Monitoring of urban structures using remotely sensed data and GIS

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The example of Leipzig-Halle

Diplomarbeit

vorgelegt an der Fakultät XVII Geowissenschaften
der Ruhr-Universität Bochum

von

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zur Erlangung des akademischen Grades „Diplom-Geograph“

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Bochum und Leipzig, im März 2002

I. Acknowledgements

The present study was carried out at the Umweltforschungszentrum Leipzig-Halle GmbH (UFZ). The preparation of the work would have been impossible without the friendly support of several members of staff at the UFZ.

Prof. Dr. Jürgen Dodt I want to thank for his support, and him and Dr. Angela Lausch for their readiness to assess my work.

Dr. Angela Lausch assisted in searching and supplying the literature needed. She gave me very useful advice regarding the content and structure of my work.

Thanks to Anja, Bastian, and Dagmar the correctors of this study.

Special thanks to my parents who financially supported me during my university education.

II. Contents

III. Abbreviations

ADAC	Allgemeiner Deutscher Automobil Club
AML	Arc Macro Language
ArcInfo, ArcView	GIS software packages by ESRI
ARL	Akademie für Raumforschung und Landesplanung
BBR/BfBR	Bundesamt für Bauwesen und Raumordnung
BfLR	Bundesforschungsanstalt für Landeskunde und Raumordnung
CCRS	Canada Centre for Remote Sensing
CD ROM	Compact Disk, Read Only Memory
DB	Deutsche Bahn
Dim.	Dimensionless
DN	Digital Number
ED	Edge Density
ERDAS	Earth Resource Data Analysis System
ETM+	Enhanced Thematic Mapper Plus
GCP	Ground Control Point
GIS	Geographical Information System
Inh.	Inhabitants
JM	Jeffries-Matusita distance
KIT	Keck InformationsTechnologie GmbH
%LAND	Percentage of a land cover class of the total land area
LPI	Largest Patch Index
LSI	Landscape Shape Index
ML	Maximum Likelihood
MNN	Mean Nearest Neighbor Distance
MPI	Mean Proximity Index
MPS	Mean Patch Size
NDVI	Normalised Difference Vegetation Index
NIR	Near InfraRed
PD	Patch Density
PR	Absolute Patch Richness
PSCV	Patch Size Coefficient of Variation

RMS	Route Mean Square
RS	Remote Sensing
SHEI	Shannon´s Evenness Index
SMUL	Sächsisches Staatsministerium für Umwelt und Landwirtschaft
Sq.km	Square kilometre
Sq.m	Square metre
TD	Transformed divergence
TM	Thematic Mapper
UFZ	Umweltforschungszentrum Leipzig-Halle GmbH
USGS	US Geological Survey

IV. List of Figures

V. List of Tables

1. Introduction

Germany is one of the most densely populated regions in central Europe. 11% of the total land area are covered by urban structures, i. e. residential, commercial, recreation, and traffic (SCHERFOSE 2000). 70 hectares of agricultural or other land are transformed to urban uses every day. This rate of urban sprawl concentrates on the cities and their surrounding rural countryside. Synonyms of countryside are hinterland, urban fringe, and rural periphery. According to AUDIRAC (1999, p. 9) the urban-rural boundary is rather a continuum depending on factors such as housing density, population density, proportion of urban structures in the landscape, the rate of land transformation and the degree of commuters. Depending on the degree of these functional links, it is possible to differentiate an immediate hinterland, also termed suburbia or inner fringe, from the remote countryside or outer fringe. However, in this study the rural countryside comprises inner and outer fringe. Definitions of urban sprawl revolve around dispersed urban developments in a predominantly rural countryside outside of compact cities and villages (Plannersweb 29.06.01). Moreover, the length of all motorways/highways doubled between 1971 and 1992 (SCHERFOSE 2000, p. 250).

Based on a steady economic growth rate of three percent annually Germany would be completely covered with urban structures within the next 80 years according to a prognosis by DOSCH & BECKMANN (1999). This consumption of land resources led to the formulation of targets to reduce the demand on land for these purposes. However, the trend has not been stopped until today (BREUSTE 2001). Even with a stagnating population individual demands on land for housing, work, mobility and leisure continue to rise. Owner-occupied housing and a high demand for commercial building land reinforce the trend especially in the periphery of cities. The increase in settlement area in urban cores is expected to be moderate, whereas strong growth can be expected in remote areas surrounding urban agglomerations and urbanised regions (DOSCH & BECKMANN 1999). The pressure exerted by multiple land uses results in a continuing loss of habitats and a severe isolation of remnant habitats. Land conservationists and biologists are aware of a considerable loss in biodiversity due to this kind of habitat destruction (HENLE & MÜHLENBERG 1996).

The region Leipzig-Halle belongs to one of the most threatened areas within the new German federal states. Right after reunification in 1990 intensified deindustrialisation in the cities´ interior accompanied by high rates of suburbanisation in their fringes led to a dramatic change in the landscape. The term suburbanisation is defined by USBECK (2000, p. 21) rather economically as "households and companies that either want to maximise the advantages of location factors or, on the other hand, minimise their disadvantages". It implies a regional deconcentration of population, work space and infrastructure in densely populated regions. ANTROP (2000, p. 258) calls it a "complex process of spatial diffusion...resulting in physical and observable changes in the landscape patterns". The transformation of semi-natural open space, i.e. agricultural land and pastures, forests etc. into urban uses is one major impact. This land consumption led to ecological impairments which are not desirable according to the sustainability definition of city regions (BREUSTE 1995). The Bundesforschungsanstalt für Landeskunde und Raumordnung (BfLR 1996, p. 19) defines sustainable urban development as being based on polycentric, mixed and dense structures (cited from JESSEN 2000; KÜHN 1998). The image of compact and mixed cities is widely accepted among scientists of different directions. Its priorities are urban concentration and inner development in order to avoid suburbanisation and urban sprawl (Leipziger Agenda 21 26.10.01; Bundesamt für Bauwesen und Raumordnung - BBR 2001; Sächsisches Staatsministerium für Umwelt und Landwirtschaft - SMUL 1999).

