Landscape Monitoring

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1 Introduction

Today's landscapes are – almost all over the world and increasingly – influenced by human actions. Even in remote areas, atmospheric transport of pollutants and modifications to our climate act on the landscape. Landscape change in turn alters the living conditions of plants, animals and of the human population. The perception, monitoring and understanding/assessment of landscape change, is therefore, a pre-requisite to predict the future conditions of life and eventually to steer landscape change in desirable directions.

Landscape monitoring is a complex issue and could be subject to an entire book in itself, covering various landscape related issues from biodiversity and vegetation monitoring over the follow up of abiotic landscape components to anthropogenic and cultural aspects such as scenery and landscape aesthetics. Some of these issues are addressed in other chapters of this book. For our part, we will concentrate on landscape monitoring in a more narrow sense, i.e. mainly land use and land cover. We will summarise the fundamental concepts of the monitoring of land use / land cover as they are presented in the literature and, of course, as we perceive them from our personal experience. There will therefore be a certain bias towards European landscapes, towards agricultural landscapes and towards the interactions between landscape change and habitat availability..

1.1 Monitoring: perception of change

A principal aim of monitoring is to perceive the changes to our ecosphere as influenced by the activities of humans or through natural disturbances. Monitoring systems in general observe the factors that affect our natural environment; they provide an assessment of the actual situation and also a prognosis of the potential future developments (Vahrson, 1998). In terms of landscape monitoring the main purpose is to assess whether the structure and the function of the landscape changes overtime. Forman & Godron (1986) state that if the landscape is left undisturbed the structure will tend towards homogeneity in the horizontal scale. Moderate disturbance will increase heterogeneity whilst severe disturbance may lead to either an increase or decrease of heterogeneity. Of particular interest then for landscape monitoring systems are the changes to the ecological situation of our landscapes, often with particular reference to anthropogenic activities. For instance we might be interested to assess if and to what extent an intensification of agricultural production affects the extent and quality of semi-natural habitats and thus – potentially the species diversity.

Landscape monitoring systems have a historical perspective. That is they examine the past situation in order to assess the current condition of the landscape and this information is used to make projections of the likelihood of future change. In the example mentioned above, scenarios can be established which predict the future extent of semi-natural habitats depending on a given increase in agricultural intensification. Above all, this will depend upon the changes in the composition, spatial configuration and function of the landscape (Vahrson 1998; Bastian et al., 2002). In an ecological context critical change factors will include the level of habitat fragmentation within the landscape, the extent of habitat loss for particular species and species groups and the effects on flows of energy, water and matter (for example nutrient leaching). The monitoring of landscape in contrast to many other programs measures in the spatial dimension and therefore analyses change on a medium to large spatial scale. Normally, the programs monitoring landscape are not confined to a single subject matter or small-scale process but observe integrative changes of structure and function.

1.2 Landscape Monitoring as a basis for the monitoring of many environmental indicators

In the context of environmental indicator systems as they are being developed by the UN (UN, 2001), OECD (OECD, 2002), the EU (Smeets and Weterings, 1999) or national governments (e.g. Orians et al. 2000; Statistics Canada, 2000; OFS – OFEFP – ARE, 2002), knowing the extent and status of the ecosystems is needed for the calculation of many of the state indicators which relate to a certain portion of the land or to some specific landscape type. Also, being informed on the distribution of different land use/land cover types may facilitate the sampling of the data for many indicators. It allows the implementation of stratified sampling strategies which can reduce the number of samples in "common" land use/land cover types (avoiding over sampling and thus reducing cost) while making sure that minor but nevertheless important land use/land cover types, which in fully random sampling would not or only rarely be sampled, are sufficiently covered (e.g. Tolle et al., 1999).

→ *remark to the editor: here we could possibly cross-reference other chapters of the book!*

1.3 Fundamental notions

Landscape: As our planet is sub-divided spatially in numerous ways (examples include, cultural, religious, social, economical, political or natural divisions; Forman & Godron, 1986; Forman, 1995) our landscapes have been defined from many view points in literally hundreds of ways (Naveh & Lieberman, 1983; Schreiber, 1990). Principally, the definitions and sub-divisions vary according to the area of research interest, planned management or monitoring programme.

Our planet is subdivided into a hierarchy of scales. For example, the globe can be sub-divided into continents which are further sub-divided into regions, landscapes and local ecosystems. Within this hierarchy, each level represents a different level of detail, different degrees of variability, different sizes, shapes as well as many other attributes. At the continental scale, each continent expresses a great deal of heterogeneity, exhibiting a diversity of climates, soils, topography, vegetation, land uses and politics. The regions on the other hand mostly consist of a broad geographical area with a similar macro-climate and common cultural, economic and political background but an extremely diverse ecological context.

By way of contrast, "**landscapes represent a mosaic where a cluster of local interacting ecosystems or land uses are repeated over a kilometres-wide area"** (Forman, 1995, p.39). According to this definition, a landscape will have similar and repeated clusters of spatial elements such as the soils, vegetation, fauna, and land use throughout its area. We intend to adopt this definition for the purpose of this chapter. However, it is important to note that the definition considers landscape from the anthropogenic perspective. From a human point of view we tend to perceive landscape on a broad scale of tens of kilometres and are able to take account of temporal changes (Forman, 1995; Turner, 2001). Most of us indeed have an instinctive sense of landscape and are able to tell the difference between certain landscapes (alpine, lowland) as well as to define elements within given landscapes (fields, hedgerows, solitary trees, small woodlands, barns). However, landscapes are not always large-scale. From the perspective of other organisms landscapes may be represented on a scale of tens of metres or less. In fact the size of the landscape and the nature by which it is defined will depend on the organisms or processes under consideration (Wiens, 1976; Wiens & Milne 1989; Farina, 1995, 2000; Mazerolle & Villard, 1999). To avoid reference to absolute scale whilst addressing the importance of spatial configuration for ecological processes, Turner et al. (2001) have deliberately defined landscape in broader terms as an 'area that is spatially heterogeneous in at least one factor of interest'.

It is important to remember that landscapes do not stand alone but are nested within other landscapes and therefore also have a regional context. Depending on our object of interest and hence our definition, our landscape can either act as open system where energy, materials and organisms will move in and out of them freely or a closed system. For example, a landscape which is open to a bird species may act as a closed system for other organisms. When establishing a landscape monitoring system, it is therefore essential that the landscape definition is suitable for the phenomenon and processes under consideration and that the regional context and openness of the landscape are taken into account.

Landscape mosaic: According to Forman and Godron (1986), landscapes have three main characteristics, namely their structure, their function and their tendency to change. Structure depends upon the spatial configuration of the elements which define the landscape of interest. The function is related to the interaction and flow of energy, materials and species between these spatial elements.

Both characteristics are subject to change. In terms of landscape monitoring the changes to the structure of the landscape and how they will affect the landscapes' function are often a principal concern in the programme.

The structure of the landscape is depicted by the **mosaic**; the cluster of interacting ecosystems or land uses repeated at the relevant scale of interest of the focal object (Forman & Godron, 1986; Forman, 1995). The mosaic can actually be broken down into a pattern of **patches**, **corridors** and **matrix**, spatial elements comprised of similar and clustered objects. At the landscape scale we refer, in this chapter, to these spatial elements as **landscape elements**. Patches consist of relatively distinct, homogeneous, non-linear areas (e.g. woodland, grassland, moor) and corridors are linear strips of a particular type (hedgerow, road verge, canal margin), both of which differ from the adjacent landscape elements (Forman, 1995). The matrix is in effect the background ecosystem or land use type of the mosaic. It is characterised by its extensive cover, high connectivity and/or major control over dynamics. For example, in an agricultural landscape the matrix will be the arable land, in a sub-urban landscape the built up areas will form the matrix and in a upland landscape the matrix may be represented by the moors.

The mechanisms which create the pattern of the land mosaic include the geomorphology of the landscape and the associated substrate heterogeneity; the natural processes and natural disturbance factors; and the level of human activity (e.g. Krönert, 1999). Natural phenomena (floods, hurricanes, earthquakes) can result in dramatic changes to the mosaic. However, the current level of human activity, through land use, is likely to instigate both more rapid and long term changes to the structure and function of the landscape.

Land use: was described by Barsch et. al. (2002) as the fundamental human process of acquiring space and in the wider sense defines the nature of the human activity within the landscape. Of course this will depend upon the natural resources which are available and the ease by which they can be obtained. Through monitoring changes in land use the demands that society directly or indirectly makes on the landscape can be observed (Bastian et. al., 2002). Land use can modify material cycles and exchange processes in the biosphere by changing landscape structure (Haefner, 1999). Furthermore, at the landscape scale the nature of our land use has a strong impact on the adaptability, the regeneration and regulation capability of ecosystems (Volk & Steinhardt, 2001).

Land cover is a (bio)physical description of the earth's surface and represents what covers the ground at the time point at which it was observed. Often but not always the cover corresponds to the habitat or vegetation present. The terms land cover and land use are closely related. However, an important difference is that land cover can have more than one land use associated with it. The moors of upland, for example, may be used among other things for farming, recreation, nature conservation and to provide habitat for game birds. A woodland cover may be used for timber production, to provide wood for specific woodland crafts, to counteract climate change, they may act as a windbelt and also serve as a recreation area.

