, as well as zoning legislation. This gave priority to intensive mono-cultural land use within each zone. Along with the post-productivist transition, and changing technological possibilities, subtler planning and land use regulations are being developed, leading to the replacement of the tradition of planning for segregated land use. This is only possible if the underlying environmental patterns influencing the landscape are recognised, and the pressures on them are better regulated.
- Urbanisation is leading to a much more dispersed pattern of settlement and economic activities, due to developments in transport technology and networks. In addition, the growing amount of leisure time, and dissatisfaction with the environmental and social conditions producing urban sprawl, are leading to calls for a more multifunctional use of landscapes.

All of these trends impact on nature conservation and nature policy, not only because they emphasise the role of a landscape perspective in monitoring, but also because they focus on processes that are crucial for the development of biodiversity.

3. Biodiversity and landscape monitoring

When threats to biodiversity are listed, environmental stresses (such as eutrophication, acidification, and climate change) and land use changes (such as intensification, afforestation, and fragmentation) are often given as primary factors.

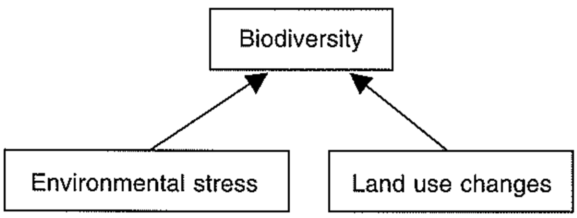

Figure 1. General threats to terrestrial biodiversity.

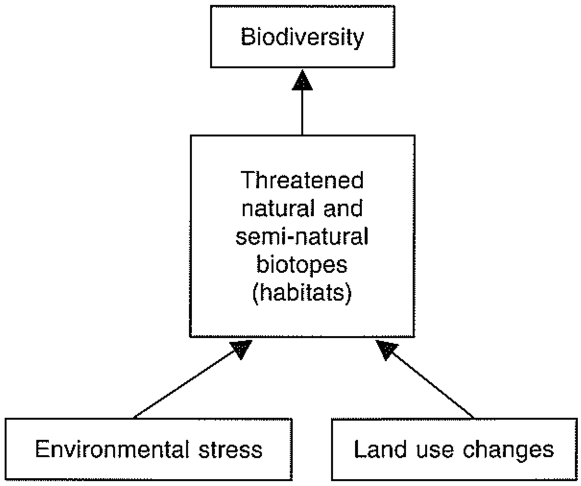

Figure 2. The pressures influencing terrestrial biodiversity.

Their direct influence is limited (Figure 1), and is recognised more on habitats than on species (Figure 2). Habitats important for wildlife are typically natural or semi-natural, and occur at a range of different scales. At the landscape scale, much terrestrial surveillance and monitoring concentrates on species and their habitats, whilst changes in quantity and quality of related types of land cover are correlated with the development of species.

Threatened habitats are only a part of the landscape system. Long-term, pro-active, landscape monitoring should cover all main types of landscape, as well as all main aspects of the landscape (Figure 3). In Figure 3, the landscape system is seen as being derived from:

- A basically natural geo-ecological system (including information on potential vegetation) made up of the natural landscape conditions and their plant and animal communities.
- A land use system, reflecting the socio-economic use of the landscape.

Together, these two subsystems give rise to a land cover system that can be described through a classification and delimitation of landscape elements, their extent, distribution and pattern. Only a minor part of each landscape element might be considered to be of direct importance for wildlife. More elements would need to be included in the description of habitats to cater for specific species. Their inclusion in the total land cover system will mostly be of importance for evaluating future trends in habitat quantity and quality, and thus of biodiversity.