Landscape change analyses are concerned with historical or recent structural and functional changes of a landscape, their interpretation and the intention to evaluate future developments. According to BASTIAN & SCHREIBER (1999) and MAAS (1999) monitoring of landscape change is primarily concerned with a regular survey and control of the state and dynamics of a particular landscape or ecosystem. Monitoring of urban expansion can be carried through with the aid of Geographical Information Systems (GIS) and Remote Sensing (RS) techniques. A GIS is a computer-based system which allows to gather, store, manage, analyse and graphically represent data in space (HAKE & GRÜNREICH 1994; Keck InformationsTechnologie GmbH - KIT 13.01.02; LILLESAND & KIEFER 2000). Any application of satellite data needs to be supplemented by additional reference sources. MESEV (1997) and STRUNZ & GÜLS (1999) point out the importance of an integration of GIS and RS data.

With the aid of RS techniques land cover can be extracted from a satellite image. Land cover and land use must be distinguished, although both terms are often used interchangeably. Land cover or form reveals information about the physical surface cover, e.g. leaves of trees, tarmac, or concrete. In contrast, land use or function refers to the purpose the ground serves, e.g. urban uses, agriculture, and recreation. Urban encroachment or expansion processes, often referred to as urban sprawl, belong to land use applications (Canada Centre for Remote Sensing - CCRS 15.05.2001).

The use of multi-temporal RS techniques allows to discriminate between rural surfaces (i.e. agricultural land, pastures, forests) and urban structures used for residential, commercial, or recreational purposes. Short revisit times of satellites allow planners to regularly monitor a landscape at comparatively low costs. Change detection, being one basic application of RS, can aid developers in planning agencies to estimate the direction of urban sprawl, and monitor adjacent environmentally sensitive areas (LILLESAND & KIEFER 2000; KIVELL 1993; STRUNZ & GÜLS 1999).

Primarily, spectral information is gained with RS techniques, whereas MENZ (1998) emphasises the use of spatial content of classified RS data. With the evolving branch of quantitative ecology in North America in the 1980s the scientists FORMAN & GODRON (1986), O´NEILL ET AL. (1988) and TURNER & GARDNER (1991) developed means to measure a landscape by using landscape metrics or indices. These vary in time and space which enables a monitoring of a particular landscape.

Many papers are dealing with the application of landscape metrics in rural landscapes (LAUSCH & THULKE 2001; MENZ 1998), whereas "little is known about pattern characteristics in relation to urbanisation processes" (ANTROP & VAN EETVELDE 2000, p. 45). This study shall focus on a highly industrialised and urbanised region in Germany and addresses the following issues.

How can landscape structure be quantified and analysed in the agglomeration Leipzig-Halle using Landsat data? Do cities show completely different values than their rather rural surroundings in a textural analysis based on FRAGSTATS software by MCGARIGAL & MARKS (1994)? Do landscape indices of different dates reveal information about changes in landscape structure in a densely populated region in Central Germany? Are landscape indices compiled for administrative areas like city quarters able to reveal information about certain structures within the city? Does a monitoring on this scale supply reliable information?

2. Summary of Chapters

This work is divided into seven chapters. In addition to the introductory chapter where the problem and goal of this work are outlined, chapter two describes and illustrates (see next page Figure 1) the structure of this study. In chapter three, the background chapter, basic definitions and concepts of quantitative landscape ecology will be introduced, as well as human impacts on landscapes will be explained. Then, in chapter four, the area of interest Leipzig-Halle will be highlighted with regard to its major development eras. In the following chapter relevant data sources are listed and explained depending on their application. Chapter six revolves around the methodology used in this investigation, i.e. the pre-processing, classification, post-classification and change detection steps of Landsat data. The seventh chapter deals with prerequisites of landscape indices and their explanation. Then, the results of the investigation are presented and discussed, followed by a final summary chapter.