Scale, grain, resolution: Scale is the spatial or temporal dimension of an object or process and is characterised by both its extent and grain size (Turner et al., 2001). The extent is the size of the study area or the temporal duration of the phenomenon under observation. The grain is the finest level of spatial resolution possible within a given data set. Together they define the upper (extent) and lower (grain) limits of the spatial resolution in the study. The spatial resolution is a measurement of precision as it dictates the smallest possible feature that can be detected in the study. It can vary enormously. For example, in terms of remote sensing and the use of satellite imagery, the grain size can vary from a few metres or less (a fine/high resolution) to several kilometres (a coarse/low resolution). Generally speaking, the finer the resolution of the image the more objects that can be detected but the less total ground area that can be covered.

Scale is either cartographic (ratio of distance on the map to the Earth's surface), absolute (actual distance, direction, shape, geometry) or relative (transformation of absolute scale to a relative scale). In cartographic terms a large scale refers to a fine spatial resolution (1:5,000) and a small scale to a coarse spatial resolution (1:200,000). This can be confusing and biologists, when they speak of large and small scale, can often mean quite the opposite. In this chapter we adopt the use of fine (small area, high resolution) and broad scale (large area, low resolution) as also suggested by Turner et al. (2001). In a landscape context a fine grained mosaic is made up of small spatial elements and a coarse grained mosaic by larger clusters of objects.

Spatial or temporal scale of an object or a process is intricately linked with the ecological hierarchy theory of Allen and Starr (1982). This theory refers to how a system of discrete functional elements are linked to at least two or more scales. Namely, in a hierarchy, each level will be composed of sub-systems on the lower-level; constrained by the layers above and linked to the other elements on its own level (e.g. tree, stand, forest; cereal crop, arable field, agricultural landscape). The individual elements will function as a unit, they will be subject to constraints and will exhibit an individual degree of stability or variability. Organisms and processes operate at different scales in time and space and are separated from one another by magnitudes of scale. To understand the stability of a particular element it is necessary to have knowledge of a minimum of three hierarchical levels. It is therefore essential that the study is directed at the level of scale at which the object of interest is known to operate (Farino, 2000, Turner et al., 2001). Without careful consideration of the grain size and extent of the study area erroneous conclusions may be drawn. If the level of scale of the object of interest is unknown it is common practice to select a finer scale than thought necessary as this can be dissolved later to a coarser scale.

The choice of scale in the design of a landscape monitoring programme is thus an extremely important issue and it should largely depend upon the focal point of the study. Scale will influence the patterns which can be detected in the landscape mosaic and therefore the conclusions that can be drawn from the study. However, from a human viewpoint landscapes are usually contemplated at a broad scale, partly as environmental issues have manifested themselves over much larger areas (Forman, 1995; Turner, 2001). The scale used also dictates whether the results can be extrapolated to other spatial or temporal dimensions (Forman & Godron, 1986; Turner et al., 2001). A pattern or process is said to be scale dependent when the response changes with the grain or extent of the measurement. When assessing landscape patterns it is not possible to extrapolate below the resolution of the grain or beyond the extent of the landscape (Wiens, 1989).

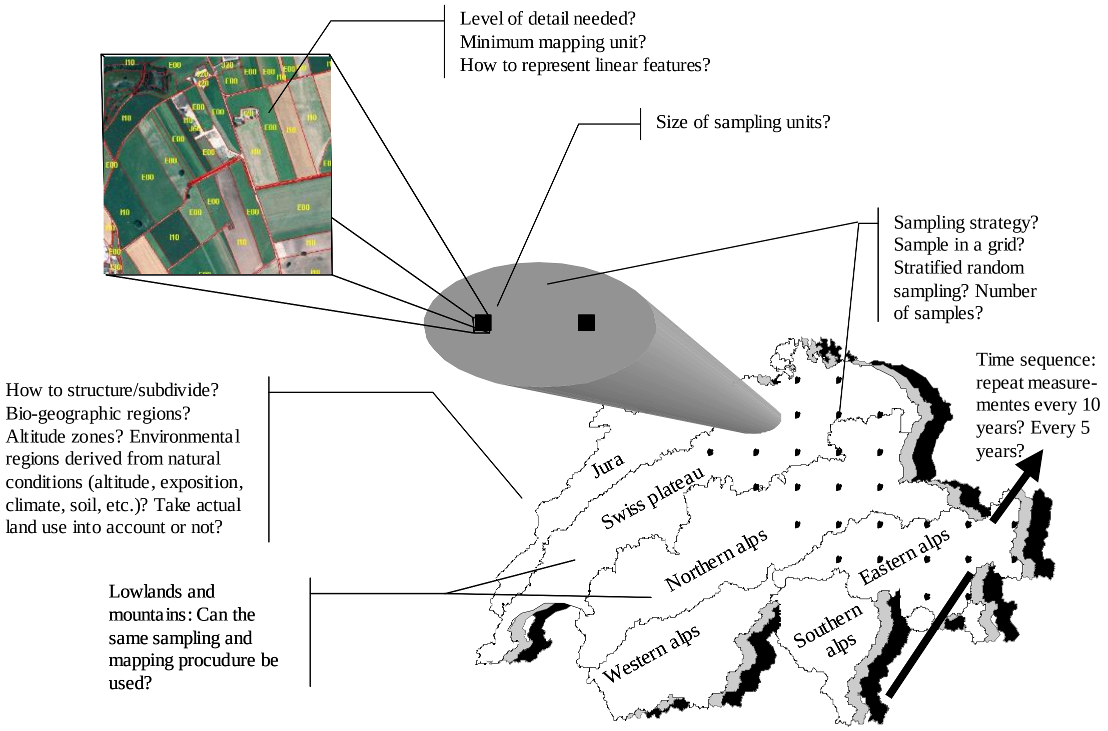
There are several problems associated with scale. Often the scale and extent of the study are dictated by the scale of the imagery available (for example spatial resolution of the aerial photographs and the coverage available) and also the computer technology which is available. In addition, much of the data needed for a landscape monitoring project will not be at the same scale. This means that it is often necessary to extrapolate the scale or extent from one scale to another or information from one data set to another at the same scale. This process is often not very straightforward and can be extremely problematic. Indeed, a modern day issue, for scientists and landscape managers alike, is the practical and theoretical problems associated with extrapolating results across scales, for example, from fine to broad scales (Bierkens et al., 2000). Interpretation of the data is often difficult across scales and therefore the prediction of an ecological attribute or environmental process can be complex when extrapolating fine scale information to broad scale issues. It is, for example, still very unclear how landscape patterns change with grain and extent (Wu et al., 2002). There are of course also problems associated with sampling design as the landscapes are often very large and variable in character.[1]

2 Mapping the land

The design of the landscape monitoring programme will depend upon the key questions of the study. Examples include: What is the rate of change which needs to be detected, i.e. do we need updated information every 5 years or every 20 years? Over what spatial dimension are changes taking place? Do we want averaged information about the entire region only or do we need data for individual sub-regions? About which ecological effects of change do we need information? Are the changes acceptable to society? ‘Box 1’ illustrates these questions with the example of designing a landscape monitoring programme for Switzerland.

[1] Think about illustrations (e.g. illustrating the concept of grain / scale, etc)

Box 1: Designing a landscape monitoring programme for Switzerland.



Switzerland is a heterogonous country with densly populated lowlands (plateau), lower mountains (Jura) and high mountain areas of different characteristics (Alps). The map represents the Swiss bio-geographic regions (Gonseth et al., 2001).

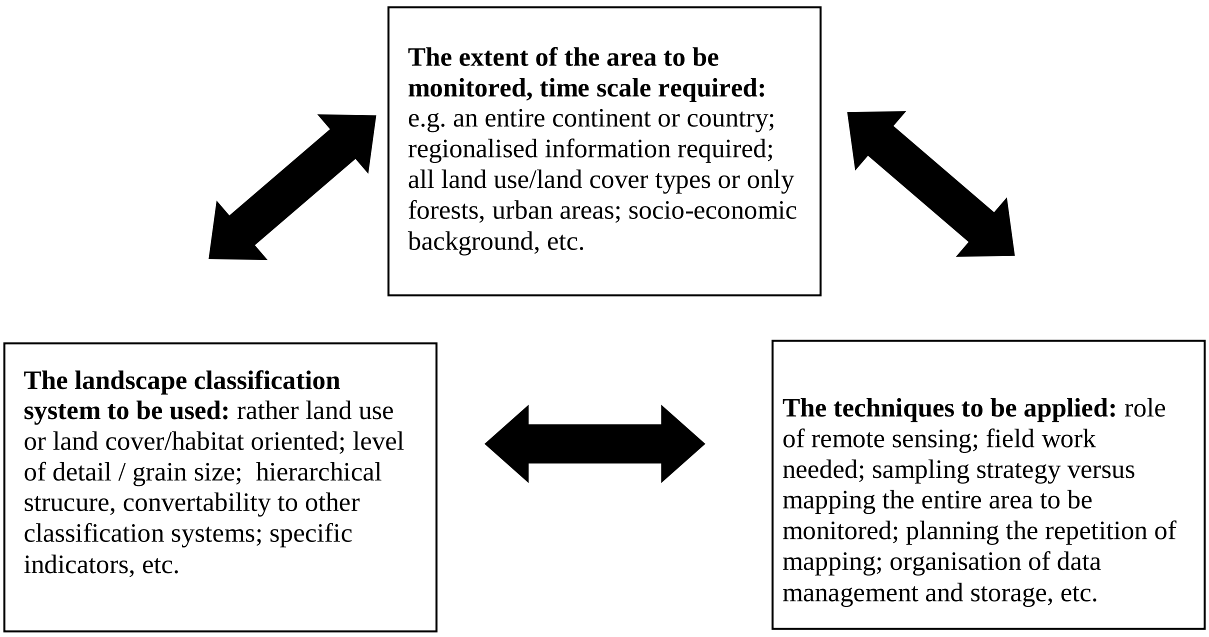


Figure 1: Major factors determining the features as well as the cost of a landscape monitoring programme.