The distinction between land use and land cover is fundamental. For example, a land use, such as cattle grazing, might give rise to different types of land cover under different agricultural systems and different landscape conditions, such as open grasslands, grassland separated by hedgerows or by ditches. One land cover type, such as highly

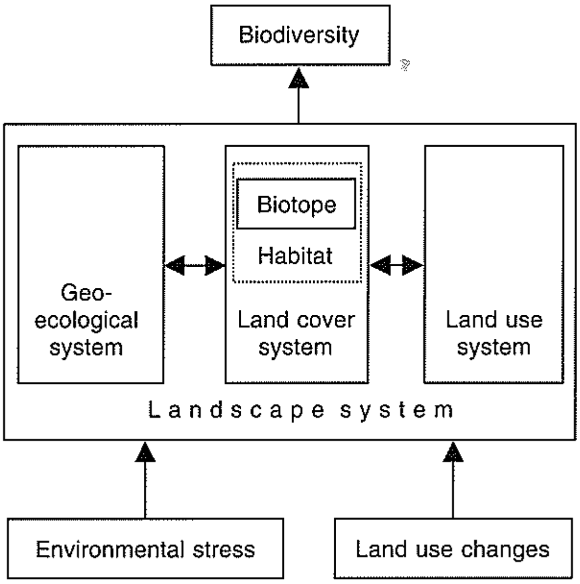

Figure 3. General threats to landscape functionality and its indirect impact on biodiversity.

fertilised grassland, can be developed from very different types of land use: intensive grazing, recreational parkland or a golf course.

Such a general framework for a landscape monitoring system has the advantage of being relevant, not only for monitoring of terrestrial wildlife, but also providing a reference framework for other uses, which may also help with funding in the longer term. Nonetheless, there is a risk that such a system provides information at the wrong level compared with the needs for monitoring threatened species and habitats.

In practice, landscape monitoring should be a combination of a monitoring system representative for the landscapes of the total territory under investigation, and at same time allow examination of particular problems or areas. The Danish landscape monitoring system works at both levels. In the following sections we describe a general landscape monitoring system. Even this is necessarily biased, since it is restricted to the agricultural landscape, and omits urban areas, forests and conservation areas.

4. Landscape surveillance and landscape monitoring

One of the basic aspects of a landscape monitoring system is the ability to detect landscape change, that is, trend monitoring. Trend monitoring incorporates the related, but different, concepts of *surveillance* and *monitoring.*

Surveillance means the general registration of shape, extent and abundance of landscape elements. It does not pre-suppose any particular objective, or aim, to the recording. Landscape surveillance has, for general purposes, tended to focus on total land cover: mapping all areas and land use within the survey areas. For surveillance of the European cultural landscapes, both the total land use and land cover should be given priority, since, together, they reflect the physical, behavioural and social characteristics of human society, and their interactions with the environment. The natural landscape structure also needs to be included.

Monitoring extends surveillance by recording changes of state over a period of time. 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. There may be a very large number of different changes which occur infrequently and need to be combined, further simplifying the surveillance system.

The two parts of the landscape monitoring system, the area surveillance and the time-dimension in monitoring are difficult to combine. Refining the surveillance system almost inevitably gives rise to serious problems in the reliability, and practical construction, of the time component and vice-versa. Detailed time-series analysis will, in practice, only be possible through substantial simplifications of the surveillance system, and the targeting towards directed questions and issues.

5. The history of the small biotope monitoring system in Denmark

In the large number of Danish studies published since the end of the 1970s the term 'small biotopes' has been defined as *uncultivated* areas that are *permanently covered with vegetation* (or water) *within or between* agricultural holdings. A small biotope was also defined as smaller than 2 ha, and either larger than 10 square metres (a little more than 3 m x 3 m) or longer than 10 m and wider than 0.1 m (Agger & Brandt 1988).

A small biotope surveillance programme in Danish agricultural landscapes was established in the late 1970s, initially with 13 test sites in eastern Denmark (Agger & Brandt 1984). This was gradually developed into a monitoring system covering 32 sample areas, each of 2 km x 2 km, during 1981, 1986, 1991 and 1996 (Figure 4).

The small biotope monitoring consists of:

- Detailed field registrations of all linear and area biotopes of size less than 2 ha.
- Recording the land cover and land use registration of all other areas within the 2 km x 2 km squares.
- Interviews with farmers concerning agricultural practice, as well as the functions of, and plans for, the small biotopes.

- An expanding frame of relevant information on the landscape, and geo-related structures and forces for each sample area, and stored, as far as possible, in an integrated GIS.
- An historical record of small biotopes for selected sample areas, based on air photographs (back to 1954) and topographical maps (back to the second half of the 19th century).

A basic principle has been to allow for time-series analysis of all Objects of Special Interest by linking every small biotope and agricultural unit through time. This has been done by a range of methods as the database has been developed.