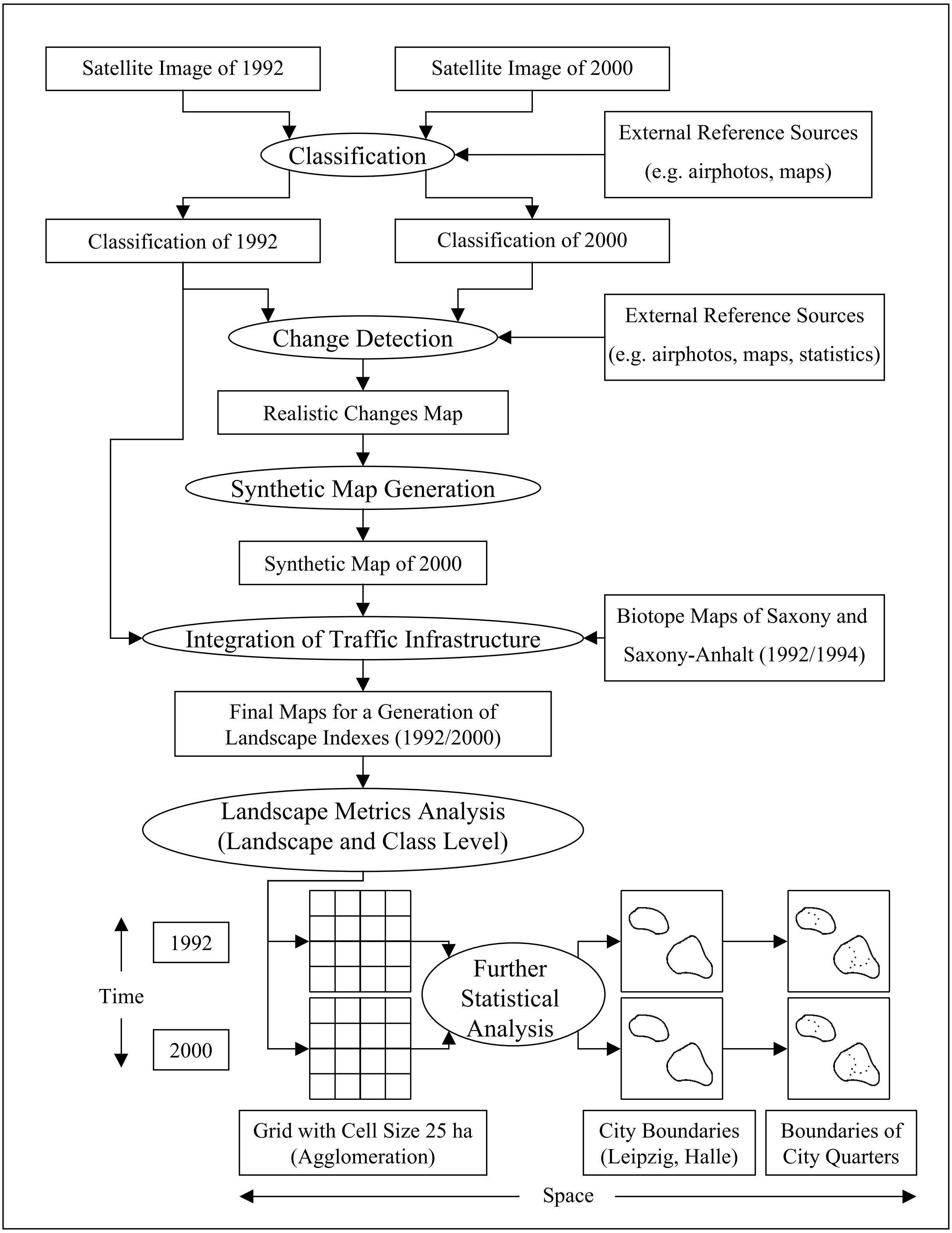


Figure 1: Structure of this work.

3. Background

3.1. Concepts and Definitions in Quantitative Landscape Ecology

Former definitions of landscape revolve around investigations on separate structures in the field without considerations of spatial relationships between different ecosystems. Especially, in North America scientists searched for a rather quantitative approach in order to explore how heterogeneous combinations of ecosystems in a landscape such as forests, pastures, villages, and cities are structured, how these function and how they change. These basic characteristics of landscape elements are defined by FORMAN & GODRON (1986, p. 11) and TURNER & GARDNER (1991) as follows. Structure is the "spatial arrangement of diverse ecosystems (size, form, number, type) that can be separated by different functions". The term function can be defined by "interactions between the components via mass exchange, energy flux or other processes". Change is concerned with the "variation of structure and function over time".

For a better understanding of complex heterogeneous landscapes a division into smaller subsystems is inevitable for a subsequent analysis (LESER 1991). The smallest component in the hierarchy can be delineated using the criterion of homogeneity. After NEEF 1964 any geographical area with the same structure and functions is homogeneous (cited from LAUSCH 2000, p. 17). The current paper focuses on the use of the term landscape element or landscape patch as defined by FORMAN (1995, p. 43) and FORMAN & GODRON (1986). A patch comprises coherent pixel of the same land cover type in a classification that differs from their surrounding (letters A, B, C in Figure 2). Because solitary patches do not occur in a landscape, scientists agreed on the term matrix, class, or patch type to describe the pattern in which patches are embedded (number 1 and 2). Following this definition, a landscape encompasses all the classes.

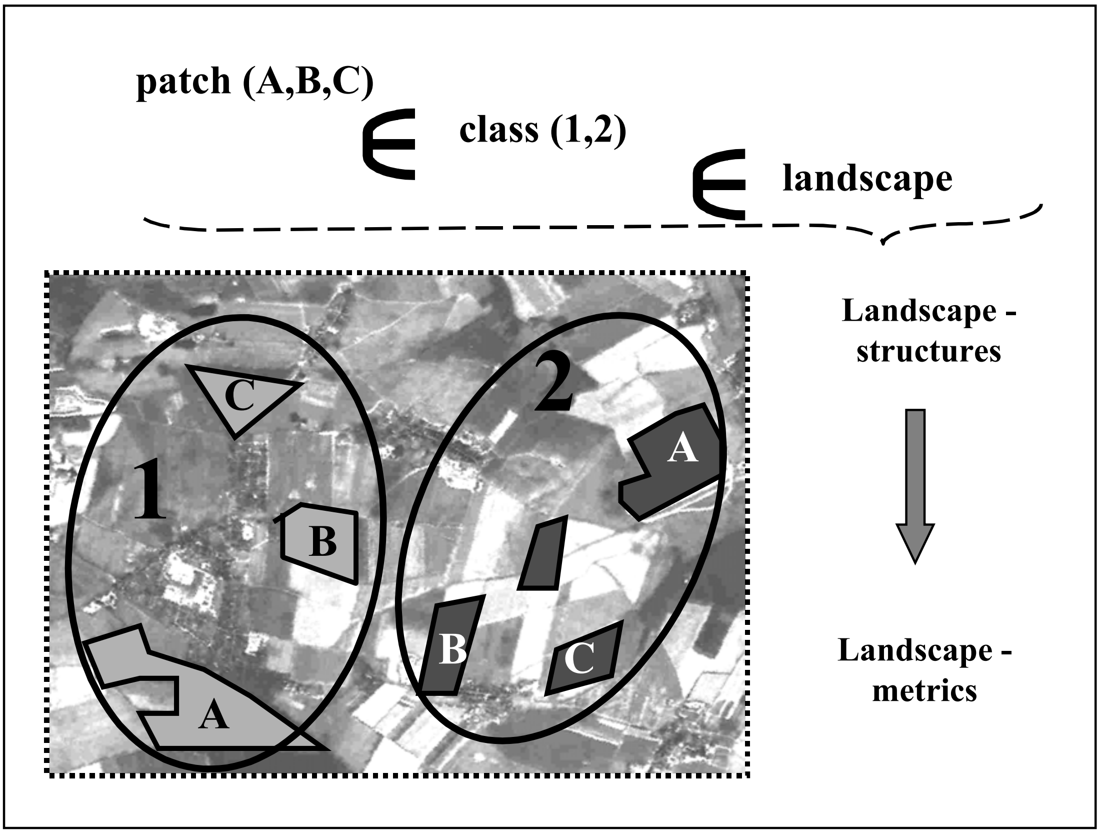


Figure 2: Hierarchy of landscape elements (LAUSCH & THULKE 2001).