Depending on the answers to these questions suitable methods for the collection, analysis and evaluation of data can be chosen. Three major decisions have to be made (Figure 1) which are inter-dependant and are the key for defining the quantity and quality of the information which can be derived. They also determine the cost of the monitoring programme.

Landscape-scale dynamics are extremely complex and difficult to explain because – in addition to the temporal component which is inherent to all monitoring programmes – they have a spatial dimension. Also, to observe temporal change the data will need to have a historical and current content. From a social and economic viewpoint it is important to have a working knowledge of the current and historical changes that have or had an impact to the ecological and landscape functions in the region of interest (Bastian, 1999). Knowledge of the driving forces behind change will help to identify the potential trends for the future development of the landscape and to suggest guidelines which aim to stop or slow down unacceptable changes. In this next section we will examine the techniques for mapping and classifying the landscapes. Principally, the data for monitoring landscapes are generated by remote sensing combined with fieldwork ('ground truthing'). In addition, statistics and censuses can be used for the interpretation of change.

2.1 Techniques

2.1.1 Remote Sensing

Remote sensing is a set of data acquisition techniques that enable the observation and monitoring of earth surface and processes at a distance. All techniques that gather data at a distance without contact with the object of interest may be called remote sensing and the technology includes: aerial photography, satellite imagery, radar and thermal imagery.

Aerial photo interpretation is a common, highly effective and accurate method for the classification of temporal change in landscapes especially when combined with other data sources and technologies (Lindgren 1985, Jensen 1986, Singh 1991, Naveh & Lieberman 1993, Falkner & Morgan, 2002). The Food and Agriculture Organisation (FAO) have been using aerial photography since the 1950's for their field projects and surveys. New possibilities due to developments in computer technology (high-resolution scanners, digital photogrammetry, digital image processing and GIS) are now also available. It is possible, for example, to analyse vegetation dynamics at a combination of spatial resolutions, spatial extents and temporal scales using aerial photographs within the GIS environment (Carmel et. al., 1999).

Ideally aerial photo interpretation is done in a stereoscopic way which – through overlapping images taken from different angles – offers a three dimensional view on the landscape. The classic instrument for this purpose is the stereoscope. More recently, this can be done electronically on the PC with the help of 3D glasses. This has the advantage that the photographs can directly be overlayed with additional GIS layers and/or – for monitoring purposes – with preceding land-use / land cover interpretations.

Satellite Technology: Since the 1970's, the entire planet has been regularly scanned by satellites. The continuity of this digital information makes it extremely useful for the monitoring of landscapes (Naveh & Lieberman 1993). Solar radiation received by the earth's surface is either absorbed or reflected in specific wavelengths, most of which are not visible to the human eye. This reflectance is recorded in different wavelengths by satellite-mounted sensors and these build up the characteristic spectral signature of a particular object. The spectral signature will vary depending on the backscattering properties of the material (e.g. soils, vegetation type, water). The spectral areas that are commonly used for monitoring are those of visible, near-infrared, infrared and the thermal part of the electromagnetic spectrum. These are not recorded in a continuous spectrum but rather in spectral bands. The data is collected by the sensors in groups of spectral bands, the number of bands depending on the particular satellite. In addition to the spectral capacities of the satellite, the spatial resolution is of interest. It determines the pixel size (grid cell) of the image and can vary tremendously (e.g. from 1m x 1m to 5km x 5km).

Spectral signatures can be processed into photograph-like images (raster format with a given pixel size) of the different surface objects. Prior to dispatch, the raw data is normally processed through standard algorithms, cleansed (corrected for atmospheric, sensor errors and geometric distortion) and possibly geo-referenced. The user will then classify the image using either a supervised or unsupervised classification method (Buiten & Clevers, 1993). A supervised classification method uses pre-determined training pixels for which the class is known (through field verification) to order the image. Unsupervised classification assigns the pixels into clusters according to certain rules and algorithms. These clusters are then identified through field verification. Spectral signatures of objects are unique. Therefore, the objective of multispectral classification is to automate the identification of features using their spectral information and thus remove the need for visual analysis of the image data (Lillesand & Kiefer, 2000). The use of multi-spectral classification has limitations, namely the spectral separation of certain classes and the spatial resolution of the image. Certain classes are difficult to separate, for example, grassland and germinating crops. Such problems can be partly avoided through selecting images from particular times of year or by using several recordings in a given year.

Satellite systems which are currently used to monitor the landscape include LANDSAT, SPOT, IKONOS, satellites in the Indian Remote Sensing program (IRS) and the Earth Remote Sensing (ERS) program. The commonly used NASA satellite - LANDSAT-7 - has a resolution of 15m in the newly added panchromatic channel. The SPOT satellites record radiation in visible and near infrared range with a spatial resolution of 20m by 20m. They also have an additional panchromatic channel which has a resolution of 10m by 10m. The panchromatic sensor of the Indian satellite IRS-1C has since 1995 a resolution of 5.8m. IKONOS panchromatic data has a 1m resolution since 1999.

Table 1 summarises the major properties of arial photographs and satellite images. In Box 2 some links to metadata systems on remote sensing data availability are given.

Table 1: Advantages and drawbacks of aerial photographs and satellite images.

	Aerial photographs	Satellite images
Availability	since 1930's in black and white, later in true and infrared colour. Many countries are regularly covered for the production and revision of maps.	since 1970's, on average 1 – 4 recordings per year free of clouds (Kühbauch et al. 1990)
Type of data	often analogous	always digital
Pre-processing	orthorectification is needed if photos are to be overlaid with maps and additional GIS information	geo-referencing
Scale/spatial resolution	on demand, often 1:2,000 – 1:30,000, resolution down to 0.3 m	1:50,000 – 1:250,000, resolution down to 1 m; the most frequently used are Landsat (30 m) and SPOT (20 m)
Interpretation	visual or electronic; stereoscopic interpretation possible	on PC, unsupervised or supervised classification with specific software packages
User friendliness	valid information can be gained from visual interpretation	sophisticated hard- and software needed

Box 2: Metadata systems

Remote sensing and computer technology has resulted in the generation of vast amounts of spatial data which is available in digital format. This can make the task of data retrieval problematic. To help solve this problem meta-information systems may be used or set up by users and suppliers to aid the collection of appropriate data. Metainformation systems aim to provide thematic, spatial and temporal references of what is available for particular specified area. A number which currently exist in the environmental domain include:

GEIN: German Environmental Information System (Germany, http://www.gein.de/index_en.html)

GISU: Geographic Information System Environment (German Federal Environment Agency, http://193.174.169.36/GISU/gisu.htm)

UDK: Environmental Data Catalogue (German, Austria, http://www.umweltdatenkatalog.de/wwwudk/V-UDKServlet)

CDS: Environmental Catalogue of Data Sources (European Environmental Agency, http://www.mu.niedersachsen.de/cds/)

NGSC: National Geospatial Clearinghouse (USA, http://nsdi.usgs.gov/)

Information packages are also available which are designed for viewing and distributing information on topics like land cover and nature in a user-friendly way. NATLAN (NATure/LANd cover) is one such information package designed and developed by the European Environmental Agency. The purpose of NATLAN is to give public access to the large amount of geo-referenced data on nature sites and areas which are collected on behalf of the Agency.

Sensor systems are also transported by aeroplanes (Falkner & Morgan, 2002). Examples include: the Airborne Visible Infrared Image Spectrometer (AVIRIS), the Thermal Infrared Multispectral Scanner (TIMS) and Digital Multispectral Videography (DMSV) and Hyperspectral sensors. The latter are normally used to identify individual minerals or water components but could also be used to monitor the change of biotopes or water quality. The big advantages of aeroplane borne sensor equipment is that they are more flexible and can react quickly to weather conditions. Generally, they also take images of a higher resolution and therefore are able to record smaller objects.

2.2 Land-use / Land cover categories

Numerous systems to define land-use / land cover categories have been proposed to classify landscape at a variety of scales (e.g. Di Gregorio & Jansen, 1996; Delarze et al. 1999; EEA, 2002;...**Gabriela do you have some more references?**). It may seem simple, at the offset, to distinguish e.g. forest from agricultural land. But reality is more complicated than that. If we stick to this example and give it a second thought, we realise that it can be quite difficult to define the edge of forests in, for example, alpine regions where towards the upper limit of tree growth, pastures, forest patches and single trees are intermixed. Blaschke (1999)[2] showed that different persons will interpret the tree line differently. To overcome this, clear definitions of land-use / land cover categories are needed with rules and quantitative specifications.

Land-use / land cover classifications systems generally have a hierarchical structure which allows the user to analyse landscapes at different levels of detail and to aggregate classes to – ideally – a common level. For example, `forest` can be subdivided into 'perennial forest' and 'decidious forest`, the latter again into different plant sociological associations if needed.