The scope of the survey has developed over time. The motivation for the 1981 campaign was the general impression of a rapid decrease in number, and quality, of small biotopes following a period of intensification of Danish agriculture. At the time, Danish nature conservationists were still mainly concerned with the most threatened natural areas. They placed only minor emphasis on the more disturbed natural, and semi-natural, sites in the countryside, although these take up about one third of the total area available for wildlife in the intensively used agricultural land of Denmark (Biotopgruppen 1986).

The 1986 survey focused on the status and development of marginal land within the intensively used Weichselian moraine landscapes in Denmark covering the eastern and northern part of Jutland, and all the islands east of Jutland. Here, the dynamics of small biotopes were considered an indicator of the intensification / extensification process within agriculture (Agger & Brandt 1987). In 1986, some of the agricultural land was becoming marginal, unlike five years earlier.

Figure 4. The 32 test sites, each of 4 square km, surveyed in the Small Biotopes monitoring programme in 1981, 1986, 1991 and 1996. (Also shown are main rivers, forests, highways and cities.)

The 1991 survey was carried out in co-operation with the Danish Ministry of Environment, as part of the national monitoring programme for wildlife, recording not only small biotopes, but also other (larger) types of habitats and selected animal and plant species. This time, a detailed land use survey of the test areas was added to the recording.

In 1996, a new survey was developed in order to provide an empirical base for a multidisciplinary research programme dealing with possible new techniques for the management of the landscapes in rural Denmark. This is related to the trend since the mid-1980s towards post-productivist agriculture, and a growing pressure for non-rural activities in the countryside, representing a shift towards multipurpose use of agricultural landscape, and reflecting very different interests and attitudes towards nature and landscape. The 1996 survey used scenario-techniques, linked to the database information in selected test-areas, to specify different landscape consequences of future options for development.

The sample areas for the 1981 campaign only covered eastern Denmark. They were selected as a representative sample of agricultural landscapes using a two step procedure. First, using municipal level data, a statistical analysis of the relevant agricultural, ecological and socio-economic data was made to identify regions. Representative sample areas of 2 km x 2 km UTM-grid-cells within the regions were then selected by stratified sampling, adding samples from less frequent, but typical, landscape types, such as reclaimed areas, at a more detailed level. Only areas with more than 75% agricultural land were accepted. (Agger & Brandt 1988). For the 1986 and 1991 surveys additional sample areas in central and western Jutland were added.

6. Basic results from the monitoring of small biotopes in Denmark

The trends in the quantitative development of small biotopes in Danish agricultural landscapes from 1981 to 1996, based on the developed database, can be seen from Tables 1 and 2 (Holmes *et al.* 1998). All the following rates of change are calculated from these tables.

For eastern Denmark, where monitoring has been carried out since 1981, the length and area of linear habitats has been almost constant. The extent of area biotopes has increased considerably

Table 1.The quantitative development of landscape elements in 13 agricultural areas in Eastern Denmark 1981-1996.