Landscapes and ecosystems can be subdivided into two different structural components: composition and configuration. Composition refers to the amount, relative probability and diversity of patches in a landscape. Spatial contexts need not to be taken into account. The diversity of a landscape can be expressed in terms of landscape richness, i.e. the total number of cover types (FROHN 1998), or evenness such as Shannon´s Evenness Index which encounters the distribution of area among the categories. On the opposite, configuration considers spatial relationships among different landscape elements and is concerned about specific locations of elements in the landscape. Indices like the Mean Patch Size, Patch Density or Interspersion and Juxtaposition index belong to this component (GUSTAFSON 1998, p. 145).

3.2. Effects of Human Interactions on Nature and/or Urban Open Space

Human modifications of a landscape encompass the degradation of natural processes by establishing boundaries and edges (e.g. roads), altering of environmental factors, and changing the degree of interactions between different levels of organisation (KREMSA 1999, p. 92). Two main human threats to nature must be considered: disturbances and fragmentation.

The first, the driving force of landscape dynamics, can be defined as "... a discrete event along time that modifies landscapes, ecosystems..." (FARINA 1998, p. 51). Besides by anthropogenic causes, a disturbance can also be driven by natural, either abiotic or biotic factors. Severe disturbances or a lack of disturbance can result in decreased biological diversity, whereas intermediate disturbances might increase biodiversity (FORMAN & GODRON 1986).

The second has a long-lasting effect and is probably "the most severe process to depress biodiversity" (FARINA 1998, p. 58). Fragmentation increases the number of patches in a landscape and augments spatial isolation due to smaller remnant patches which are far apart from each other (SWENSON & FRANKLIN 2000). This might lead to a decrease in population density of a species and the danger of genetic separation, thus enhancing the risk of extinction. Moreover, small areas show signs of increased predation rates among animals and modify their behaviour, such as movement and food searching (FARINA 1998, p. 60).

4. Study Area

4.1. The Agglomeration Leipzig-Halle

The conurbation Leipzig-Halle is located in the new German federal states of Saxony and Saxony-Anhalt, and extends to more than 2000 km^2 (Figure 3). The range from north to south is about 40 kilometres, from west to east it spans more than 50 km.

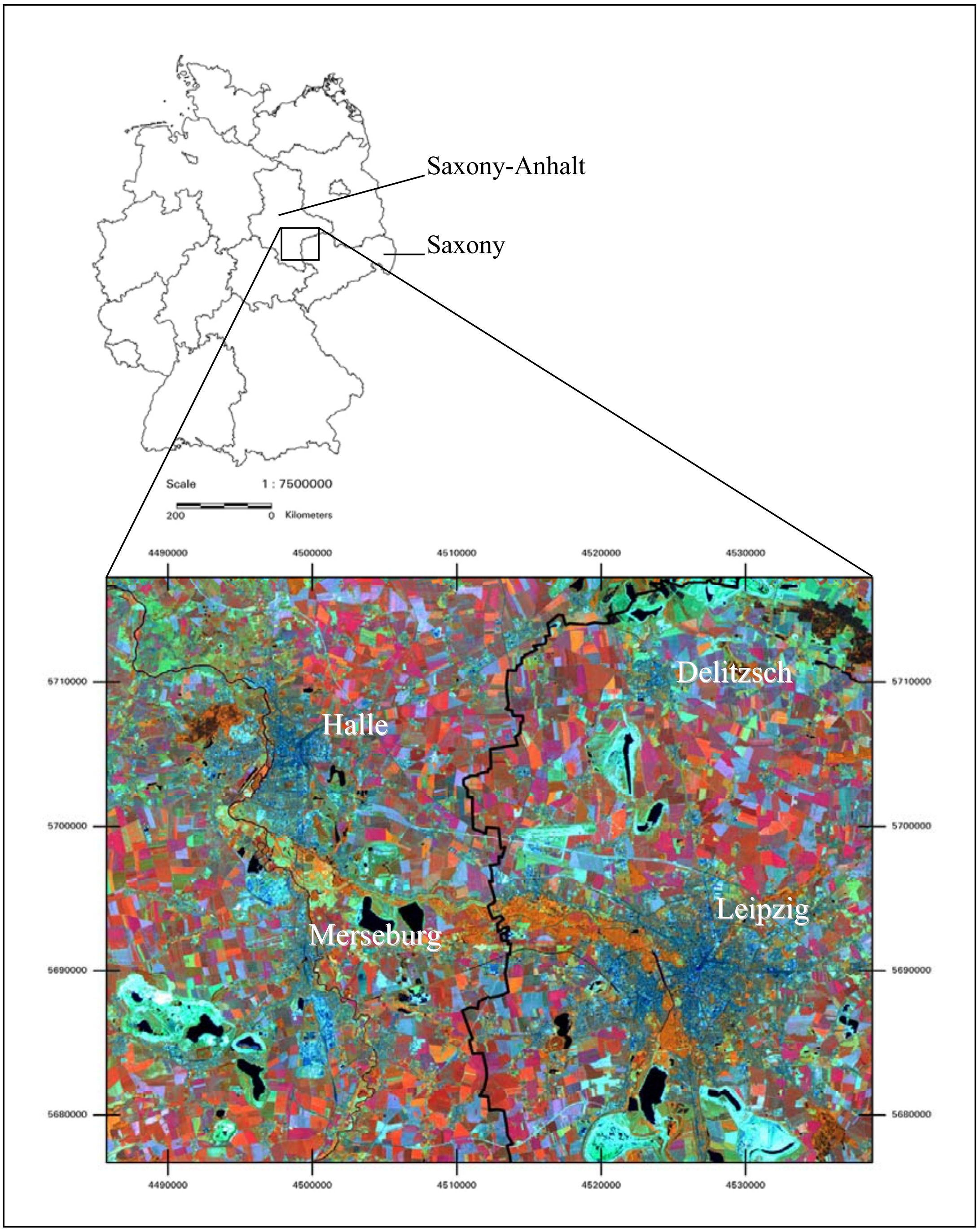


Figure 3: Study area of the agglomeration Leipzig-Halle in East Germany.