For monitoring it is important that the definitions of the different classes remain constant, at least at the level of detail which is relevant for the phenomenon of interest. Ideally, different classifications can be converted into each other, probably at a more general level. This approach is currently developed in the EUNIS habitat classification (http://mrw.wallonie.be/dgrne/sibw/EUNIS/home.html). The system can be linked to the EU Habitat Directive, to the Bern Convention Resolution EMERALD network, to the Palaearctic Habitat Classification, to the CORINE land cover classification, to some regional and national classifications and also to systems such as the European Vegetation Survey (Moss & Davies, 2002a, 2002b, 2002c).

2.4 Repeating the mapping

Monitoring consists of repeated measurements of a certain feature. In order to detect change we will want to reduce all other factors which act on the feature's indicator value. In landscape monitoring

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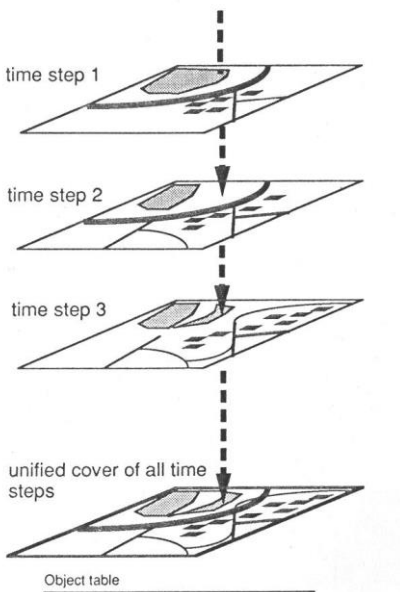
[2] Blaschke has a very nice illustration of this, waiting for his permission to use it

these disturbance factors are namely the exact geographical location of measuring points or of recorded geometries and the actually assigned land use / land cover type.

The satellite images and aerial photographs used in the monitoring study will need to be geo-referenced. This process assigns spatial data with a coordinate system and enables the images to be associated with a specific location on the earth. The coordinate system should be projected. Many different projections exist and it is essential that the correct projection is selected for the study location. Map projections transform the spherical surface of the Earth on to a flat surface such as a map. An advantage of georeferencing is that it allows spatial data to be overlayed and analysed with other forms of geographic data.

If remote sensing images are translated in GIS layers and the changes are detected through the analysis of subsequent GIS maps, subsequent maps need to be based on each other. That is, land use / land cover should not be digitised from scratch each time but only the changes should be recorded. Otherwise minor shifts in the position of individual patches or lines will occur and this will result in a false interpretation of the modifications which are actually not real. Kienast (1993) developped a procedure to generate a spatio-temporal data model based on a subsequent set of topographical maps. By overlaying and intersecting the digitised maps, land cover change can be analysed for each location (Figure 2, see also Box 3).



Object no.	Time-steps 1	2	3
1	forest	openland	forest
2	resident.	road	road

Figure 2: Conceptual model for the analysis of subsequent time steps based on topographic maps. Source: Kienast (1993).

As for the analysis of land use / land cover types from satellite or aerial photographs (Box 3), observing seasonality is a key issue. Photographs must be taken in the same season of subsequent years when vegetation development is at a similar stage. Broadleaved forest, for example, reflects differently when the trees have leaves than when there are no leaves. This is quite obvious for temperate climates where usually images are taken during the summer season. It may become more complicated in tropical climates where some tree species drop their leaves during the dry season whereas others loose them at other times of the year.[3] In agricultural landscapes the crop rotation introduces an additional difficulty because the spatial pattern changes from one year to another, somethimes even more rapidly. If individual crops are to be identified, multitemporal techniques where two or more images of the same year are combined can largely improve the accuracy of classification. For example, in satellite images grassland and germinating cereal crops have a similar spectral signature. Later in the year, when the crop is harvested and the grassland is still there, they will differ clearly. By combining images from both seasons and backed up by field checking and information on the agricultural management, crops can then be identified.

A particular difficulty in land-use / land cover or habitat mapping is – as it can be illustrated in the example of defining forest edge[4] - that the transition from one class into another is often gradual. To solve this problem it is necessary to establish rules and definitions which enable the designation of landscape patches to specific classes. When the mapping is repeated, the boundaries between neighbouring patches of the classes which have these transitional qualities should only be changed if the real situation in the landscape has actually changed. It is important therefore that the people who do the mapping of the subsequent time steps also take the original rules and definitions into account.

[3] I'll have to check this

[4] here again we could refer to that illustration of Blaschke

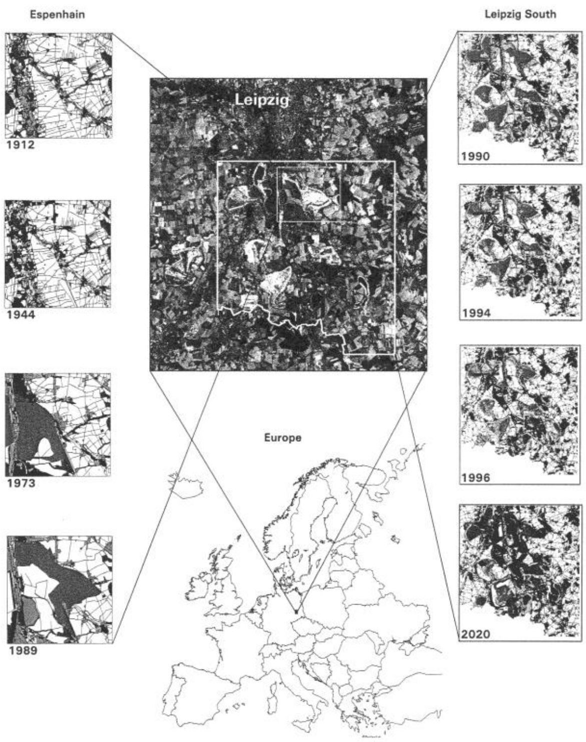
Box 3: Methodological lessons on landscape monitoring from surface mining regions

Surface mining landscapes change rapidly and radically over comparatively short time scales. This makes them extremely suitable to test landscape monitoring techniques. A 7000 sqkm region, south of Leipzig, in central Germany has been subject to open cast lignite mining throughout the 20th century: about one third of the land has been mined so far and this will be reclaimed by 2020. Two monitoring approaches were tested (Herzog & Lausch, 2001):

- based on historical maps and photographs a sequence of four maps (1912 – 1989) were digitised manually using GIS for a sample of the „Espenhain“ region;
- based on satellite images (Spot-XS) and reclamation plans, a sequence of four maps (1990 – 2020) were established for the entire „Leipzg South“ region.

Major lessons with respect to landscape monitoring techniques were:

- for the establishment of a series of GIS maps, start with one map and – for the subsequent maps – only digitise the changes. This approach avoids numerous small polygons which falsify changes and which have to be removed manually.
- accounting for linear elements is a pre-requisite when the changes in size and shape of polygons is of interest. For example, the increase of the size of agricultural fields – which is due to the intensification of agricultural production – can only be measured if the streets and paths between the fields are an integral part of the polygon layer.



- the „data model“ – polygon based GIS maps or raster based satellite images – has a major influence on the values of the landscape metrics which are calculated (see section 3.1). If landscape metrics are to be regularly used in landscape monitoring, this would require rigorous standardisation of data acquisition and processing. Most importantly this would concern the number and definition of land use / land cover classes, the definition of patches (minimum mapable units; in case of raster maps one has to define whether diagonal adjacent pixels of the same class are considered one patch or two),
- future landscape monitoring will be based more and more on satellite images. Their spatial resolution must be sufficient to capture linear landscape features not only visually but also for their classification. This will facilitate the interpretation of landscape change with respect to the function of landscapes, for example as habitats. Depending on the species under consideration, some linear elements act as barriers (e.g. traffic infrastructure, rivers), others as corridors or specific habitats (e.g. hedgerows, rivers).

Source: Herzog & Lausch 2001, Lausch & Herzog 2002

2.4 Examples of ongoing landscape monitoring programmes

At a global level there are a number of interdisciplinary projects that observe and try to understand the dynamics of land use and land cover change. In particular, reference is made to the potential consequences to global environmental change and sustainable development. Programmes that monitor landscape change include the Land Use and Land Cover Change (LUCC) programme, prompted by the International Geosphere and Biosphere Programme and the International Human Dimensions of

Global Environmental Change Programme (IHDP), NASA's Land Cover Land Use Change Program (LCLUC) and the Global Terrestrial Observing System (GTOS) co-sponsored by FAO, UNEP, UNESCO, WMO and ICSU.

The US. Geological Survey (USGS), the University of Nebraska-Lincoln (UNL) and the European Commission's Joint Research Centre (JRC) have developed a 1-km resolution global land cover characteristics data base (Loveland et.al., 2000). Released initially in 1997 there are now two versions currently available for use in a wide range of environmental research and modelling applications. The data set is derived from 1-km Advanced Very High Resolution Radiometer (AVHRR) satellite data spanning the period April 1992 to March 1993. Based on seasonal land cover regions the dataset provides a framework for presenting the temporal and spatial patterns of vegetation. The land cover regions are composed of relatively homogeneous vegetation associations (similar floristic and physiognomic characteristics) which exhibit a distinctive phenology (onset, peak, and seasonal duration of greenness), and common level of primary production. Developed on a continent-by-continent basis, each continental database contains unique elements based on the geographic aspects of the specific continent. The continental databases are combined to make seven global data sets, each representing a different landscape based on a particular classification legend. Further specifications as well as the data itself are available at http://edcdaac.usgs.gov/glcc/glcc.html.