Eastern Denmark 1981-1996 13 agricultural areas of 4 km² each	Number of elements pr km²				Length (in km) of linear element pr. km²				Area of elements (in % of total area)			
	1981	1986	1991	1996	1981	1986	1991	1996	1981	1986	1991	1996
Solitary trees	0.75	0.87	1.12	1.33					0.00	0.00	0.00	0.00
Mixed area	0.83	0.98	0.63	0.58					0.69	0.82	0.51	0.51
Forest	1.31	1.38	1.88	2.21					1.22	1.25	1.68	1.85
Herbaceous cover	1.58	1.52	1.52	2.10					0.64	0.64	0.78	0.94
Dry area biotopes	*4.46*	*4.75*	*5.15*	*6.21*	*no data*				*2.55*	*2.71*	*2.98*	*3.31*
Moor	1.90	1.83	1.71	1.54					0.48	0.51	0.50	0.49
Lake	2.27	1.98	2.02	2.04					0.26	0.26	0.29	0.38
Wet area biotopes	*4.17*	*3.81*	*3.73*	*3.58*					*0.75*	*0.78*	*0.79*	*0.87*
Area biotopes, total	**8.63**	**8.56**	**8.88**	**9.79**					**3.30**	**3.49**	**3.76**	**4.18**
Embankments	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Hedgerows	9.67	9.56	9.13	8.87	1.31	1.29	1.37	1.40	0.51	0.48	0.51	0.54
Road verges	5.13	5.08	5.13	5.04	2.08	2.09	2.07	2.04	0.55	0.55	0.55	0.51
Field divides	8.13	8.27	7.04	7.13	1.22	1.21	1.10	1.16	0.21	0.21	0.19	0.22
Dry ditches	1.35	1.29	1.15	0.69	0.34	0.33	0.29	0.14	0.08	0.08	0.07	0.04
Tree raws	0.69	0.73	0.77	0.88	0.13	0.14	0.14	0.17	0.05	0.05	0.05	0.04
Dry linear biotopes	*25.21*	*24.98*	*23.29*	*22.67*	*5.11*	*5.08*	*5.00*	*4.93*	*1.43*	*1.41*	*1.41*	*1.38*
Rivers/brooks/channels	0.48	0.50	0.48	0.54	0.32	0.33	0.32	0.35	0.28	0.28	0.28	0.28
Wet ditches	1.54	1.46	1.33	1.83	0.37	0.36	0.34	0.49	0.15	0.15	0.14	0.17
Wet linear biotopes	*2.02*	*1.96*	*1.81*	*2.37*	*0.69*	*0.69*	*0.66*	*0.83*	*0.42*	*0.43*	*0.42*	*0.44*
Linear biotopes, total	**27.23**	**26.94**	**25.10**	**25.04**	**5.80**	**5.77**	**5.66**	**5.77**	**1.85**	**1.83**	**1.83**	**1.82**
Biotopes, total	**35.88**	**35.52**	**34.04**	**35.00**					**5.26**	**5.42**	**5.78**	**6.16**
Closed Settlements	0.81	0.85	0.85	0.87					3.22	3.53	3.58	3.61
Dispersed built-up areas	4.96	4.96	4.96	4.96	*no data*				2.46	2.49	2.56	2.62
Area non-biotopes	*5.77*	*5.79*	*5.81*	*5.83*					*5.68*	*6.02*	*6.14*	*6.23*
Paved roads	1.60	1.60	1.56	1.60	1.01	1.01	0.99	1.00	0.45	0.47	0.47	0.50
Gravel roads	1.54	1.50	1.71	1.63	0.47	0.46	0.56	0.47	0.11	0.11	0.14	0.11
Soil roads/tracks	2.23	2.21	2.08	2.15	0.66	0.67	0.58	0.66	0.09	0.09	0.09	0.10
Linear non-biotopes	*5.37*	*5.31*	*5.35*	*5.38*	*2.14*	*2.14*	*2.13*	*2.13*	*0.65*	*0.67*	*0.70*	*0.70*
Non-biotopes, total	**11.13**	**11.10**	**11.15**	**11.21**	*no data*				**6.44**	**6.80**	**6.95**	**7.04**

since 1981. Rates of change have accelerated from +1.2% per year in the first half of the 1980s, to +1.5% by the end of the 1980s, reaching +2.2% per year in the early 1990s. Looking at the number of area biotopes, the trend is even more dramatic. A minor decrease in the number of area biotopes in the beginning of the 1980s (-0.2% per year) changed into an increase of 0.7% by the end of the 1980s, accelerating to +2.0% per year in the beginning of the 1990s. The recent increases have been due to the expansion of dry area biotopes; wet area biotopes have decreased throughout the same period. The number of moors has decreased, but their extent has altered relatively little.

At the national level (Table 2), in the period 1991 – 1996 all biotopes increased, in number and extent, except for the wet area biotopes, and the number of bogs is still decreasing. The length of wet ditches has increased by 6.4% per year.

An important goal for the monitoring of small biotopes has been to influence policy and decision making by changing the focus of conservation interests to incorporate widespread fragments of semi-natural vegetation. This has been achieved in the sense that the term "small biotopes" is now an everyday concept in the Danish environmental debate.