In general, three basic categories, i.e. rural regions, urbanised regions, and agglomerated regions, are defined by the BBR (2000, p. 2) depending on the importance of central cities and the population density in surrounding areas. In the area of interest, Halle, though similarly dense populated compared to Leipzig (more than 2000 inhabitants/km^2), has slightly less than 300.000 inhabitants. Therefore, this city belongs to category II (urbanised region). In contrast, Leipzig with about 500.000 inhabitants is surrounded by lower centres in a rather rural hinterland with a population density ranging from 100 to 300 inhabitants/km^2. This is a monocentric agglomeration or conurbation according to the above stated criteria. In this study the term agglomeration is adapted for the whole area of interest. The degree of urbanisation in Saxony reaches 90%, that is more than 90% of all Saxons live in urban settlements having a population of at least 2000 inhabitants (KOWALKE 2000, p. 90).

The densities within both cities boundaries varies from below 100 tenants/km^2 to more than 10.000 inhabitants/km^2 as in very densely populated parts of both cities such as “Grünau-Mitte” and “Grünau-Nord” in Leipzig, and “Westliche Neustadt” and “Silberhöhe” in Halle (Amt für Statistik und Wahlen der Stadt Leipzig 2001; Stadt Halle 2000). The class intervals in Figure 4 are not constant as suggested by BAHRENBERG ET AL. (1990) to account for very low population densities. These census data will provide the basis for an interpretation of calculated landscape indices in chapter 6 (see also Figure 8 and Table 15 in the Appendix for details about the city quarters of Leipzig and Halle).

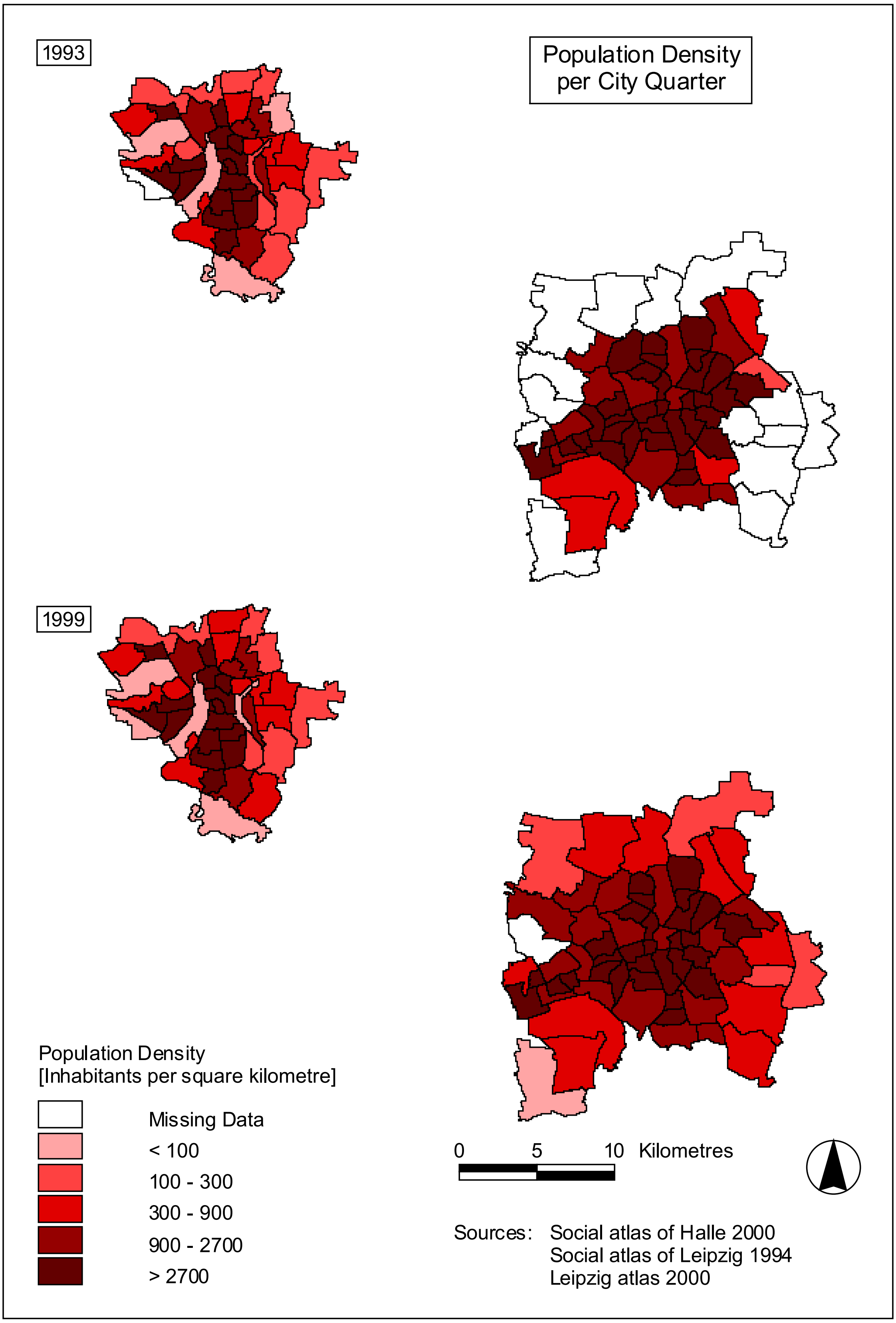


Figure 4: Population densities in the cities of Halle and Leipzig 1993 and 1999 (Amt für Statistik und Wahlen der Stadt Leipzig 2000; Stadt Halle 2000; Umweltforschungszentrum Leipzig-Halle GmbH - UFZ 1997).