At a continental level, for Europe several land cover databases exist. CORINE (**Co**-o**r**dination of **In**formation on the **E**nvironment) was initiated in the European Union in the 1980's. Using a 44 class nomenclature, the aim of the database is to provide consistent localised geographical information which can be used at the Community level to determine and implement environmental policy. Furthermore, the database can be combined with other data (climate, inclines, soil, etc.) to make complex environmental assessments. The land cover database provides a benchmark of the actual land cover and through updating enables monitoring of both mid and long-term change. The mapping scale of the database is 1:100,000 and the minimum mapping unit is 25 hectares. The project is still ongoing. Consequently, certain parts of Europe are still missing from the database and there are large differences in the satellite acquisition dates for the various countries which are covered. Based on CORINE, topographical datasets and AVHRR sensor data, PELCOM (Pan-European Land Cover Monitoring), was established by the European Union in response to the need for up-to-date and reliable information for their current policy Frameworks (e.g. European Environmental Outlook, Economic Assessment of Priorities for a European Environmental Policy Plan). See: http://www.eea.eu.int/ for CORINE, http://cgi.girs.wageningen-ur.nl/cgi/projects/eu/pelcom/index.htm for PELCOM.

A further land use and land cover database which is currently under development in Europe is LUCAS (Land Use / Land Cover Area Frame Statistical Survey) (Gallego, 2002). The objective is to provide annual and harmonised data which can be used for agricultural statistics and other environmental applications (e.g. to generate landscape and regional indicators). In contrast to CORINE and PELCOM which cover the entire territory of the EU, LUCAS is to be based on a sampling strategy. The observation points are arranged in a regular grid. In addition to mere land use / land cover information, LUCAS is to yield information on e.g. soil erosion, natural hazards, landscape features (e.g. hedgerows, isolated trees) and farming practice. See: http://www.eea.eu.int/

Large areas (continents, countries) are often very heterogenous with important differences in natural conditions. Subdividing them into eco-regions of similar climate, topography, geology helps landscape monitoring because (i) these eco-regions can be used for stratification if sampling techniques need to be applied (ii) they help the definition of the land use / land cover classes and (iii) they can facilitate the understanding of the observed land use / land cover and its changes. Examples for ecoregions comprise the Digital Map of European Ecological Regions (Bohn, 1994), Canada's ecozones (Marshall & Schut, 1999) and, more recently, the European Environmental Regions (Fig. 3). By defining relatively homogeneous ecological conditions it should be possible to make meaningful comparisons and assessments on biodiversity (Painho *et al*, 1996).

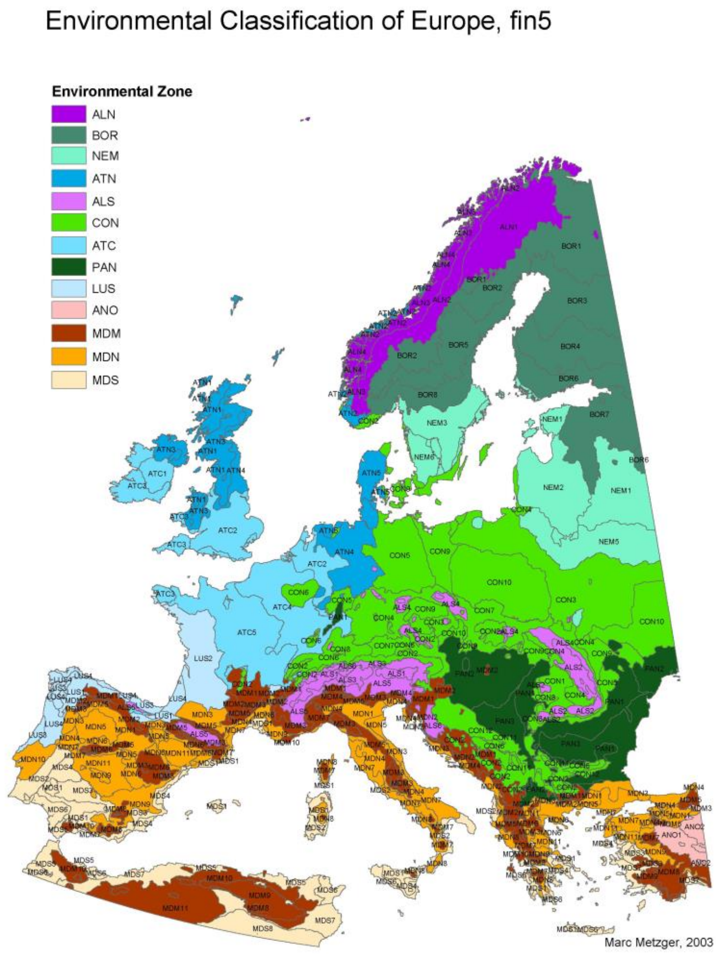


Figure 3: Environmental calssification of Europe based on climatic and topographic data. Such a classification is designed to serve as a base for stratified sampling of landscapes. Preliminary version. Source: *to be properly referenced, check with Bob Bunce / Sander Mucher*

In addition, there are sectoral monitoring programmes which focus on specific land use / land cover types. Forest monitoring, for example, or the monitoring of specific habitats which are relevant for nature conservation such a moors, or the monitoring of the development of deserts. The most prominent example is the UK countryside survey which concentrates on rural Great Britain. It is the first landscape monitoring scheme which has implemented a stratified random sampling technique (Gabriela can you provide some references **REF, REF**). Detailed field observations are made in randomly selected 1 km grid squares. Many of the sample sites were first visited in 1978 and subsequently in 1984, 1990 and 2000 providing a time series of changes in the countryside. Collection of data such as habitat types, hedgerows, plant species and freshwater invertebrates complements powerful satellite imagery and enables a deeper level of ecological understanding. http://www.cs2000.org.uk/

3 Analysing land use / land cover change

3.1 Techniques

There are basically three ways to analyse the change of land use / land cover. The most common and widely used analysis compares the increase or decrease of the extent (or share) of land use / land cover types over time (land use statistics). Examples are the continuous increase of urban areas in industrialised countries or the decrease of forest in some tropical countries. At a second level of analysis, one is interested to know which land use / land cover types have converted into each other. Is the increase of urban areas, for example, mostly at the expense of agricultural land and the deforestation in the tropics due to an increase of agriculture? This analysis is done by means of a transition matrix and of related Markov transition models (Turner & Gardner, 1991; Muller & Middleton, 1994; Aaviksoo, 1995). Markov transition models enable the effects of disturbance on heterogeneous landscapes to be examined using a spatially aggregated approach. These models are stochastic as an explicit value is given to the probability of the transition from one state and another. The transition probability itself is usually related to a suitable time period. Markov transition models are useful in that they are relatively simple, can be applied to many scales and using hierarchical data the appropriate level of detail can be selected.

At the landscape level, the combination of remote sensing data, geographic information systems and Markov modelling have been used to predict the loss of prime agricultural land (Hathout, 2002; Wenig, 2002) or desert and other habitats to urbanisation (Jenerette & Wu, 2001; Lopez et al., 2001); to explain forest-cover change as a result of socio-economic change (Brown et al., 2000); to model land degradation (Stoorvogel & Fresco, 1996) or simulate forest succession (Jarvis, 1993). At the habitat level, metapopulation extinction through permanent loss of patch habitat, erosion of existing habitats and random environmental catastrophes (Casagrandi and Gatto, 2002); transitions in vegetation structure (Dale et al., 2002; Li, 2002; Callaway & Davis, 1993) and habitat availability to mammals (Cuaron, 2000) have been modelled. Markov models have also been used to project backward missing land cover data in a long-term time series (Petit & Lambin, 2002) or to generate short-term land cover change projections in a region characterised by exceptionally rapid rates of change (Petit et al., 2001).

A more recent tool in landscape monitoring are landscape metrics. They allow us to indicate whether, e.g., an increase in urban areas is focused and concentrated around existing settlements or whether built up areas are scattered throughout the landscape. As for the loss of forest, it is important to know if it leads to fragmentation, i.e. if forest islands are created which are isolated from each other and which can become too small to sustain the original biocenoses. Correlations between landscape metrics and various landscape functions are sought (Figure 3). In the particular field of landscape monitoring, the application of landscape metrics has been tested in a number of studies representing a wide range of test areas and methods of data acquisition and treatment (Table 2). There are considerable variations in the size of the test areas, the spatial and temporal resolutions, the number of different land-use / land cover types, and the kind of raw data used. The most frequently applied landscape indices belong to the broad category of edge and shape metrics. They quantify the occurrence of ecotones, and are often related to patch area, the fractal dimension, or the discrepancy between actual and isodiametric shapes. Diversity measures are usually derived from information theory and often involve the use of Shannon’s diversity index. The number and size of patches (Patch area) are also often measured, whereas metrics for landscape configuration (contagion indices) were seldom applied.