Small biotope monitoring has also been used as a basis for the Nature Protection Act of June 1992 (Miljøministeriet 1992). This gives a list of nature types under 'general protection', that cannot be altered without permission, although no compensation is given. The Act expands the list of nature types regulated by the general protection. In addition, the minimum size of landscape elements regulated by the law has also been lowered considerably, to only 100 square meters (10 m x 10 m) for small lakes and ponds

Table 2.The quantitative development of landscape elements in 32 agricultural areas in Denmark 1991-1996.

Denmark, total, 1991-1996 32 agricultural areas of 4 km² each	Number of elements pr km²		Length (in km) of linear element pr. km²		Area of elements (in % of total area)	
	1991	1996	1991	1996	1991	1996
Solitary trees	0.84	1.11			0.00	0.00
Mixed area	0.75	0.72			0.63	0.61
Forest	1.89	2.12			1.80	1.95
Herbaceous cover	2.13	2.71			0.72	1.00
Dry area biotopes	*5.61*	*6.66*	*no data*		*3.15*	*3.56*
Moor	1.30	1.16			0.50	0.47
Lake	2.51	2.59			0.34	0.39
Wet area biotopes	*3.81*	*3.75*			*0.84*	*0.86*
Area biotopes, total	**9.42**	**10.41**			**4.00**	**4.42**
Embankments	0.04	0.07	0.02	0.02	0.03	0.03
Hedgerows	11.80	11.90	2.01	2.03	0.65	0.68
Road verges	6.88	6.76	2.65	2.60	0.67	0.65
Field divides	7.05	7.41	1.21	1.30	0.20	0.23
Dry ditches	2.74	2.31	0.86	0.73	0.18	0.15
Tree rows	0.78	0.86	0.14	0.18	0.04	0.04
Dry linear biotopes	*29.30*	*29.30*	*6.91*	*6.87*	*1.77*	*1.78*
Rivers/brooks/channels	0.49	0.52	0.25	0.27	0.19	0.19
Wet ditches	2.16	2.72	0.50	0.66	0.17	0.20
Wet linear biotopes	*2.65*	*3.24*	*0.75*	*0.93*	*0.36*	*0.39*
Linear biotopes, total	**31.95**	**32.55**	**7.66**	**7.79**	**2.13**	**2.17**
Biotopes, total	**41.40**	**43.03**			**6.20**	**6.66**
Closed Settlements	0.88	0.88	*no data*		2.52	2.60
Dispersed built-up areas	5.84	5.82			3.22	3.22
Area non-biotopes	*6.72*	*6.70*			*5.74*	*5.82*
Paved roads	1.99	2.04	1.31	1.32	0.61	0.63
Gravel roads	2.66	2.66	0.75	0.72	0.18	0.18
Soil roads/tracks	2.40	2.32	0.64	0.65	0.08	0.08
Linear non-biotopes	*7.05*	*7.02*	*2.70*	*2.69*	*0.88*	*0.89*
Non-biotopes, total	**13.77**	**13.71**	*no data*		**6.66**	**6.75**

and 2,500 square meters (0.25 ha) for most other biotopes (Table 3).

The protection of threatened plant and bird species, and habitats, was the reason for including more of the extensively used agricultural types of land, such as small meadows, heaths and commons. The protection of Denmark's historical heritage has also been strengthened in the legislation. The first landscape elements to come under general protection were barrows from the Iron and Bronze Ages. The legislation has been widened to include almost all recognisable archaeological features and their immediate surroundings. Historically recent cultural elements, such as stone and earth walls from the 19^{th} century have been incorporated, based on a true mixture of culture and nature protection of the cultural landscape.

The majority of these newly protected types of biotopes, which occur across the whole of Denmark, as well as those that are unprotected, are historically and functionally closely related to agriculture. Any changes, therefore, have been linked to agricultural practice. A small biotope monitoring system must take this dual linkage into account. The system must enable a continuous evaluation of the effectiveness of the legislation (*effect-monitoring*). It must also support the development of new methods for regulation, by offering flexible tools for the analysis of the mechanisms behind changes of the small biotope network.

7. Monitoring landscape elements: what should be included?

Originally, the term 'small biotope' was created to help assess the rapid decrease in number, and

Table 3.The history of general protection - without compensation - of biotopes in the Danish agricultural landscape according to the Nature Conservation Act (1937, 1972, 1978, 1984 §43) and the Nature Protection Act (1992 §3, §4 and §12). (Minimum sizes in square meters).