4.2. Nature Potential

The Central German agglomeration is located in the lower basin of northern Germany with vast stretches of loess covered land surrounding the major cities of Leipzig and Halle (Leipziger Land and Hallesches Lößhügelland, Figure 5). The loess plain of Köthen and glacial outwash (Düben and Dahlener Heide) build the northern and north-eastern border. To the south, west and south-east, loess covered hills encompass the area under investigation. Floodplains of Saale and Weiße Elster rivers are embedded in a relief with slightly increasing altitudes from the lowlands in the north towards the mountainous areas in the south. In the loess dominated area the ratios of agricultural land to forests reach proportions between 85% for agriculture and 15% for forests. The degree of forested areas is exceptionally low (KOWALKE 2000; LIEDKE & MARCINEK 1995; RICHTER 1995; SCHÖNFELDER 1993).

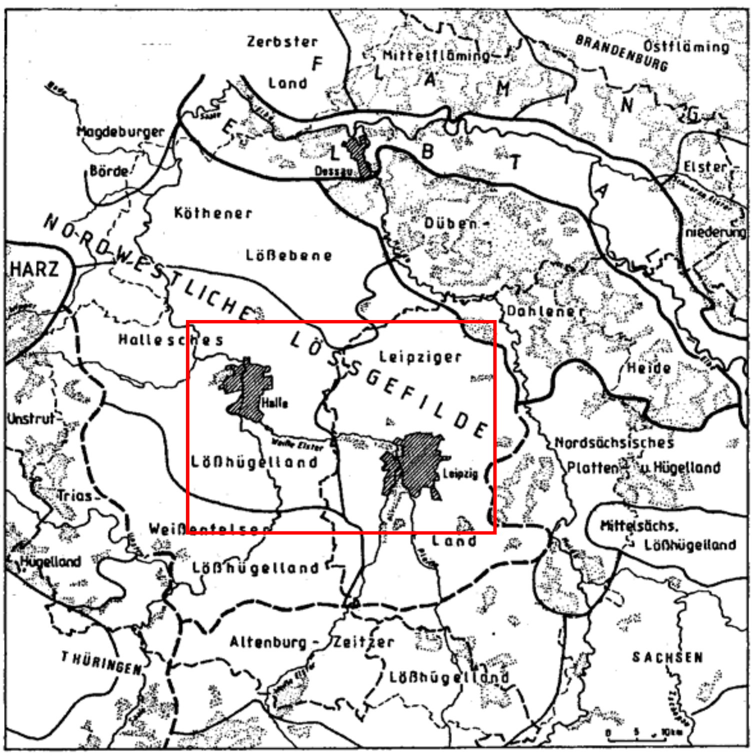


Figure 5: Natural potential in the area Leipzig-Halle (SCHÖNFELDER 1993).

4.3. Important Development Eras and Future Potentials

4.3.1. Historical Development until 1945

Settlement patterns in the area stem from pre-war times with a few major cities being surrounded by urbanised villages or even towns. Due to its very long history of colonisation the area is rather sparsely vegetated by forests. These are mainly concentrated either in the riparian floodplains of the Elster or Luppe rivers or remote from the centres on glacial outwash towards the north-east (e.g. Dahlener and Dübener Heide, KRÖNERT 1997).

After World War I, a unification of the region was attempted despite its political and administrative boundaries. A public planning organisation was established that developed the "Merseburger Planungsatlas", a guide for a future development of the whole region (SCHÖNFELDER 1993).

Since the beginning of industrialisation in the middle of the 19th century the exploration of energy resources increased successively. Historically, lignite in the Geiseltal was the first to be exploited in small open pits by local farmers for personal use. Although the development of advanced drainage and pumping techniques between 1850 and 1920 allowed to mine in greater depth, pits remained rather small and dispersed across the landscape. The demand for coal increased dramatically with raising energy consumption and chemical goods production after World War I. Initially for military purposes huge excavators began to exploit large open cast mines after 1930. To cope with the increasing workforce many former settlement cores in a rural surrounding were extended, to become part of the urban-industrialised agglomeration (KOWALKE 2000; SCHÖNFELDER 1993).

4.3.2. The Era of 1945 to 1989

Eastern German cities have developed in a completely different way compared to their western German counterparts. The industrial decline in the East was due to heavy devastations during World War II and, in addition, to reparation payments to the Soviets right after the war in the 50s. During this period of time politicians preferred the establishment of new industrial capacities to the rebuilding of houses, focussing on the reconstruction of formerly destroyed areas. Therefore, many people emigrated to West

Germany. In the 60s pre-fabricated housing estates were erected which demanded large areas that were mainly to be found at the urban fringe. In the 70s housing construction concentrated on major cities being regional centres, whereas smaller towns were neglected. During the 80s many old houses in the centres decayed and people intended to move elsewhere. This process led again to the construction of new pre-fabricated housing complexes predominantly in the outskirts (HÄUßERMANN 1996, p. 15; KOWALKE 2000, p. 92; PÖTZSCH 1998).

The loss of fertile agricultural land for construction purposes was not to be stopped until the beginning five-year plan between 1981-1985, when a law enforced the construction of houses in the cities´ interior. These means established by the GDR government to plan industrial production as well as coordinating the use of land for various purposes can be compared with West German space plans such as "Flächennutzungsplan" or "Bebauungsplan". Subsequently, dilapidated residential quarters were pulled down to create space for new buildings (GRUNDMANN 1996).

Contrary to West German cities, settlement dispersal could not take place because owner-occupied housing was restricted by law until the late 70s. The rejection of private property resulted in building construction by

- state-owned companies,
- workers` housing co-operatives,
- and municipal authorities.