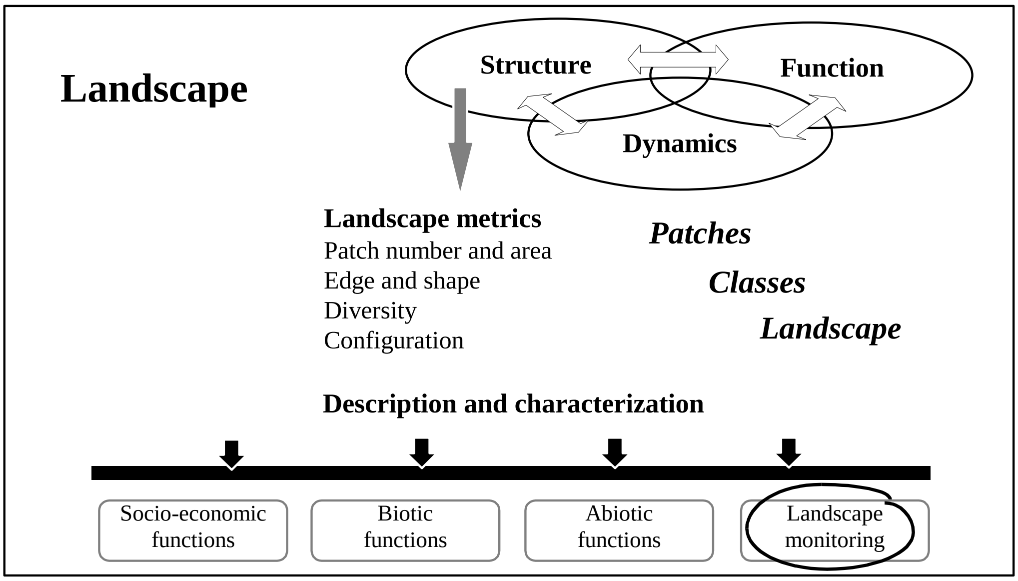


Figure 4: The application of landscape metrics. Source: Lausch and Herzog, 2002.

<u>Table 2:</u> Selected landscape monitoring studies combining statistical information on the spatial extent of land use / land cover types (LT) with an analysis of landscape pattern Source: Herzog et al. (2001), modified.

Study area	Size	Scale of investigation	Spatial resolution	Temporal resolution	Data source	Reference
Finland	3.2 sqkm	1:5,000	2 m raster	ca. 16 years 1944 - 1991	Aerial photography	Ruuska and Helenius (1996)
Japan	4.4 sqkm	1:7,500 - 1:20,000	Vector data	ca. 15 years 1948 - 1994	Aerial photography	Maekawa and Nakagoshi (1997)
Switzerland	~ 10 sqkm	1:25,000	Vector data	ca. 8 years 1880 - 1982	Topographical maps	Kienast (1993)
France	32 sqkm	1:25,000	Vector data	25 years 1964, 1989	Aerial photography	Poudevigne and Alard (1997)
USA	36 sqkm	1:24,000	Vector data	ca. 30 years 1926 - 1988	Aerial photography	Thibault and Zipperer (1994)
Germany	75 sqkm	1:12,000 - 1:25,000	Vector data	ca. 25 years 1912 - 1989	Topographical maps, aerial photography	Herzog *et al.* (2001)
Netherlands	100 sqkm	1:50,000	200 m raster	ca. 20 years 1845 - 1982	Topographical maps	Hulshoff (1995)
USA	208 sqkm	1:13,000 - 1:24,000	10 m raster	ca. 25 years 1935 - 1984	Aerial photography	Medley *et al.* (1995)
USA	242 sqkm	1:20,000 - 1:40,000	Vector data	ca. 16 years 1940 - 1988	Aerial photography	Simpson *et al.* (1994)
Estonia	879 sqkm	1:42,000 - 1:50,000	Vector data	ca. 30 years 1900 - 1989	Topographical maps	Palang *et al.* (1998)
USA	2230 sqkm	1:100,000 - 1:250,000	80 m raster	16 years 1972, 1988	Satellite images	Luque *et al.* (1994)
Canada	4200 sqkm	1:100,000 - 1:250,000	25 / 50 m raster	17 years 1975, 1992	Satellite images	Sachs *et al.* (1998)
China / North Korea	9678 sqkm	ca. 1:50,000	30 m raster	16 years 1972, 1988	Satellite images	Zheng *et al.* (1997)

There is a wealth of different landscape metrics proposed (Gustafson, 1998), starting from e.g. Forman and Godron (1986), O'Neill et al. (1988), Turner and Gardner (1991), Baker and Cai (1992) to more recent publications (Baskent and Jordan 1995; Mcgarigal and Marks 1995, Ritters et al. 1995, Cain et al. 1997, Jaeger 2000). Several programs compute landscape metrics automatically from GIS maps (Baker and Cai 1992; Mcgarigal and Marks 1995; Menz 1997, Gardner 1999, APACK - http://landscape.forest.wisc.edu/Projects/APACK/apack.html).

When applying landscape metrics, one is confronted with the question of selecting indicators relevant for the area and the problem under investigation. Because of the danger of "getting lost" in a wealth of data and figures which are difficult to interprete, Turner et al. (2001) have included a "read this first" section in their guidelines to landscape pattern analysis. Basically, there are two ways to approach the problem. Based on expertise and experience, meanigful indices which address the problem to be investigated can be selected (e.g. Herzog and Lausch 2001). For example, if landscape fragmentation is to be examined, one will choose metrics which relate to patch size, nearest neighbourhood, core area, etc. The advantage is that one knows what one is doing, the disadvantage is that, due to the wealth of available indices, one is never totally sure whether one has really selected the most relevant and appropriate index.

Alternatively, statistical methods can be used. The approach then is to calculate a high number of indices and, through the application of statistical techniques such as data mining, correlation and factor analysis, identify those indices which react to landscape change more strongly than others (e.g. Riiters et al. 1995, Cain et al. 1997, Herzog et al. 2001, Lausch and Herzog 2002). The problem there is that the interpretation of the resulting indices may not be straight forward. The advantage, however, is that this is an unbiased method which can potentially lead to new and unexpected insights.

The first, targeted approach is more useful if metrics are to be related to specific landscape functions (e.g. the support of biodiversity) whereas for landscape monitoring we feel that at the present state of knowledge, the second, statistical approach is the better one.

There is no core set of indicators yet which have proven robust towards different data models. All of them depend on grain, scale and whether they are computed from raster or from vector maps. That is, for the very same landscape the values of most landscape metrics differ depending on the data source, the spatial resolution and the way of data interpretation (in case of satellite image interpretation, for example). This is the major drawback which hampers the application of landscape metrics for statistical purposes: their calculation would require drastic standardisation in data acquisition and analysis if time series and cross-country comparisons should make sense. Yet, some indices are more sensitive to these factors than others. Patch size indices, indices relating patch area to edge length such as fractal indices for patch shape, landscape composition indices are among the ones which have proven more robust than others (Lausch & Herzog, 2002).

At the same time, landscape metrics should be sensitive towards landscape change and allow an early perception of (un-)desirable developments (O'Neill et al., 1988). There is, however, an inherent contradiction between these two requirements – robustness and sensitivity – both can hardly be fulfilled by the same index. An index which is robust or tolerant towards different data sources and models will only detect more aparent and obvious changes whereas sensitive indices will only indicate real phenomena (instead of artefacts) if the data quality is somparable and consistent throughout time.

3.2 Interpretation

Once the analysis of landscape change has been successful we will aim to interprete it, understand the driving forces behind the observed changes, make projections into the future and evaluate whether the observed changes are desirable for society or not. Censuses and other published statistics, used separately or in combination with remote sensing data and map data, are extremely useful in this context. Examples include the use of Agricultural Censuses to monitor the distribution of agricultural land and crops (Ilberry and Evans, 1989; Cardille et al., 2002; Frolking et al., 2002; Xiao et al., 2002), the use of population census data to study land degradation (Liu et al., 2003), the use of the 1990 U.S. Decennial Census data to monitor landscape change and to suggest landscape level forest management strategies (Radeloff, 2001), the use of land use/land cover statistics to monitor change in metropolitan areas (Lo & Yang, 2002) and the use of socio-economic censuses data to monitor tropical deforestation (Geoghegan, 2001).

4 Conclusions, recommendations

We all live in landscapes. They form the basis of life not only for humankind but for all living organisms on earth. It is therefore imperative that we are careful about what we do to our landscapes. We have to keep them "healthy" and give them a regular health check. This is now widely recognised and landscape monitoring programmes are, as a result, mostly policy driven (e.g. O'Neill et al., 1994; Groom & Reed, 2001). Whilst it is good that policy makers increasingly recognise the importance of landscape monitoring, policy needs can also act as a source of conflict and misunderstanding. Landscape monitoring programmes are long term undertakings. Monitoring time intervals of about a decade are appropriate and trends can only be observed after repeated measurements, hence after several decades. Policy makers and stakeholders, however, have to act and react in shorter periods, election periods of four years for example. Thus there may be a call for more frequent measurements over a shorter time scale. Naturally, this is possible but it will increase the cost of the monitoring programme exponentially due to the finer changes which will need to be detected and thus the higher measurement precision.

This brings us to the financial aspects of landscape monitoring. The real challenge, actually, is not the design of a monitoring programme as such but the optimisation of expected information and the cost of the programme. Landscape monitoring is usually conducted with public money which, of course, has to be spent carefully. Therefore, monitoring has to be limited to the essential information and additional, "nice-to-have" information can, in most cases, not be collected. The cost depends on the spatial and temporal accuracy and on the desired level of classification of data which is needed. This need determines the spatio-temporal density of sampling. Below a certain density of samples – and, consequently, below a certain amount of money which is spent on the programme – observed changes will no longer be statistically significant. The problem is that, when designing the programme, this limit is not known. Therefore the lower acceptable limit is usually negotiated between the policy maker and the scientist. It is important that this negotiation is not driven too strongly by actual policy needs because these requirements change and it would be contra-productive to design a long term monitoring programme only to meet short term requirements. The information gathered later on would then be useless.