Category	Year				
	1937	1972	1978	1984	1992
Barrows	all	all	all	all	all, incl. 2 m buffer zones
Other archaeological sites					most types, incl. 2 m buffer zones
Water courses		> 1.5 m	> 1.5 m + specially selected	> 1.5 m + specially selected	high priority water courses, incl. 2 m buffer zones
Lakes and ponds		all natural lakes	> 1 000	> 500	> 100
Bogs			> 5 000	> 5 000	> 2 500
Heaths				> 50 000	> 2 500
Salt marshes				> 30 000	> 2 500
Freshwater meadows					> 2 500
Commons					> 2 500
Stone and earth walls					all registered dikes, incl. 2 m buffer zones

quality, of small, uncultivated areas within the agricultural landscape of Denmark during the 1970s (Brandt *et al.* 1994). In this definition, the small biotopes are regarded as part of the land-use and land cover, in contrast to the cultivated areas. Thus the small biotopes are *not* defined in terms of natural landscape structure in a geo-ecological sense, such as ecotopes, physiotopes, nanochores or similar basic landscape units. Such structures are seen as important statistical references for monitoring, allowing a systematic analysis of composition, density and change of structures within different cultural landscapes, primarily at the detailed landscape level in the present Danish cultural landscape.

In the first surveys, only small biotopes less than 2 ha in size, within or between the agricultural fields were recorded. For monitoring purposes this proved difficult, as potential small biotopes within or directly adjacent to farmsteads and urbanised areas were not registered.

Initially, the study was based on the model of the landscape ecological tradition, where biotopes are regarded as patches and corridors embedded in the agricultural matrix. This has problems, especially when, comparing between surveys, small biotopes can appear and then disappear, solely as a result of changes in the surrounding matrix. For instance, the dismantling of an agricultural holding might change the land use of the former farmstead. New thickets (evolved from the former farm garden), some hedgerows and maybe a pond will 'appear', although all these landscape elements already existed as parts of the former farm garden.

Another problem arises from the upper limit for inclusion as a small biotope, of < 2 ha. The limit was used to focus on the smaller biotopes (< 2 ha), more liable to change, because in Danish landscapes nature areas up to this size usually belong to only one landlord. The sharing of ownership among several agricultural holdings often favours the stability of the larger biotopes.

The drawback of the 2 ha limit has been that changes in the small biotopes may be wrongly interpreted. Small biotopes may, for instance, arise from fragmentation of larger biotopes. When a bog is drained it often results in several small bogs remaining in the lowest parts of the area, and consequently drainage may result in an increased number of small biotopes. On the other hand, the amalgamation of two small biotopes to just one, in excess of the 2 ha threshold will reduce both the number and area of these biotopes in the summary tabulations. These problems can be overcome by regarding the small biotopes as a part of the general land-use, thus supporting the integration of the small biotope classification into the general land-use and land cover classification. This total landscape coverage principle has been in place since 1981, but the maximum size for classification of semi-natural biotopes no longer exists. Since the 1991 survey, all types and blocks of semi-natural areas have been considered objects of special interest. All data from the 1981 and 1986 surveys have been converted to match this change.

The many different questions that could be asked of landscape monitoring could potentially involve a huge range of data sets. Time and cost, and the need to share the work between differing disciplines, heavily influence the choice of datasets used. These will change as the monitoring system continues to develop. The data sets in the small biotope part of the Danish monitoring system are the result of the interdisciplinary developments since the early 1980s. The data sets can be loosely grouped:

- Landcover / landuse
- Agricultural practises
- Abiotic and complexes
- Regulatory /administrative boundaries and constraints
- Descriptions of the 'historical landscape development', such as maps dating back before 1981
- Auxiliary data

These data sets have been acquired from pre-existing datasets and through fieldwork (Figure 5). They are held in the Integrated Landscape Database (ILDB) (Holmes 2001).

8. Classifying landscapes for monitoring purposes

From the very beginning of the small biotopes project, the cultural origin of most small biotopes has been recognised. Only approximately a quarter of the small biotopes can be considered to be of natural origin, and even these are often highly modified. The origin of the rest can be traced to man-made features, primarily related to present, or former, agricultural land-use, such as ditches and marl pits.