As a result, private property in cities (example Halle-Neustadt) is often less than 10 %, in contrast to rural areas where up to 80 % of all tenants own a house. (KÜHN 1998, p. 500). In cities housing organisations dominate the municipal market. Many city inhabitants cared for rented gardens. These garden areas or allotments account for large areas in east German cities (HÄUßERMANN 1996, p. 33; KÜHN 1998; PÖTZSCH 1998).

Tertiarisation as in West Germany was nearly completely missing until the 80s. Even regional governments focused on intensifying industrial production. Hence, the tertiary sector was underdeveloped in the former German Democratic Republic (GDR). According to NIEMANN & USBECK (1996) it was 20% less than in the West right after the reunification.

With suburbanisation processes hardly existent in the former GDR the urban-rural fringe remained distinct until the political and economical change in the 90s. (BBR 2001; GRUNDMANN 1996; PATZ & KUHPFAHL 2000).

4.3.3. Trends after Reunification

Since 1989 three changes have become apparent in the landscape. Firstly, alterations of agricultural entrepreneurship from socialistic to capitalistic forms also caused a land use change. In contrast to 1989, when all agricultural land was cultivated, nowadays more and more land lays bare and derelict. Secondly, the economic pressure on the energy sector in general and, in particular, on the lignite industry lead to a decrease in open pit mining. This has been the starting point for intensive recultivation of devastated land including an infill of mines with water in order to create artificial lakes (Figure 6).

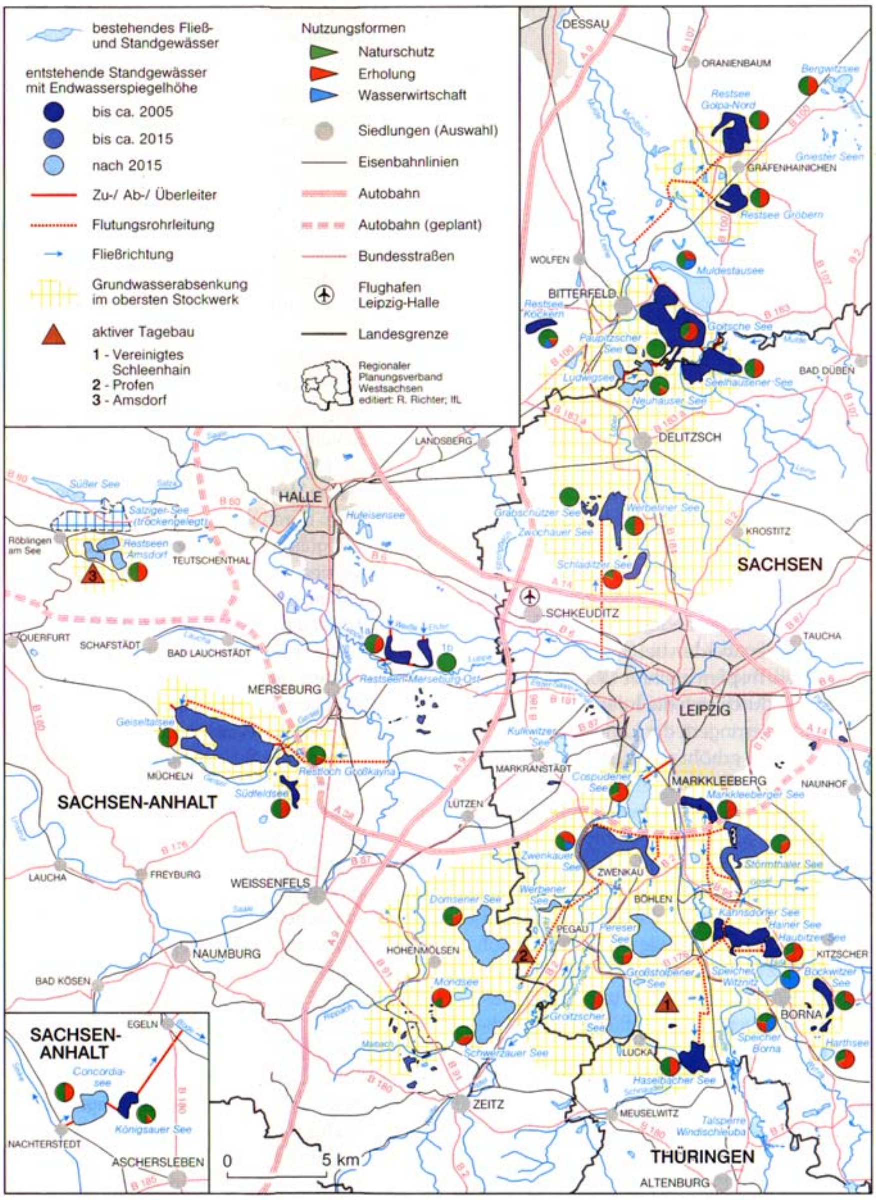


Figure 6: Future perspective of artificial lake development in Central Germany (BERKNER ET AL. 2001).

Finally, an increase in surface sealing and urban sprawl has been observed (KRÖNERT 1997).

The dynamic of land use change increased extraordinarily. This development was driven by modern requirements concerning infrastructure, traffic and commerce. The German term "Strukturbruch" is defined as a very fast restructuring process in the new federal states in Germany compared to its western states. The overall de-industrialisation was accompanied by a substantial decrease in the workforce. Severe job losses in the primary and secondary sector can not be compensated for by an increasing demand for employers in the tertiary sector (GRUNDMANN 1995; KOWALKE 2000; USBECK 1996a).

Changes in space planning from the socialistic regime of the GDR to West German standards resulted in a time delay of plans depending on specifications that were to be released by major authorities. Though a land development plan for Saxony-Anhalt could pass in 1992, regional plans remained to be presented until 1996. Therefore, plans of minor authorities in the communes could not be adapted to these, resulting in a "planning deficit" (OELKE 1997). These problems right after the reunification led to an uncontrolled declaration of building land in rural areas. Generally, suburbanisation mainly affects villages in the surrounding of major urban centres (BBR 2001).

