4 Researching state and dynamics in landscape using remote sensing

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This chapter looks at the usage of remote sensing data for practical research. Remote sensing data can be used for individual applications and research studies as well as routine work, and basic data sets can be provided as vital pieces information for landscape ecological investigations. Experimental work such as tests related to sensor development, signature research and non-operational digital analysis methods are not dealt with here as this chapter is more concerned with applied remote sensing. Nevertheless, the importance of basic research is self-evident and is much respected for efficient, rational applications.

The main fields of investigation that use remote sensing are disciplines that ascertain the Earth's surface, especially its land cover, sealed or unsealed, with or without vegetation, and its use and possible conservation, as well as its sometimes vast changes and high dynamics. Attention is focused on local, regional and general environmental planning, mainly in connection with opencast mining, agriculture, (sub)urban development, and information needed for surveys and planning authorities. Rather than listing all the activities carried out during the past few years, instead useful examples will be given of practical applications that have been undertaken. The remote sensing data collected for all applied landscape ecological investigations are based on electro-optical scanner images. Generally used sources of spatial data are listed in Table 4.1.

4.1 Image processing

4.1.1 Image correction, enhancement, and manipulation

Geometric and radiometric corrections, image enhancements and manipulations are applied to data sets that have already been geometrically and radiometrically corrected. These processing steps mainly depend on the purpose of image analysis and can be divided into basic radiometric and geometric corrections or enhancements, and digital image processing steps with changes to data set content.

All these operations transform input data by means of digital image processing and mathematical functions to produce new, changed output data.

Table 4.1: Example sources of spatial data

Point	Line	Area
Monospectral and multispectral data (geometric, spectral and radiometric information for each single raster cell)	Road maps	Landscape units
Topography	Contour lines	Land use maps
Climatic measurements (rainfall, temperature, evapotranspiration, etc.)	Administrative units	Land cover maps
Soil samples	Watercourses	Soil type maps
Individual spectrometric measurements in test areas	Railway network	Biotope maps
		Geological maps
		Town plans
		Watersheds
		Hydrogeological maps

With respect to **geometric corrections**, the form and location of the pixels (= picture elements) are changed and transformed into a defined spatial reference system without altering the grey levels. Such transformations are necessary for:

- Mathematical links between several image matrices that are to be made congruent, e.g. multispectral, multitemporal or multisensoral image data. This is the main field for landscape-ecological questions dealing with land cover dynamics, changes and change detection.
- Overlaying the input data with other thematic information derived by digitized maps, e.g. landscape units, political boundaries, planning networks or contour lines. For visual interpretation, for example, it is essential that satellite image data can be overlaid by further information often gained by digitized vector data, as a satellite image itself can be the subject of a regional map. Another example is if image information is to be transferred into a GIS or any other related landscape ecological model, when the same geometrical correction of all input data sets is compulsory for proper analysis.

In **radiometric corrections and enhancements**, grey values of pixels are transformed for system corrections or image restorations necessitated by technical shortcomings and a lack of information of the sensor system or data transmission. In contrast to such corrections of raw data, specific radiometric enhancements are carried out on system-corrected data to allow better data analysis and to optimize the data quality for individual demands. They include:

- Pixel-based grey value manipulation: This manipulation is carried out to produce linear contrast-stretching or contrast-smoothing, to reduce atmospheric influence, and to diminish bright differences caused by relief. These options change the input data and are usually included in the preprocessing work when a certain operation is to follow. For multispectral image analysis, the data sets of each individual band necessary to produce colour composites are worked on separately and linked afterwards with all the calculations based on the grey value histograms of each individual data set. The same procedure can be carried out before a digital image is classified to increase the input data quality.

Atmospheric correction:

Frequently, detailed correction for the scattering and absorbing effects of the atmosphere is not required and often the necessary ancillary information such as visibility and relative humidity is not readily available. In these cases, if the effect of the atmosphere is judged to be an imagery problem, approximate correction can be carried out to remove haziness so that the dynamic range of image intensity is improved. Consequently the procedure of atmospheric correction is frequently referred to as haze removal (Richards & Jia 1999).

- Threshold procedure: This procedure, also known as density slicing, either comprises equivalent densities in which grey level slices are aggregated to form one grey value so that the different slices can be shown distinctively, or alternatively it comprises non-equivalent grey level classes that represent certain object classes in a monospectral data set. The latter is a method added to a hierarchical image classification as the classification result is not accurate enough and certain classes need to be characterized, for example by an additional image. In a monospectral data set, the threshold procedure defines two or more grey value levels: if the resulting image only contains two values, a binary image is produced. Hence important image segments are masked and inserted into further classification steps. This procedure fulfils two aims: the calculation process is reduced, and disturbing or competing objects are excluded (Hildebrandt, 1996).
- Digital filters: Digital filters change not only individual grey values in an image but more importantly the neighbourhood of grey values in defined window sizes such as the most commonly used windows 3x3, 5x5 or 7x7 (number of pixels in both directions: columns and rows) with each pixel being at the centre of the kernel and thus the centre of the filter operation. Apart from offering radiometric correction by substituting missing pixels or bad lines, these filters are used to emphasize or to smooth grey value differences due to specific object characteristics. High-pass filters like the edge enhance filter make local contrasts (streets in contrast to buildings, contours in open landscapes, etc.) more evident, whereas low-pass filters suppress such contrasts.
- Another form of radiometric manipulation is carried out when data fusion is calculated. For better image interpretations, it is useful to merge a multispectrally high resolution image with a geometrically high resolution image. Since IRS-1C and Landsat-7-ETM went into operation, both sensors - multispectral

and panchromatic - have been installed on the same satellite system, ensuring that the acquisition date and time are the same. Otherwise such merges were and still are carried out with different satellite systems, e.g. Landsat-TM or Spot multispectral images being transformed with panchromatic images such as those from a Spot panchromatic sensor. The disadvantage is that two acquisition dates are involved and thus phenological variations, atmospheric differences and many other deviations impair the merged product.