To reflect the anthropogenic nature of the small biotopes, everyday terms have been used in classification, such as 'marl pits', 'ponds', 'prehistoric barrows', 'hedges', 'avenue', 'verge', 'field divides', and 'small areas of fallow'. Attempts have been made to give these genetic-functional terms a precise definition, and to fit them into an ecologically relevant hierarchical classification (Brandt *et al.*1994).

This classification has been useful for many purposes. However, looking at the 1996 survey, it became clear that the mixture of a genetic,

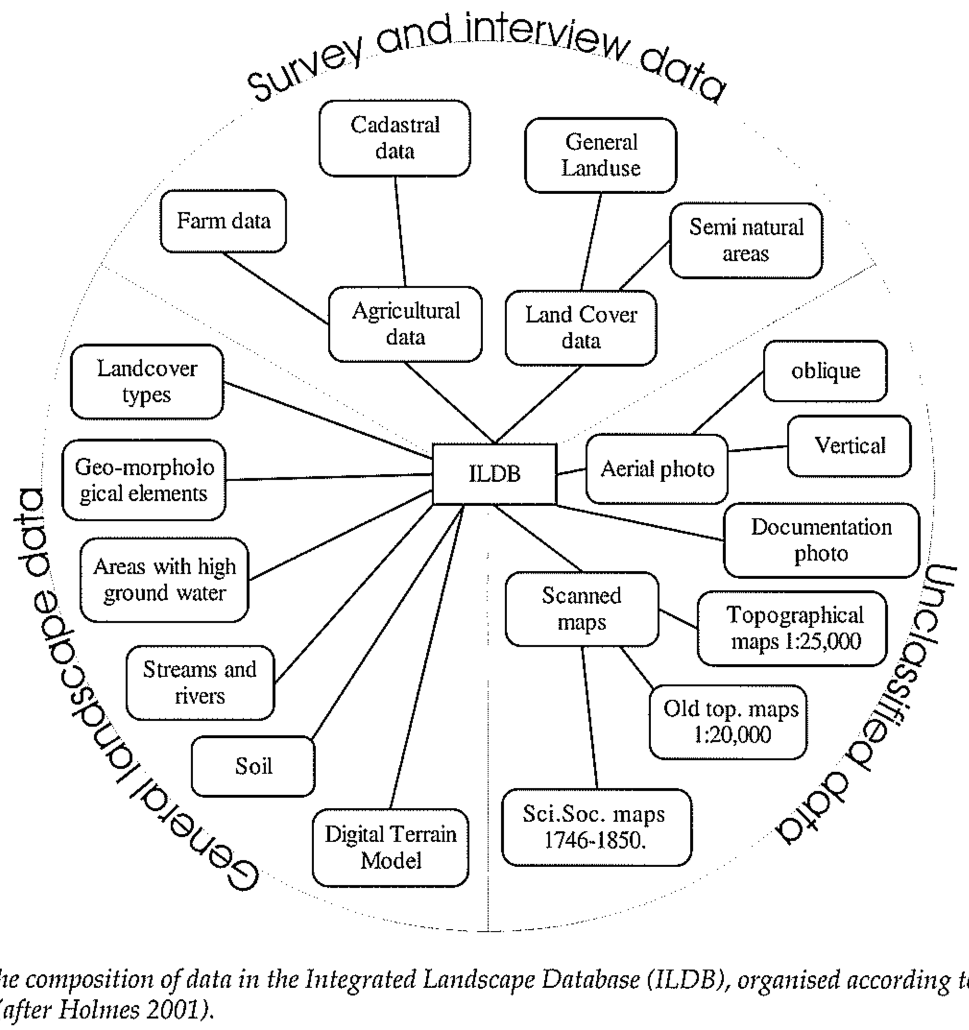

Figure 5. The composition of data in the Integrated Landscape Database (ILDB), organised according to the origin of the data (after Holmes 2001).

functional and ecological based classification is not suitable for long-term monitoring, since it makes the detection of change complicated. For example, how should one define the transition of a marl pit to a pond or a game plantation?