Landscape monitoring programmes have to be representative for the landscapes they investigate. If the entire region of interest cannot be covered, sampling strategies have to be employed. The point here is that the sampling has to be random, either based on a grid or on pre-defined strata (Gabriela can you suggest some?-**REF, REF**[5]). Biased sampling, e.g sampling only nature protection zones or sampling only regions which can easily be accessed will only yield information on these particular locations but not reflect the development of the entire landsacape.

[5] Bunce reference. Is this sufficient or do we have to say more?

Another consequence of the long-term character of landscape monitoring – and this probably applies to all monitoring programmes – is that when the programme starts there can only be guesses on the future needs of information. This has two consequences:

1. The programme has to concentrate on broad, fundamental (long term) features which are independent of political (short term) characteristics.
2. Where ever possible, raw, non-interpreted data must be collected and stored which later can be re-interpreted to allow the uptake and integration of future requirements.

For example, forest monitoring programmes which started decades ago focussed mainly on wood production. Later the interest in additional functions of forests (resource protection, recreation, etc.) increased. Ideally these assessments can be made retrospectively on the original datasets which were recorded decades ago. Unfortunately, this is often not the case because budget restrictions originally restrained the programme to the sole purpose of assessing productivity (Bättig et al., 2002). Another example concerns the assessment of the effects of agri-environmental measures on landscape and biodiversity. An evaluation which only focuses on specially managed areas (according to the political guidelines) and assesses their effects only according to general, pre-defined criteria cannot be used for monitoring because these guidelines are likely to change over time and thus prevent a comparison (Hofer et al., 2002).

Long-term monitoring programmes, therefore, have to be more general in nature. They have to be provide fundamental information on status and trends of particular indicators. In addition, they can form the basis for other, shorter-term evaluation programmes which assess the effectiveness of specific environmental measures and policies. These evaluation programmes can be specifically targeted to support decision making and meet the societal needs for sustainable landscapes.

References

Aaviksoo K. (1995) Simulating vegetation dynamics and land use in a mire landsape using a Markov model. Landscape and Urban Planning 31, 129 – 142.

Baker WL and Cai Y (1992) The r.le programs for multiscale analysis of landscape structure using GRASS geographic information system. Landscape Ecology 7: 291-302

Baskent EZ & Jordan GA (1995) Characterizing spatial structure of forest landscape. Canadian Journal of Forest Research 27: 1675 - 1684

Bastian, O (1999) Description and analysis of the natural resource base. In: Krönert R, Baudry J, Bowler IR, Reenberg A (eds) Land-use changes and their environmental impact in rural areas in Europe. Man and the biosphere series 24. UNESCO Paris, The Parthenon Publ, New York, Lancs, pp 43 – 44

Bastian, O., Beierkuhlein, C. & R.-U. Syrbe (2002): Landscape change and landscape monitoring.- In: Bastian, O. & U. Steinhardt (eds.): Development and Perspectives of Landscape Ecology.- Kluwer acedemic Publishers

Bättig C., Bächtiger C., Bernasconi A., Brändli U.-B., Brassel P. (2002) Landesforstinventar: Wirkungsanalyse zu LFI1 und 2 und Bedarfsanalyse für das LFI3. Bern, BUWAL, Umweltmaterialen 143 Wald.

Bierkens M. F. P., Finke P. A., de Willigen P. (2000) Upscaling and downscaling methods for environmental research. Dordrecht, Kluwer.

Blaschke, T. (Hrsg., 1999): Umweltmonitoring und Umweltmodellierung. GIS und Fernerkundung als Werkzeuge einer nachhaltigen Entwicklung. Wichmann Verlag, Heidelberg, 278 S.

Bohn, U (1994) International project for the construction of a map of the natural vegetation of Europe at a scale of 1:2.5 million - it’s concept, problems of harmonisation and application for nature protection. Working text, Bundesamt für Naturschutz (BfN).

Brown DG, Pijanowski BC, Duh JD (2000) Modelling the relationships between land use and land cover on private lands in the Upper Midwest, USA. Journal of Environmental Management 59(4): 247-263.

Cain D.H, Riiters K, and Orvis K (1997): A multi-scale analysis of landscape statistics.- Landscape Ecology, 12: 199-212.

Callaway RM and Davis FW (1993) Vegetation dynamics, fire and the physical environment in coastal central California. Ecology 74(5): 1567-1578.

Cardille JA, Foley JA, Costa MH (2002) Characterising patterns of agricultural land use in Amazonia by merging satellite classifications and census data. Global Biochemical Cycles. 16:3 art. no. 1045

Carmel Y, Kadmon R, Lahov-Ginot S. (1999) Studying long-term vegetation dynamics using image processing of historical aerial photographs. Proc 5th IALE World-Congress, Snowmass Village, USA.

Casagrandi R and Gatto M (2002) Habitat destruction, environmental catastrophes, and metapopulation extinction. Theoretical Population Biology 61(2): 127-140

Cuaron AD (2000) Effects of land cover changes on mammals in a neotropical region: a modelling approach. Conservation Biology 14(6): 1676-1692

Dale M, Dale P, Edgoose T (2002) Using Markov models to incorporate serial dependence in studies of vegetation change. Acta Oecologica – International Journal of Ecology 23(4) 261-269.

Delarze R., Gonseth Y., Galland P. (1999): Lebensräume der Schweiz. Ott Verlag, Thun.

Di Gregorio A., Jansen L. J. M. (1996) FAO land cover classification: A dichotomous, modular-hierarchical approach. Paper presented at the US Federal Geographic Data Committee (FGDC) Vegetation Subcommittee and Earth Cover Working Group meeting in Washington, DC 15-17 October 1996. Rome, FAO. http://www.fao.org/sd/EIdirect/EIre0019.htm

Dunn C P, Sharpe D M, Guntenspergen F S, Yang Z (1990) Methods for analysing temporal changes in landscape pattern. In Turner MG and Gardner RH (eds) Quantitative methods in landscape ecology. The analysis and interpretation of landscape heterogenity. Ecological Studies , Vol. 82, Springer-Verlag, New York.

EEA (2002) EUNIS habitat classification. European Environment Agency, http://mrw.wallonie.be/dgrne/sibw/EUNIS/home.html
Falkner E and Morgan D, (2002) Aerial Mapping: Methods and Applications. 2nd Edition. Lewis Publishers
Farino A (2000) Landscape Ecology in Action. Kluwer Academic Publishers, Dordrecht
Foran B and Wardle K (1995) Transition in land use and the problems of planning: a case study from mountainlands of New Zealand. Journal of Environmental Management 43: 97-127
Forman RTT (1995) Land Mosaics: The ecology of landscapes. Cambridge University Press.
Foster DR, Motzkin G, Slater B (1998) Land use history as long term broad scale disturbance: regional forest dynamics in central New England. Ecosystems 1: 96-119
Frolking S, Qiu JJ, Boles S, Xiao XM, Liu JY, Zhuang YH, Li CS, Qin XG (2002) Combining remote sensing and ground census data to develop new maps of the distribution of rice agriculture in China. Global Biogeochemical Cycles. 16:4 art. no. 1091
Gallego J. (2002) Building Agro Environmental Indicators Focussing on the European area frame survey LUCAS. Ispra, European Commission Joint Research Centre. 176 pp. http://agrienv.jrc.it/publications/ECpubs/agri-ind/
Gardner RH (1999) RULE: A program for the generation of random maps and the analysis of spatial patterns. IN JM Klopatek and RH Gardner, eds. Landscape Ecological Analysis: Issues an dApplications, pp. 280-303. Springer-Verlag, New York, New York, USA.
Geoghegan J, Villar SC, Klepeis P, Mendoza PM, Ogneva-Himmelberger Y, Chowdhury RR, Turner BL, Vance C (2001) Modelling tropical deforestation in the southern Yucatan peninsular region: comparing survey and satellite data. Agriculture Ecosystems & Environment 85:1-3 25-46
Gonseth, Y., Wohlgemuth, T., Sansonnens, B., Buttler, A. (2001): Die biogeographischen Regionen der Schweiz. Erläuterungen und Einteilungsstandard. Umwelt Materialien Nr. 137 Bundesamt für Umwelt, Wald und Landschaft Bern.
Groom G., Reed, T. (2001) (eds.) Strategic landscape monitoring for the Nordic countries. Copenhagen, Nordic Council of Ministers, TemaNord 2001:523.
Gustafson EJ (1998) Quantifying landscape spatial pattern: What is the state of the art? Ecosystems 1: 143-156
Hathout S (2002) The use of GIS for monitoring and predicting urban growth in East and West St Paul, Winnipeg, Manitoba, Canada. Journal of Environmental Management. 66(3) 229-238
Herzog F., Lausch A. (2001) Supplementing land-use statistics with landscape metrics: some methodological considerations. Environmental Monitoring and Assessment 72, 37 – 50.
Herzog F., Lausch A., Müller E., Thulke H.-H., Steinhardt U., Lehmann S. (2001) Landscape metrics for the assessment of landscape destruction and rehabilitation. Environmental Management 27(1), 91 – 107.
Hofer G., Herzog F., Spiess M., Birrer S. (2002) Vegetation und Brutvögel als Ökoindikatoren im Mittelland. Agrarforschung 9(4), 152 – 157.
Hulshoff R. M. (1995) Landscape indices describing a Dutch landscape. Landscape Ecology 10(2), 101 - 111.
Ilberry B W and Evans N J (1989). Estimating Land loss on the urban fringe: A comparison of the agricultural census and aerial photograph / map evidence. Geography 74:214 – 221.
Jaeger AG (2000). Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation.- Landscape Ecology, 15: 115-130
Jarvis C (1993) Modelling forest ecosystem dynamics using multitemporal multispectral scanner (MSS) data. Remote Sensing of Earths Surface and Atmosphere Advances in Space Research 14(3) 277-281
Jenerette GD and Wu JG (2001) Analysis and simulation of land use change in the central Arizone-Phenix region, USA. Landscape Ecology. 17(7): 611-626.
Jensen J R, (1986) Introductory digital image processing. Englewood Cliffs, N.J. Prentice-Hall.
Kienast F. (1993) Analysis of historic landscape patterns with a Geographical Information System - a methodological outline. Landscape Ecology 8(2), 101 - 118.
Krönert R. (1999) Introduction. In: Krönert R., Baudry J., Bowler I. R., Reenberg A. (eds) Land-use changes and their environmental impact in rural areas in Europe. Paris and New York, UNESCO and Parthenon, 1 – 22.
Kühbach W, Kupfer G, Schellberg J, Müller U, Dockter K, Tempelmann U (1990). Fernerkundung in der Landwirschaft. Luft- und Raumfahrt 11:36-45