4.1.2 Visual image interpretation

Satellite image maps are produced every five years for the area of Leipzig, Halle and Bitterfeld. They are all drawn to a scale of 1:100,000, show the regional landscape structure with its dynamics from 1989 onwards, and cover an area of about 5,000 km². A large, complex area is presented with a spatial resolution of pixels measuring 15 metres by 10 metres pixel sizes with a valuable information content for regional planning. The colouring has been chosen such that the contents are similar to those on physical maps in atlases (Banzhaf 1998). As towns are shown in red, woodlands and floodplains in green, and rivers and lakes are printed in dark blue, the satellite image map can easily be read by non-remote sensing experts, too. This satellite image is the result of Landsat bands 1, 5, and 7 being assigned to red, green, and blue, and also being enhanced by means of image processing techniques such as contrast-stretching and histogram manipulation. The merged panchromatic band, taken either by Spot (for the year 1994, shown here) or Landsat-7-ETM (for the year 1999) was spatially enhanced by an edge enhance filter before resolution merge was carried out. The merger of the two different data sets only succeeded because both images underwent the very same geometric correction and therefore are a perfect spatial match. Ancillary data such as names of towns and federal states, motorways, landscape elements (e.g. opencast mining areas and nature reserves) help make the map readable, while a legend with interpreted characteristic landscape types boost its comprehensibility. As it is printed as an analogous product on a DIN A0 Format, it has become a useful remote sensing product and thus an instrument for planners, who do not need to know much about remote sensing techniques (such as the name and equipment of the satellites used) or the image processing methodology (image enhancement, resolution merge method; see chapter above) on which the map is based (Seger 1998).

As this image shows a landscape at a regional level without the information limitations often stemming from the involvement of administrative units, it gives an insight into small details and overriding correlations and is able to dispense with generalization.

In contrast to mathematically oriented operations including digital classification, such a visual analysis works without statistical results, diagrams or thematic evaluation. It still provides information on land use patterns and distributions and is a tool for decision-makers. What has to be taken into consideration is that phenology, atmospheric conditions and the date of acquisition influence the visual impression and the information details of each individual map. This makes a major difference to updating any thematic presentation or topographic maps where a chosen colour stands for the same type of legend in each copy of a time series.

In the case of visually interpreting satellite image maps the possess the same pattern recognition as on aerial photos just covering a larger area. Such patterns are areas, or lines or point information that form the basis of an image (or photo) analysis and they are equivalent to a certain land use area and, beyond that, they can represent normative space categories of estate parcels. Patterns differ by color and texture from their surroundings, and these characteristics as well as their outline and size gives an idea on the structure of land use. Its analysis and assessment lead to political decisions that are usually made by restricted local information. The use of parcels mirrors socio-economic and ecological aspects, land use classes represent real eco-systems, and spatial patterns dominate the use of a certain landscape, its aesthetical equipment, and its temporal dynamics.

As the maps have shown a time series since the roots for the reunification in Germany were laid in 1989 they show the extremely high dynamics of an important conurbation area in East Germany. During the first years the urban centers Leipzig and Halle spread into its surroundings and an overdevelopment took place outside the cities first of all connected with huge building-complexes of commercial sites and later on also with new quarters of buildings for housing. Infrastructure has changed with the construction of new motorways, the extention of the airport Leipzig-Halle, a new freight traffic center and a new central market. The land use functions cannot be interpreted in the map, this is reserved for people with a profound regional knowledge, as local decision makers usually are. What can be derived is that land use has changed rapidly and that the sealed area outside the large cities has increased. Another phenomenon is the land use change connected with the traditional open pit mining: as most of the mining activities were stopped in the early 1990’s and flooding started the whole landscape changes from a devastated type to a landscape type with lots of lakes and possible recreational sites. Such vast changes are very well documented in such satellite image maps as the regional scale offers the possibility to get a detailed overlook over an “initial” land cover distribution and its variation and dynamics usually connected with a socio-economic and ecological change of the regional land use and function.

4.1.3 Quantitative analysis of classified images

Computer interpretation of remote sensing data is known as quantitative analysis because of its abilities to identify pixels based upon their numerical properties and to count pixels for area estimations. It is also generally called classification, which is a method by which labels may be attached to pixels depending on their spectral character. This labelling is performed by a computer trained to recognize pixels with spectral similarities.

The image data for quantitative analysis must be available in digital form. This is an advantage with image data types, such as that from Landsat, Spot, IRS, etc. compared to more traditional aerial photographs, as the latter require digitization before quantitative analysis can be performed. Detailed procedures and algorithms for quantitative analysis are the subject of specific remote sensing handbooks and will not be discussed here. Instead an outline of the essential concepts in classification will be followed by a number of study cases.

Recognition that image data exists in sets of spectral classes, and identification of these classes as corresponding to specific ground cover types, is carried out using the techniques of mathematical pattern recognition or pattern classification and their more recent neural network counterparts. The patterns are the pixels themselves, or strictly speaking the mathematical pixel vectors that contain the sets of brightness values for the pixels. Classification involves labelling the pixels as belonging to particular spectral (and thus informational) classes using the spectral data available. There are two broad classes of classification procedure, and both are applied in the analysis of remote sensing data. One is referred to as 'supervised classification' and the other as 'unsupervised classification'. These can be used as alternative approaches but are often combined into hybrid methodologies.

Unsupervised classification

Unsupervised classification is a means by which pixels in an image are assigned to spectral classes without the user having foreknowledge of the existence or names of these classes. It is usually performed using clustering methods. These procedures can be used to determine the number and location of the spectral classes into which the data fall and to determine the spectral class of each pixel. The analyst then identifies these classes a posteriori, by associating a sample of pixels in each class with available reference data, which could include maps and information from ground visits. Unsupervised classification is therefore useful for determining the spectral class composition of the data prior to detailed analysis by the method of supervised classification.

Supervised classification

Supervised classification procedures are the essential analytical tools used for the extraction of quantitative information from remotely sensed image data. An important assumption is that each spectral class can be described by a probability distribution in multispectral space. The distribution found to be most useful is the normal or Gaussian distribution. It is robust in the sense that classification accuracy is not overly sensitive. The multidimensional normal distribution is completely specified by its mean vector and its covariance matrix. Consequently, if the mean vectors and covariance matrices are known for each spectral class, the set of probabilities that describe the relative likelihoods of a pattern at a particular location belonging to each of these classes can be computed. It can then be considered as belonging to the class which indicates the highest probability. Before classification can be performed, a representative set of pixels, commonly called a training set, is defined for each of the classes and referred to as supervised learning. The view of supervised classification adopted has been based on the assumption that the classes can be modelled by probability distributions and are consequently described by the parameters of these distributions. Other supervised techniques also exist, in which neither distribution models nor parameters are relevant. More recently, new classification methods and combinations such as neural network non-parametric classification or pre-classificational segmentation, followed by an object-based classification including a fuzzy logic algorithm plus expert knowledge, have been shown to be promising for remote sensing applications. However, as they are still in the test phase, no study case will be presented here.