Instead, a precise physiographic classification was used, adding an internal 'sub-land cover' classification, called a tessera-classification. Subsequently, all the former material was reclassified into a physiographic classification (Brandt & Jakobsen 1998). Genetic and functional characteristics were added to the description as attributes. For instance, a 'hedge' is defined as "20 metres of a linear biotope of which a minimum of 50% is covered with trees or shrubs, and where the surface is between 0.25 m below and 0.75 m above the surrounding fields". If the surface was higher, it would be the small biotope type 'hedge on earthwall'.

The use of a precise physiographical description, and classification, is a precondition for a repeatable detection of land cover changes, and is of fundamental importance for the monitoring system. It is interesting to note that this monitoring-oriented change in classification results in types that, in their basic form, are compatible with the legend of the Danish topographical maps, although they are, of course, more detailed.

9. Problems of surveillance reliability in landscape monitoring

The unique character of landscapes, combined with the amount of data, makes them difficult to survey, since many errors are never detected. Quality assurance is rarely discussed, and is usually absent from monitoring exercises. Increasingly, the reliability of remote-sensing-based surveys has been discussed, especially when calculating different landscape-indices. In a commentary on pattern and error in landscape ecology, Hess (1994) stated that:

> "Landscape ecologists have been using remotely sensed data to calculate measures of broadscale landscape pattern, but have devoted no effort to quantifying the uncertainty in these measures. Without statistical confidence one cannot use measures of pattern to detect differences in landscapes over space, or changes in a landscape over time."

To undertake detailed landscape monitoring, it is necessary to rely on field surveys. However, if field surveys lack consistent definitions and quality assurance, they can be as unreliable as remotely sensed data, due to their higher degree of subjectivity and registration errors. There may also be data coding errors, both in the digitising of boundaries and the recording codes.

Wyatt *et al.* 1994 summarised the many different land use and land cover surveys in the UK, involving mapping from satellite image data, aerial photography, and stratified ground sampling network. They found that the overall errors were of the order of 20% – 30%. Quality control checks, undertaken as part of field surveys, indicated 74% – 83% recording accuracy by field surveyors. For landscape monitoring, such errors could be serious. They can be greatly reduced if the repeat field sampling is carried out in the same locations at the same time of year. One additional lesson could be that the surveys of the fields should, whenever possible, be integrated with other data, such as satellite images or air photographs.

10. The use of GIS in landscape monitoring

Any modern monitoring system needs to have an appropriate data management system. Data processing of the large amount of data typical for a monitoring system can be very difficult to handle without such a system, and almost impossible when remotely sensed data are involved. However, it is important to realise that a relevant GIS can be very expensive, and time-consuming, to design and implement. It should be noted that some monitoring systems have been handled more easily and efficiently without using a GIS. However, the big advantage of a database system, and especially a GIS system, lies in the better control of data-collection, data-storage and data processing. Also, if further analysis of spatial relationships is required for landscape ecological studies, then GIS is absolutely essential. For detailed landscape surveys, these advantages can probably best be achieved by using a vector-based system.

One of the most interesting outcomes of setting up a landscape monitoring system, rather than a surveillance system, is that it allows, or indeed forces, a critical stance to be taken on 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 and the integrated-layer model.

In the *separate-layer model* emphasis is put on the independent surveys, where all the reliability checks are related to each survey. In the model, 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 very dependent on the surveyors' skill, 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.

In the *integrated-layer model* - used in the Danish small biotope monitoring system - emphasis is put on the registration of changes compared with 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 reasonably distinct, which will in general be the case in most intensively used lowland agricultural landscapes of Western Europe, including Denmark. 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, 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 along with the monitoring process.

The result of this procedure is that the monitoring has not only become more reliable, due to better registration techniques, but also the editing of former registrations has added to the quality. In fact, a considerable part of the time used for the refinement of the database has been devoted to the systematic control of all detected changes back in time. Such a rigorous change control is necessary, since landscape monitoring relies on the detection of small changes. With an average of about 200 small biotopes per sample area (2 km x 2 km) in the Danish monitoring system, even a 1% annual change means changes in only ten biotopes over a five year period. With very different trends for the wide range of biotope types, there is little room for error or misinterpretation if reliable quantitative statistics are required.

It can be concluded that the reliability of surveillance is substantially improved by quality assurance within the monitoring programme, by repeated records of the same elements over time, and a procedure for incorporating change control as a part of the monitoring system.

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