Lausch A., Herzog F. (2002) Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability. Ecological Indicators 2, 3 – 15.
Li BL (2002) A theoretical framework of ecological phase transitions for characterising tree-grass dynamics. Acta Biotheoretica 50(3): 141-154.
Lindgren D T, (1985) Land use planning and remote sensing. Dordrecht, Netherlands. M Nijhoff Publishers.
Liu YS, Gao J, Yang YF (2003) A holistic approach towards assessment of severity of land degradation along the Great Wall in Northern Shaanxi Province, China. Environmental Monitoring and Assessment 82: 2 187 - 202
LO CP and Yang XJ (2002) Drivers of land use/land cover changes and dynamic modelling for the Atlanta, Georgia Metropolitan Area. Photogrammetric Engineering and Remote Sensing. 68:10 1073 – 1082.
Löffler J, Steinhardt U, Volk M, Walz U (2002) Investigation methods / tools. In Bastian, O. & U. Steinhardt (eds.): Development and Perspectives of Landscape Ecology.- Kluwer acedemic Publishers
Lopez E, Bocco G, Mendoza M Duhau E (2001) Predicting land cover and land use change in the urban fringe – A case in Morelia city, Mexico. Landscape and Urban Planning 55(4): 271-285.
Luque S. S., Lathrop R. G., Bognar J. A. (1994) Temporal and spatial changes in an area of the New Jersey Pine Barrens landscape. Landscape Ecology 9(4), 287 - 300.
Maekawa M., Nakagoshi N. (1997) Riperian landscape changes over a period of 46 years, on the Azusa River in central Japan. Landscape ans Urban Planning 37, 37 - 43.
Marshall I.B., Schut P. H. (1999) A national ecological framework for Canada. Environment Canada and Agriculture and Food Canada. http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html
Mazerolle M. J., Villard M.-A. (1999) Patch characteristics and landscape context as predictors of species presence and abundance: A review. Ecoscience 6(1), 117 – 124.
McGarigal K and Marks BJ (1995) FRAGSTATS. Spatial Analysis Program for Quantifying Landscape Structure. USDA Forest Service General Technical Report PNW-GTR-351
Medley K. E., Okey B. W., Barrett G. W., Lucas M. F., Renwick W. H. (1995) Lndscape change with agricultural intensification in a rural watershed, southwestern Ohio, U.S.A. Landscape Ecology 10(3), 161 - 176.
Moss D and Davies CE (2002a) Cross-references between the EUNIS habitat classification and the nomenclature of CORINE Land Cover. Centre for Ecology & Hydrology. NERC
Moss D and Davies CE (2002b) Cross-references between the EUNIS habitat classification and habitats included on Annex I of the EC Habitats Directive (92/43/EEC) Centre for Ecology & Hydrology. NERC
Moss D and Davies CE (2002c) Cross-references between the EUNIS habitat classification and the Palaearctic habitat classification. Centre for Ecology & Hydrology. NERC
Muller M. R., Middleton J. (1994) A Markov model of land-use change dynamics in the Niagara Region , Ontario, Canada. landscape Ecology 9(2), 151 – 157.
Naveh Z and Liberman A S, (1993) Landscape Ecology Theory and Application. 2nd Edition. Springer-Verlag.
OECD (2002) Environmental Indicators - Towards Sustainable Development 2001. . Paris, OECD.
OFS – OFEFP – ARE (2002) Mesurer le développement durable. Un aperçu de MONET – le système suisse de monitoring. Neuchâtel, Office fédéral de la statistique. http://www.statistik.admin.ch/stat_ch/ber21/
Orians G.H. et al. (2000) Ecological Indicators for the Nation. Washington DC, National Academic Press,
Painho et al (1996) Digital Map of European Ecological Regions (DMEER): its concept and elaboration. Second Joint European Conference (JEC) & Exhibition on Geographical Information, Barcelona .
Palang H., Mander Ü., Luud A. (1998) Landscape diversity changes in Estonia. Landscape and Urban Planning 41: 163 - 169.
Petit C, Scudder T, Lambin E (2001) Quantifying processes of land cover change by remote sensing: resettlement and rapid land cover changes in south-eastern Zambia. International Journal of Remote Sensing 22(17): 3435-3456.
Petit CC and Lambin EF (2002) Long term land cover changes in the Belgium Ardennes (1775 – 1929): model-based reconstruction vs. historical maps. Global Change Biology 8(7): 616-630

Poudevigne I., Alard D. (1997) Landscape and agricultural patterns in rural areas: a case study in the Brionne Basin, Normandy, France. Journal of Environmental Management 50, 335 - 349.
Radeloff VC, Hammer RB, Voss PR, Hagen AE, Field DR, Mladenoff DJ, (2001) Human demographic trends and landscape level forest management in the northwest Wisconsin Pine Barrens. Forest Science 47:2 229 – 241.
Riitters KH, O'Neill RV, Hunsaker CT, Wickham JD, Yankee DH, Timons SP, Jones KB, Jackson BL (1995) A factor analysis of landscape pattern and structure metrics. Landscape Ecology 10: 23-40.
Ruuska R., Helenius J. (1996) GIS analysis of change in an agricultural landscape in Central Finland. Agricultural and Food Science in Finland 5, 567 - 576.
Sachs D.L., Sollins P., Cohen W.B. (1998) Detecting landscape changes in the interior of British Columbia from 1975 to 1992 using satellite imagery. Canadian Journal of Forest Research 28, 23 - 36.
Simpson J. W., Boerner R. E. J., DeMers M. N., Berns L. A. (1994) Forty-eight years of landscape change on two contiguous Ohio landscapes. Landscape Ecology 9(4), 261 - 270.
Smeets E., Weterings R. (1999) Environmental indicators: Typology and overview. Technical report No 25. Copenhagen, European Environmental Agency. http://reports.eea.eu.int/TEC25/en/tab_content_RLR
Statistics Canada (2000) Human activity and the environment. Ontario.
Stoorvogel JJ, Fresco LO (1996) Quantification of land use dynamics: An illustration from Costa Rica. Land degradation & Development 7(2): 121-131.
Thibault P. A., Zipperer W. C. (1994) Temporal changes of wetlands within an urbanizing agricultural landscape. Landscape and Urban Planning 28, 245 - 251.
Tolle T., Powell D. S., Breckenridge R., Cone L., Keller R., Kershner J., Smith K. S., White G. J., Williams G. L. (1999) Managing the monitoring and evaluation process. In: Sexteon W. T., Malk A. J., Szaro R. C., Johnson N. C. (eds.) Ecological Stewardship Volume III, 585 – 601.
Turner MG; Gardner RH, O'Neill RV (2001) Landscape Ecology in theory and Practice: Pattern and Process. Springer-Verlag. New York
Turner, MG (1987) Spatial simulation of landscape changes in Georgia: A comparison of 3 transition models. Landscape Ecology 1: 171-197
Turner, MG (1989) Landscape ecology: the effect of pattern on process. Annual Review of Ecology and systematics 20:171-197
UN (2001) Indicators of sustainable development: Framework and methodologies. Background paper N°3. New York, United Nations, Department of Economic and Social Affairs, Commission on Sustainable Development.
Wenig QH (2002) Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. Journal of Environmental Management. 64(3) 273-284.
Wiens JA (1989) Spatial scaling in ecology. Functional Ecology 3: 385-397
Wu J., Shen W., Shun W., Tueller P.T. (2002) Empirical patterns of the effects of changing scale on landscape metrics. Landscape Ecology 17: 761 – 782.
Xiao X, Boles S, Frolking S, Salas W, Moore B, Li C, He L, Zhao R (2002) Landscape-scale characterisation of cropland in China using vegetation and landsat TM images. International Journal of Remote Sensing. 23: 18 3579 – 3594
Zheng D., Wallin D. O., Hao Z. (1997) Rates and patterns of landscape change between 1972 and 1988 in the Changbai Mountain area of China and North Korea. Landscape Ecology 12, 241 - 254.