4.1.4 Examples of quantitative approaches to image classifications

Image enhancements and methodological improvements

One target of landscape ecology is to obtain spatial information on land use distribution, either for planning purposes or as a basic input data set for various model applications. This example refers to the urban and industrial planning of Bitterfeld and Wolfen, two small towns in eastern Germany with vast industrial sites, including their changes during the past decade since German reunification and their possible future development. It discusses some aspects of an undergraduate dissertation (Ihl, 1999, pp.1-58).

In order to document land use and its rapid changes, several time intervals of satellite imagery are used. These images form the instrument to derive the spatial information needed for this highly dynamic region and to compare land use at different points in time in order to characterize the total consumption of sealed areas and the changes of opened-up and sometimes resealed areas.

Methodological procedures are applied on the basis of three different satellite sensor systems, i.e. Landsat-5-TM, Spot and IRS-1C. As they are listed in Table 4.1, it only needs to be mentioned that they possess different spectral and spatial resolutions and that comparison of the data sets for their application to urban planning is of major interest. Therefore, first of all certain preprocessing steps are carried out before classification takes place. In a further image interpretation step, land use differences are calculated for the points in time photographed, synthetic images are produced showing the spatial changes, and statistical analyses of this extremely dynamic industrial region are presented to urban decision-makers. They form the basis for partners in local administrations and regional authorities to work out action programmes together with industrial enterprises.

Remote sensing tasks dealing with the research of urban spaces need to have an especially high precision for details such as building complexes, land use parcels, edges and other high frequency information. As this precision depends on the geometric resolution, image processing is geared towards enhancement to derive spatial details.

Data merging of multispectral and panchromatic images

Combining panchromatic and multispectral image data boosts the geometric resolution of the latter. Various methods have been developed for data fusion: most of them have the disadvantage that the radiometric resolution is changed, especially outside the visible spectra. This phenomenon can easily be neglected when visually interpreting the image, but for classification processes and resulting comparisons it proves to be a serious problem.

Color transformation methodology

In the IHS method, three bands are extracted from the multispectral data set in the red, green and blue (RGB) colour space and transformed into an image of intensity, hue, and saturation (IHS). As intensity is equivalent to the sum of the colour components, it is statistically adapted by histogram matching. This intensity band can now be substituted by the stretched panchromatic image. This manipulated multispectral data set is retransformed into the original red, green and blue, and possesses the same geometric resolution as the panchromatic image.

Principal component analysis

Multispectral data sets have a multidimensional data space with different bands. As the spectral attributes of surface objects contain a certain grey level in one band, it can be related to the grey value interval in a second band. The band correlation is high, meaning that the gain in information is little and thus mainly redundant. The aim of principal component analysis is to transform the grey values of the different bands so that the covariances, which express the semantic context of bands, diminish. The mathematical procedure first calculates the eigenvalues and standardized eigenvectors and then manipulates the variance-covariance matrix to obtain covariances with the value of zero. The new bands possess uncorrelated information and redundancies are avoided. The main advantage of this data transformation is data compression, where the first principal component is equivalent to the total intensity of the image which can be used for data fusion such as the ‘resolution merge’. The disadvantage is that certain structures and textures are only found in higher and usually reduced principal components.

Filter operations

Digital filters are algorithms that change the original frequency within a chosen window box and cause radiometric transformation. The high-pass filter method is used to try and separate the spectral from the spatial information. The addition of the spatially and spectrally stressed data sets results in a new, improved image. The panchromatic image is transformed into a high-pass filter image by subtracting the low-pass filter image from the original data. Thus a high-frequency image with a spatial component, mostly edges, emerges. Low-pass components usually carry spectral information that show high variability with less correlation between the individual bands.

Comparison between the different methods

Visual comparison reveals that the IHS method and principal component transformation lead to a distinct improvement in the optical resolution. Even industrial building complexes can be visually made out . The opposite of this enhancement is the high-pass filter method, where the results are much less distinctive. Due to radiometric alteration, the IHS method results in the severe fluctuation of the optical colours in the near and middle infrared, making it unsuitable for classification.

In contrast to other studies, a relatively small correlation coefficient is calculated for the Spot and the Landsat-5-TM images. This is due to phenological changes between the acquisition data of 16/05/94 (SPOT) and 21/07/94 (TM) resulting in different spectral reflections. In spring the fields still have no green vegetation, whereas in midsummer arable crops predominate. To obtain better quality information, difference images are calculated by subtracting the products taken from the data fusion from the original image. The comparisons are performed for the bands 3, 4, 5 which show distinct changes in the grey values for the principal component procedure. Especially in the near infrared band, the distortion is evident, whereas in the visible red (band 3) and in the infrared (band 5) the deviation is still visible but weaker. Thus woodlands and green spaces could not be separated in a classification approach. It is only the high-pass filter method that does not show such changes. The distortions are reduced to the edge enhancements which implies no phenological deviations as seen in the other images. Thus the high-pass filter method will be used for classifying the images.

Hierarchical supervised classification

When carrying out hierarchical classification, the image is segmented step by step according to different criteria. In this case the first step is to generate a binary image by defining a certain threshold. This segmentation is restricted to a single image or to one spectral band. Such preparation is useful for the following masking of the multispectral data set. After segmentation, the actual classification can start. For classification, the panchromatic and the multispectral image are merged (high-pass filter) and masks for main classes typical for the region are generated by the above-mentioned binary image. Then the maximum-likelihood classification is calculated for all three masked images. After this mathematical operation, the three sub-classifications are reassembled and presented in one map for statistical analysis. The following Table 4.2 shows the classification accuracy for each point in time investigated and for all defined classes.

Table 4.2: Classification accuracy for the land use of Bitterfeld and Wolfen (Ihl 1999, p.30)

	1989 (TM & Spot sensors)		**1994** (TM & Spot sensors)		**1997** (IRS-1C LISS & pan)	
Class name	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy
Built-up	90.2	95.8	84.9	88,2	87,9	89,4
Open area	-	-	80.6	86,2	86,6	83,8
Water	93.4	97.7	100.0	100,0	90,6	85,2
Open pits	94.7	90.0	96.8	96,8	70,3	63,3
Wood-land	83.6	83.6	94.3	98,0	74,5	88,3
Field / meadow	95.5	90.1	93.2	90,1	76,4	69,3
Field	83.7	85.7	88.2	78,9	73,5	83,3
Total accuracy	**90.3 %**		**91.3 %**		**80.0 %**	

Derivation of vegetation indices for agricultural differentiation

This study case deals with land use classification for the area south of Leipzig. This region is dominated by two main economic sectors, for as well as historically being an area of intensive agriculture, it has also been exploited for lignite mining, as a result of which vast open pits have become characteristic for the whole district. From the 1950s until 1990, farming was economically and politically organized in the form of collective farms in which equipment and production were shared. To manage this form of cultivation, paths, hedges, and baulks were eliminated and large fields were created. In particular, recultivated areas reclaimed from opencast mining industries were endlessly vast treeless plains with poor-quality soil. After 1990 opencast mining was almost completed ceased. The renaturation of the mining landscape is closely linked to agriculture and forestry.

The target of land use classification is to divide land use classes within agricultural use. Rather than produce a detailed classification of the opencast mining areas, the aim is to derive a differentiated data set as a basic level to be used for simulation models of farms and vegetation matters (e.g. nitrogen, phosphorus).

For multispectral classification, a Landsat-5-TM image is taken, acquired on 21/07/94. The field maps of the agricultural holdings on the acquisition date are available as ground truth information. In the first step feature space images are generated that can be used for the selection of training sites. These features are derived from the principal component analysis of the seven TM bands for which the first three principal component values describe 98% of the variance. The spectral separability of crop species is shown in Table 4.3.

Table 4.3: Spectral separability of cultivated plants

land use	leaves / shrub	grassland	stubble	hay	spring barley	winter crop	sun-flowers	lucerne	rape	onions
leaves / shrub	x	x	x	x	x	x	--	x	x	x
grass-land		x	x	x	x	x	--	--	x	x
stubble			x	x	x	x	x	x	x	x
hay				x	x	x	x	x	x	x
spring barley					x	--	x	x	--	--
winter crop						x	x	x	--	x
sun-flowers							x	--	x	x
lucerne								x	x	x
rape									x	--
onions										x

Two classification algorithms are tested and their results compared on qualitative and quantitative levels. The minimum distance classification is qualitatively weaker with respect to sunflowers and alfalfa, although it offers a fairly high quantitative precision of about 82%. Maximum-likelihood classification with a 1st Pass Parallelepiped preclassifier attains a total accuracy of about 90%. The latter is taken to derive further information on textural analysis and vegetation indices.

From the qualitative point of view, mistakes occur in the assignment of the classes ‘built-up area’ and ‘leaves/shrubs’. Furthermore, not all of the standing water spaces can be clearly distinguished from woodlands. For these two groups of classes, an attempt is made to establish unambiguous separability by means of a textural filter. In addition, an attempt is made to distinguish between certain crop types that cannot be recognized in the multispectral classification by testing vegetation.

Texture analysis

Texture analysis is taken as a possible step when optimizing a multispectral classification in this case study. By masking the two groups of classes ,’built-up area’ against ‘leaves/shrubs’ and ‘water’ against ‘woodland’, two masks are generated and transformed into a binary image for each of them. Table 4.4 shows the separation of the spectrally similar but texturally different class types inserted into the results of the spectral analysis.

The procedure of this textural analysis is based on co-occurrence matrices supporting textural characteristics. These are a specific type of histogram which is not based upom a standardized distribution of grey values as is assumed for the maximum-likelihood classification; instead it is based on the relative distribution within a certain defined space, the co-occurrences of the grey values. The multinomial distribution is taken to characterize features as a probability distribution. In this case, which parameters lead to a positive result is empirically tested.
The following parameters are defined:

Number and spectral frequency of used bands:	*band 4,5,3*
Choice of the searching directions:	*horizontal, vertical, left diagonal and right diagonal*
Choice of window size:	*(1) 5x5; (2) 9x9*
Choice of grey value differences:	*(1) 5 grey levels; (2) 10 grey levels*
Number of feature spaces:	*four*

The test phase shows that the separability of the above-mentioned classes are characterized best when taking choice number (1) with a window size of 5x5 pixels, six grey levels and all four searching directions. The most important factor for achieving a good result is that the textural differences between the distinguished objects are obvious even though they are spectrally very similar. As some of the agricultural crops like alfalfa, rape, sunflower and grassland are spectrally very similar and cannot be separated by either standardized maximum-likelihood classification or textural analysis, these classes must be merged into superordinate classes implying a loss of information. This prompts the testing of vegetation indices for better assignment.

Table 4.4: Spectral analysis (x principal component values) and application of a textural filter (TF)

Land use	leaves/ shrub	grass-land	stubble	winter crop	spring barley	Hay	wood-land	water	built-up area	open-cast mining	embank-ment along opencast mining
Leaves / shrub	x	x 1/3	x 1/2	x 1/3	x	X	x 1/3	x 1/3	TF	x	x
Grass-land		x	x	x 1/3	x	X	x	x	x 1/3	x	x
Stubble			x	x	x	X	x	x	x	x	x
Winter crop				x	x 1/3	X	x	x	x 1/3	x	x 1/2
Spring barley					x	X	x	x	x	x	x 2/3
Hay						X	x	x	x	x	x
Wood-land							x	TF	x 1/2	x	x
Water								120	x	x	x
Built-up area								120	x	x	x 1/2
Open-cast mining										x	x
Embank-ment along opencast mining											x

Vegetation indices

It is assumed that the application of different vegetation indices allows thresholds to be defined that lead to an unambiguous division between certain crop types. The exemplified type ‘alfalfa’ can be classified as either grassland or a winter crop. This assumption is tested and proved in the classified image. Hence altogether three different indices are chosen to distinctively assign the crop type ‘alfalfa’. One of the indices is a ratio index known as NDVI (normalized difference vegetation index), another is the perpendicular index (PVI), and the third is a multidimensional index (tasseled cap).

For each land use class, areas of interest are defined and masked so that the spectral information only exists for the areas of interest. Thus single images are produced for each of the class types and then the vegetation indices are calculated. This calculation enables the user to check whether thresholds are exceeded for other classes and serves to estimate a complete index classification. The procedure is then continued on the object classes ‘winter crop’ and ‘grassland’ as ‘alfalfa’ is assigned to ‘winter crop’ in the multispectral analysis.

After having calculated the NDVI, a clear distinction between ‘grassland’ and ‘alfalfa’ can be made out thanks to the threshold. The classes ‘winter crop’ and ‘alfalfa’ are generally separable with a small overlap area between the maximum value of ‘winter crop’ and the minimum value of ‘alfalfa’. This is the best result gained and is therefore used to improve the multispectral classification (see Fig. 4.1). The tasseled cap index allows ‘alfalfa’ to be distinguished from either ‘winter crop’ (brightness) or ‘grassland’ (greenness and wetness), but not from both simultaneously. The perpendicular vegetation index (PVI) does not meet the required demands; although ‘grassland’ and ‘alfalfa’ can be separated, the area overlapping with ‘winter crop’ is too high. The following tables show the result of the different indices tested including the thresholds for the exemplified classes (see Table 4.5, Table 4.6 and Table 4.7).

Some steps in classification are tested that could improve the standardized multispectral classification method. Generally speaking, methodological improvements are needed to achieve more unambiguous classification results and to be able to work with more subordinate classes to meet the demands in agricultural management and control and to be able to supply distinguished data sets for landscape-ecological models.

Table 4.5: Threshold value for the normalized difference vegetation index (NDVI)

	winter crop	grassland	lucerne
min	0.067	0.488	0.250
max	0.297	0.669	0.434
mean	0.155	0.604	0.341

Table 4.6: Threshold value for tasseled cap

	winter crop	grassland	alfalfa
min	123.00	141.00	144.00
max	146.00	171.00	162.00
mean	133.14	156.40	153.98

Table 4.7: Threshold value for perpendicular vegetation index (PVI)

	winter crop	grassland	alfalfa
min	0.167	0.243	0.197
max	0.229	0.323	0.225
mean	0.197	0.295	0.211

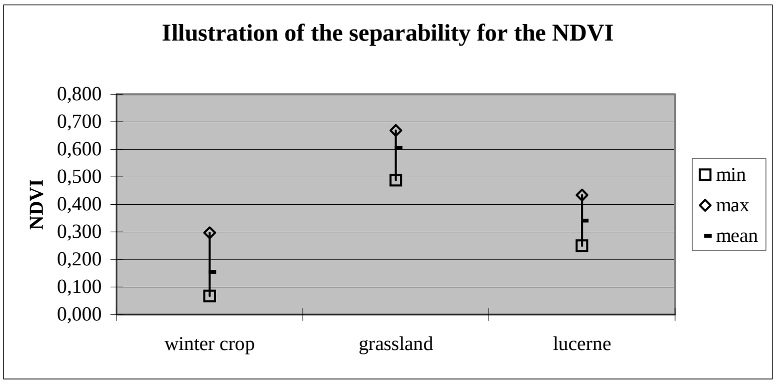

Fig. 4.1: Separability for the NDVI

Unsupervised classification to typify objects for a floodplain area

The various environmental authorities need more and more up-to-date and spatial data to carry out their statutory tasks. Conventional aerial photo interpretation is beset by the dual problems of remaining up-to-date and high costs when large areas have to be covered. As the implementation of satellite imagery necessitates intensive image processing and analysis, the direct use of primary data is impossible for public authorities. What the authorities need is a way of conveniently using preprocessed satellite images. If this could be achieved, satellite data sets could provide a genuine alternative to aerial photography in the day-to-day work of planning authorities. A project for the federal state of Saxony-Anhalt started in 1999 aims to develop catalogues (satellite products, procedures, features characteristic of environmental information) to meet the demands of different end-users. The results are transferred into a user-friendly software so that the decision-makers can perform their tasks independently using an intuitive GIS environment.

The project covers landscape types such as opencast mining, agriculture, forestry, open spaces, urban landscapes and floodplains. The part of the project dealing with floodplains is presented where the condition and the change of this land cover type is investigated on the basis of high resolution satellite imagery. Attention is focused on classifying different data phenologically (during one year) and chronologically (over the years) and, if data is available, also for flooded rivers. Different classification procedures are tested and interpretation is subsequently carried out in a GIS to derive parameters relevant for nature preservation and for landscape evaluation. To detect changes the satellite image data are compared with the biotope mapping and land use typification on the basis of colour infrared photography produced in 1992/93 for the whole state.

One methodological target is to develop a concept to record landscape changes. Standardized classification is difficult for this type of landscape because with a high water level the phenology changes so rapidly during the year and moreover cannot be easily made out from one year to the next either as precipitation and groundwater levels keep on changing irregularly. Tree-trunks and leaves are employed for the first land use type to be characterized. The test site is the middle part of the river Elbe between the towns of Wittenberg and Dessau; the data basis is provided by three Landsat-5-TM images taken in June, August and September 1997. Apart from initial visual interpretation, unsupervised classification is carried out to find out more about the spectral variations of this specific land use type. Reference areas taken from the biotope mapping are only partly accurate as extensification has taken place in the use of grassland.

To register the spectral characteristics of floodplain grassland, an ISODATA cluster analysis is calculated for all three TM data sets. As it is an unsupervised classification, 25 spectral classes are defined in a preprocessing step before classification takes place. A very high number of clusters was found in the separated grassland biotope types. The signature mean values of the TM bands show the heterogeneous spectral character of grassland. The unambiguous assignment of the calculated spectral classes to one of the defined biotope types is not possible (Banzhaf & Fistric 2001).

When aggregating the spectral classes to a single target class named grassland, the problem of mixed classes occurs. Such incorrect assignment mainly concerns fields and deciduous forest, although the spectral overlaps vary depending on the points in time captured. Fig. 4.2 shows the spectral variation for the band combination 3,4,5 (visible red spectra, near infrared, and shortwave infrared). In order to obtain a better result and higher separation accuracy, a much higher number of spectral classes must be defined before a cluster analysis is calculated. Furthermore, a multitemporal approach must be investigated for grassland including additional synthetic bands to increase separability.

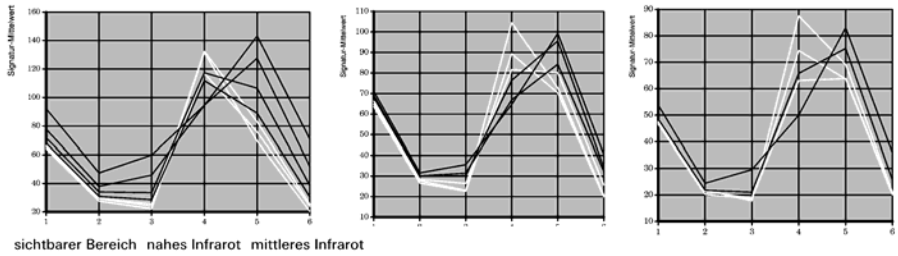

Fig. 4.2: Signature mean values of certain spectral classes for grassland (visible red spectra, near and short wave infrared) in June (left), August (centre), and September (right)

The signature mean values presented are calculated using ISODATA cluster analysis of Landsat-TM images from 1997 (June, August, September) to derive the class grassland. The thermal band was not included in this unsupervised classification, and so the displayed spectra are equivalent to TM bands 1-5 and 7.

For a supervised classification procedure, the standardized maximum-likelihood algorithm will hardly be applied alone as the spectra allows too many differentiations to obtain a single class as a result. Thus a new direction for classifying this land use type needs to use a multi-step operation possibly starting with segmentation, followed by object-based classification with fuzzy logic and/or maximum-likelihood algorithms and including a knowledge-based approach.

4.2 Possibilities and limitations for land use monitoring with remote sensing data and GIS methods

4.2.1 The role of remote sensing data in urban and regional monitoring

Since reunification, the redevelopment process in east German urban regions has resulted in structurally modified and often diffuse settlement structures in an extraordinarily short period of time. This highly dynamic impact has led to a clear reevaluation of the surrounding countryside and to an absolute deconcentration of population and places of employment. Simultaneously, population density and employment figures indicate extensive social, economic and ecological consequences for the urban and peri-urban spaces.

The degree of anthropogenic influence has reached its peak in urban landscapes. It increases in the suburban region compared to almost natural and agricultural landscapes with the growth of overdevelopment. With respect to the rapidly expanding suburbanization and settlement dispersion in German (and other European) urban-suburban regions, importance is shifting from town centres to the suburbs. This process is closely connected with an enhancement of the suburban status and with an increasing deconcentration of population and working-places.

Suburbanization processes need to be observed by scientific investigations, although this has sadly not been the case so far. Such a monitoring could serve to analyse and evaluate the complex and widespread development processes in the suburban area, and could form a basis for deriving models and recommendations for action plans. This recording and description of spatial and dynamic processes calls for the application of new quantitative methods and evaluation approaches.

If remote sensing data are only used for landscape monitoring and land-use classification, the experiences of the methodological tools of satellite data will only be partially exploited. Due to the improved geometrical resolution of new sensors, the analysis of settlement areas is faced by new challenges. Depending on higher monitoring scales, analysis could even involve the identification of individual objects if only whole settlement areas of towns and villages need to be derived. Because of such extended possibilities, several current research efforts are trying to develop new strategies for very heterogeneous and rapidly changing urban and suburban areas from different points of view. Increasing precision means that predicting for example abiotic and biotic components in landscapes and the sealing degree in urban agglomerations is possible.

In addition to the latest satellite-based remote sensing data (e.g. Landsat-TM-7, IRS-1C&D, IKONOS), aerial photographs (e.g. CIR photographs taken to produce country-wide biotope mapping) are available for many urban regions, which can be used as further sources of information. The use of fuzzy logic classifications and the application of textural parameters allow special classification methods that enable the better exploitation of different data. Furthermore, the combination of remote sensing data and spatial models allow predictions that can be essential for urban and regional planning.

Landscape structure analysis as a new tool for natural area potential analysis

According to Plachter (1991) and Fiedler et al. (1996), the dimensions of human influence on spatial structures are so fundamental that land use is entitled to an indicator function for the detection and valuation of a social influence (Schönfelder 1984). The appearance of a landscape is characterized by its natural features including its complex effects on the one hand and the social demand expressed by intensive land use and multipurpose land demands on the other. Therefore landscape monitoring is understood as a system of observations showing modifications in the state of landscape under human impact, and referring to landscape components such as vegetation and soil cover, land use and landscape structure.

Landscape monitoring includes

- The observation and evaluation of factors which have an influence on the landscape, its state and dynamics
- The estimation and evaluation of such influencing factors
- Forecasting and estimation showing the development of the state of a landscape (Bastian & Schreiber 1999, Zierdt 1997).

Integrative, spatially oriented landscape monitoring requires the entry of a landscape's historically grown variety, landscape structure, substantial landscape functions, and also their consequences such as land use modification, fragmentation, diffuse settlement, the modification of the spatial structure of a landscape, as well as the loss of habitats. Such structural features of the terrestrial land cover are directly or indirectly linked with a multiplicity of functions. Landscape metrics can be taken as indicators to analyse, describe, and quantify patterns, compositions and configurations of a landscape type and its compartments.

In particular in the peri-urban cultural landscape, nature is described by indicators such as structure (linear or planar expansion, fragmentation, island areas, etc.), dynamics (entry of the modification processes) and texture (neighbourhood relations to other land use forms). This is based on the identification and computation of static and dynamic indicators that help provide a synthetic assessment of peri-urban landscapes. The indicators also allow the comparison of the environment's condition in different conurbations. The static indicator includes the proportion of urban land uses at different points in time, of land use interrupted by the road network, but also the fragmentation of recreational sites within metropolitan areas, and of built-up areas within green spaces in peri-urban areas. Dynamic urban area indicators refer to the typology of changes and the transition from one land use class to another.

The landscape between the agglomerations of Leipzig and Halle (east Germany) is gripped by a process of rapid transformation by anthropogenic, often uncontrolled interventions. Thus new landscape structures are established which enable new development and process cycles in the region. So far structural investigations have addressed flora and fauna. Using the available research concept, criteria are to be compiled for the need for local recreation and for nature-related conditions concerning the quality of life.

Initially a detailed inventory of the different areas examined should be compiled depending on data availability and the entry of the natural-space configuration which is as up-to-date as possible (e.g. nature protection areas, watercourses, woodlands, forest/field proportion, cycle track configuration, etc.). On the basis of these empirical investigations indicators can be derived to evaluate landscape features, attractions and deficits regarding the following characteristics:

- natural area potential
- suitability for recreation
- aspects of nature protection
- aspects of cultural protection

The rapid change of current modifications and processes simultaneously require and enable the execution of landscape monitoring. Using the latest methods and geo-information data, an important contribution can be made in particular to monitor and evaluate developments being carried out. Landscape monitoring dedicates itself to check and forecast state and dynamics from natural to technical ecological systems. It refers to landscape components such as vegetation and soil cover, land use and spatial landscape structure (Bastian & Schreiber 1999).

Change detection classification based on Landsat TM-5 and TM-7 images

The area between the two conurbations Leipzig and Halle is classified for the years 1989 and 1999 in order to identify the development of human interventions immediately following the Peaceful Revolution and German reunification. As IRS data have only been available for Germany since 1996 and as the two classifications need to be compared as precisely as possible, both dates are classified on the basis of Landsat-TM data. Several preprocessing steps are necessary on the images before classification can take place. The older image was taken by Landsat-5-TM (7 July 1989) and contains bad lines that need to be eliminated and veils of clouds that are diminished by applying the histogram minimum method. The latter image was taken by Landsat-7-TM on 4 September 1999 and does not contain any disturbances.

Atmospheric conditions of the two images are corrected by means of the histogram minimum method. In this preprocessing step histograms of all TM bands are computed for the full image, which generally contains some areas of low reflectance (e.g. clear water, deep shadows or exposures of dark basalt). These pixels will have values very close to zero in the short-wave infrared band (TM band 4). If the histograms of TM bands 1 to 3 are plotted they will generally be seen to be offset progressively towards the higher grey levels. The lowest pixel values in the histograms of these three bands is a first approximation to the atmospheric path radiance, and these minimum values are subtracted from the respective images (Mather 1987). In both images band 6 is eliminated and a synthetic NDVI band calculated and attached.

Both classifications are calculated using the maximum likelihood classifier with the non-parametric rule of the parallelepiped optimization put first. A hierarchical classifications needs to be generated as different settlement densities and opencast mining are spectrally very similar, as well as fields without crops and unsealed ground (e.g. airport) are difficult to distinguish.

The change detection for this region is shown in Table 4.8. It is obvious that the settlement density and sealed areas have increased at agricultural land’s expense. As rather natural wetlands have remained under conservation, their share has not diminished during the decade. Based on these classifications, buffer zones along the motorway A14 are calculated for the first three kilometres adjacent to the motorway linking Leipzig and Halle. This limitation stems from an investigation in the federal state of Thüringa where most changes along the motorway have taken place within this small range of kilometers. The results shown in Table 4.9 express the immense increase in sealed areas within the first few hundred metres and the reduction of the agriculturally used land.

Hence buffer zones or other GIS methods are an important tool for analysing rapid, vast development structures. Quantified analysis is a first step towards investigating land use changes and, by supplementing it by GIS methods, modifications at this scale can be structured.

Table 4.8: Classified Land Use for the Region between Halle and Leipzig

Image Acquisition Date and Sensor Land use classes	07.07.1989 TM-5 [%]	TM-7 [%]	Change detection [%]
Disperse settlement	7.6	14.1	+ 6.5
Dense settlement	3.5	4.2	+0.7
Sealed area (e.g. roads)	3.5	7.1	+3.6
Area without green vegetation	9.0	5.5	-4.5
Fields with crop	35.3	31.8	-3.5
Green top and bush vegetation	10.9	15.3	+4.4
Pasture and meadow land	21.1	9.7	-11.4
Forest	7.2	11.0	+3.8
Water	1.9	1.1	-0.8

Table 4.9: Buffer Zones along the Motorway A 14

Classes [%]	Year	Buffer Zones [m]							
		< 100	< 300	< 500	< 800	< 1100	< 1600	< 2100	< 3000
Sealed area	1989	27.0	8.5	3.4	5.6	5.5	4.4	5.7	9.6
	1999	80.0	23.8	11.9	12.2	9.0	6.0	6.8	14.4
Unsealed area	1989	0.0	0.9	0.5	0.3	0.5	0.4	1.5	1.8
	1999	3.8	7.6	2.7	3.0	3.4	3.0	2.5	1.2
Agriculturally used area	1989	71.0	87.8	91.4	89.0	87.6	87.6	83.1	81.3
	1999	13.5	66.5	81.1	79.5	81.2	82.7	80.3	78.0
Woodland	1989	1.2	2.0	1.5	1.4	2.1	2.9	3.4	1.2
	1999	0.9	0.9	0.8	1.1	1.9	2.7	3.7	1.1
Water	1989	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.4
	1999	0.8	0.4	0.3	0.3	0.5	0.3	0.4	1.3

* mean values are taken from the summarized buffer zones and rounded to one decimal place

Binary classification concentrating on green spaces by means of IRS-1C LISS Data

In this first classification phase, a conventional, multispectral classification is applied to the IRS data. The intermediate result produced provides a set of spectrally rather homogeneous land cover classes, and thus it can be reliable used to identify land cover classes, such as water or woodlands. A multi-step, hierarchical procedure is then carried out of the type developed in earlier projects to classify both satellite-based and airborne, multispectral scanner data (Netzband 1998, Netzband et al. 1999). In a first step, an unsupervised classification (i.e. without signature analysis by the analyst) is executed which supplies 15 classes. These classes have to be assigned to land-use types by interactive, visual checks and postprocessing or, if necessary, aggregated. Furthermore, it is important to separate individual classes that are spectrally unique. The class separation is performed by a multispectral, supervised classification in which each identified class is ‘extracted’ by masking it in the intermediate result, in order to exclude it from the following classification steps. For the classification, a parallelepiped classifier is used. In this procedure pixels are not classified which do not belong to clusters of the spectral signatures, and pixels in the overlap area of two clusters are classified according to the maximum likelihood method. The resulting classes can be overlaid as masks on the image finally resulting and can be stored as independent layers.

For the following calculation process especially two classes could be separated (also compare Fig. 4.3 and Fig. 4.4):

- Forest, stand of woods (larger trees),
- Allotments as well as grassland and meadow surfaces in the inner and peri-urban areas.

Calculating the green spaces according to the Ring-Sector-Model

To evaluate the green area distribution by classified satellite image data in the peri-urban area, the ‘ring-sector-model’ is suggested. This space reference model was developed by Simon (1990) to analyse intra-regional occupation commuter relations in Switzerland. It is based on the dimensional grid (same distances) of conurbations, by superposing any number of concentric sets and sectors over a region.

The model guarantees that a uniform external limitation of different test areas is given. Additionally, it serves to describe intra-regional characterizations of features. Gradients between the town centre and outskirts can be analysed and quantified with the ring-sector model in a differentiated manner (see Fig. 4.3 and Fig. 4.4).

In this case the greenery distribution is investigated in the region of Leipzig using four radii (5km, 10km, 15km, 20km) with eight selected sectors. The following figure shows the calculated green proportions of concerning woods (forest, larger trees) and of allotments and shrub vegetation. In each case it is calculated for all radii and sectors for the classified IRS-1C LISS image data.

Distinct differences are recognizable in the distribution:

- Forest and large tree vegetation is mainly concentrated in the north-west and south/south-west of Leipzig (area of wetlands)
- The internal ring-road (5 km) is best furnished with large vegetation
- Large deficits exist in the northern peri-urban area
- The eastern to southern environment has a higher stand of large vegetation
- The provision of the suburban landscape with small trees and bushes is generally very poor
- Theses small trees and bushes are distributed relatively evenly throughout the city
- Small trees and bushes tend to be concentrated in the eastern surroundings
- The highest values appear towards the city centre

Fig. 4.3: Relative Vegetation Cover (Forest and larger trees) calculated from IRS-1C LISS

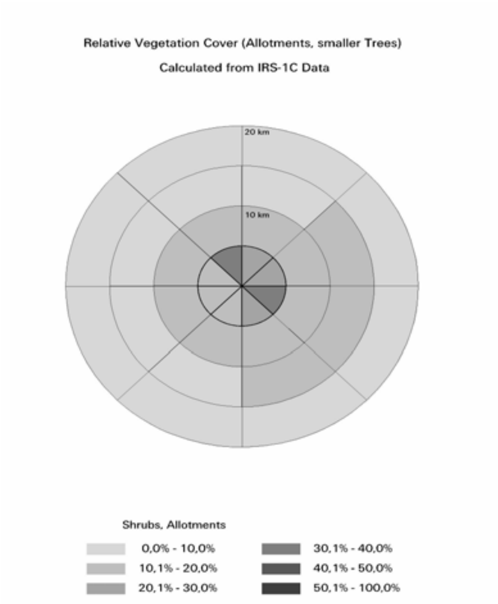

Fig. 4.4: Relative Vegetation Cover (Allotments, smaller trees) calculated from IRS-1C Data

The main characteristics of this landscape type are:

- The suburban landscape as a whole is poorly furnished with small trees and bushes
- These small trees and bushes are distributed relatively evenly throughout the city
- Small trees and bushes tend to be concentrated in the eastern surroundings
- The highest values appear towards the city centre

The patch density (PD) (Turner 1990) calculated for the ring-sector model delivers the following information (see Fig. 4.5, Fig. 4.6 and Fig. 4.7):

- PD equals the number of patches of the corresponding patch type (NP) divided by the total landscape area, multiplied by 10,000 and 100 (to convert to 100 hectares).
- It facilitates the comparison of landscapes with different sizes.
- The peak of forest patches is in the 5-10 km zone and an increase in shrubs and smaller trees can be identified towards the city center.

A historical land use comparison for the conurbation of Leipzig was carried out between 1930 and 1998 to monitor the changes in landscape over several decades. With the exemplified structural metrics 'patch density' and 'edge density' it can be seen that linear structures of green spaces such as alleys, rows of trees and hedges have diminished enormously. The reasons are the vast, monostructured agricultural landscape and the devastation of large sections of the landscape by opencast mining activities.

With respect to the structural analysis of landscape metrics, it can be stated that the ability to quantify landscape structure is essential for the study of landscape function and change. For this reason, much emphasis has been placed on developing methods to quantify the landscape's structure (Banzhaf & Netzband 2000).

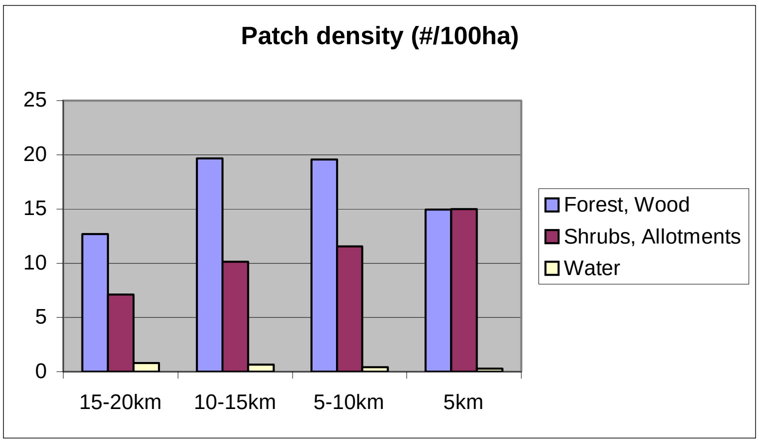

Fig. 4.5: Land use monitoring and structural analysis for the patch density

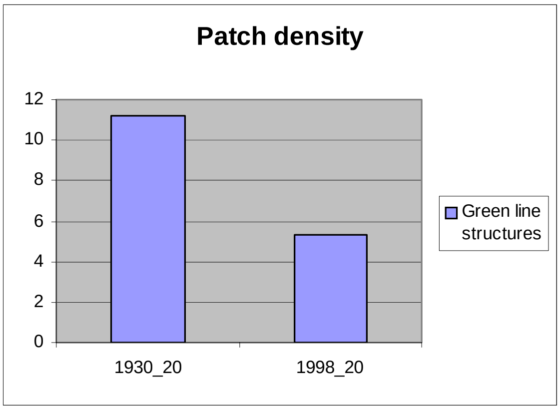

Fig. 4.6: Patch density for the land use classifications of the conurbation of Leipzig

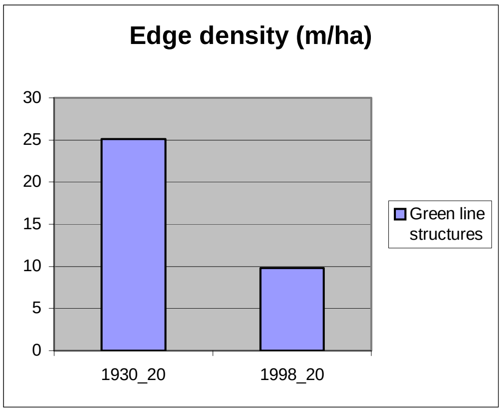

Fig. 4.7: Edge density for the land use classifications of the conurbation of Leipzig

4.3 Conclusion and outlook

Methods for the efficient spatial and temporal classification of the urban natural environment using geo-information are discussed. Multicriteria evaluations of urban nature are compiled for the suburban area regarding the quality of life, biotope protection, biodiversity, natural aesthetics and recovery. A balance and a modelling of the dynamics in nature and a conflict analysis will follow.

Nature, in particular, in the suburban cultural landscape is to be described and analysed with respect to indicators such as structure (linear or areal propagation, fragmentation, etc.), dynamics (entry of the modification processes) and neighbourhood relations with other land use forms, such as with housing estates or business parks.

Initial results for drawing up the inventory of the supply of natural areas clarify the possibilities offered by modern monitoring methods using geo-information to evaluate the natural area potential in the peri-urban landscape. The development of applicable indicators for planning processes is of particular importance.

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