In contrast to West Germany, at first commercial suburbanisation began, then followed by retail suburbanisation, and at last followed by residential suburbanisation (PATZ & KUHPFAHL 2000). In Saxony more than 30% of all applications for commercial investments are located in small villages of less than 2000 inhabitants (SMUL 1999; USBECK 1996b, p. 301). More than 55% of already realised and prospected retail space in the new federal states is located in the outer fringe compared to less than 30 % in the old states (HÄUßERMANN 1996, p. 27). After establishing industry or technology parks with the aid of state funds, small towns and villages grow considerably (
Figure 7).

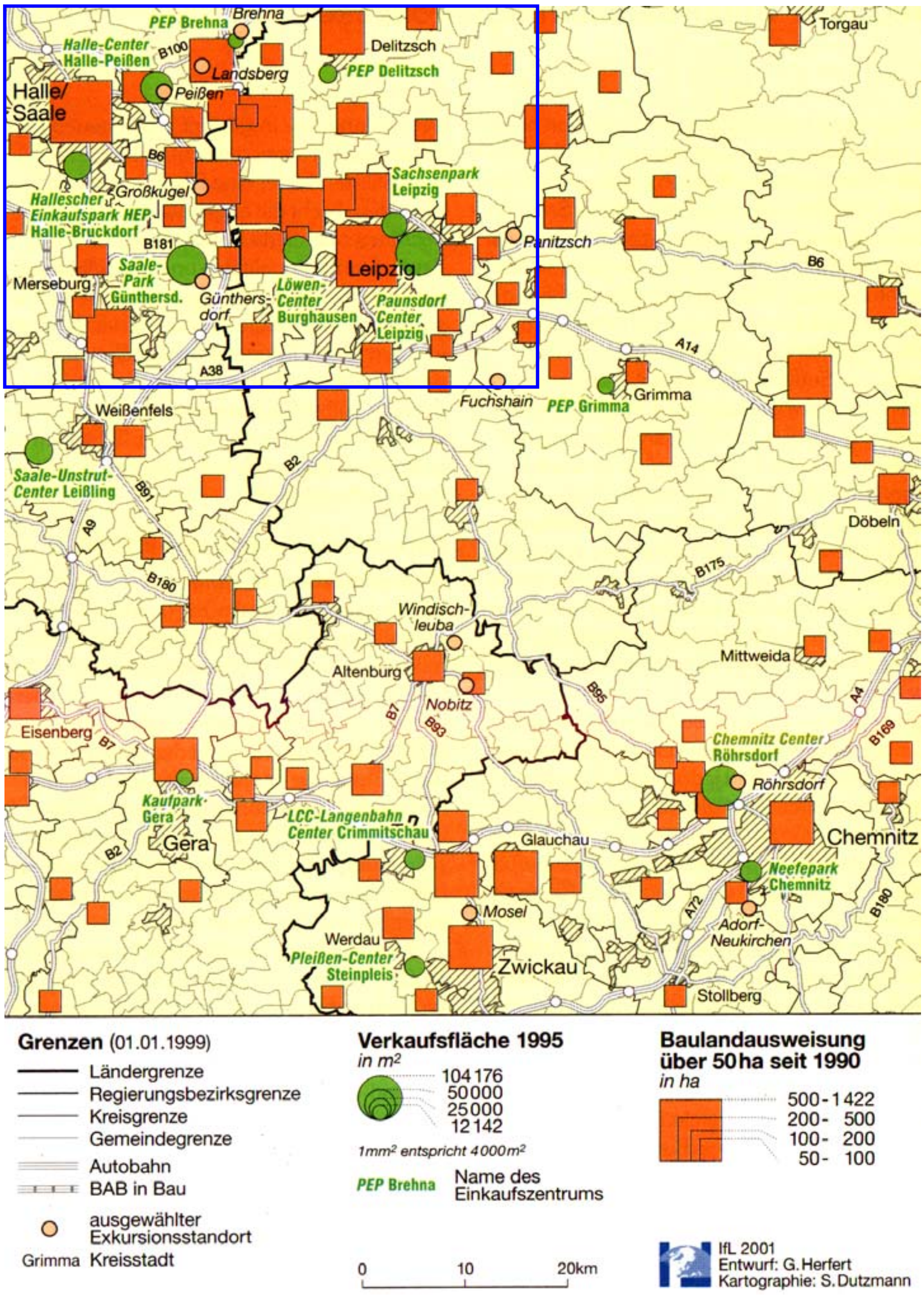


Figure 7: Suburbanisation in the area of interest (BERKNER ET AL. 2001).

The pull factors for companies investments on the meadow in the urban countryside are abundant space, low ground prices, easy access, and no obstructions with regard to noise, gaseous emissions etc. due to near-neighbouring inhabitants. Major location factors and drawbacks of cities were compiled by HÄUßERMANN (1996) and USBECK (1996a, see Table 1).

Table 1: Location factors and city development obstacles (HÄUßERMANN 1996; USBECK 1996a).

Location factors (positive)	Inner city drawbacks (negative)
- modern traffic infrastructure	- shortage of free space (especially for traffic and recreation)
- diversity of branches	- contaminated former industrial/military sites
- skilled workforce	- uncertain property rights
- scientific institutions	- high ground prices
- cultural institutions	- large area demands of modern industry and commerce
	- nearby residential quarters

Retail stores are prohibited in rural areas of Saxony-Anhalt since 1991, other than in other eastern federal states. Exceptions are permitted in primary and secondary centres only, if their functioning is not impaired (PÖTZSCH 1998). Applications for building land in the periphery exceed those in urban cores (Amt für Statistik und Wahlen der Stadt Leipzig 2001; GRUNDMANN 1996). This current development of inner-regional deconcentration of inhabitants and work space leads to a change in spatial structure. The economic importance of the urban fringe increases, whereas it decreases in urban cores. These developments contradict regional development plans (GRUNDMANN 1995; KOWALKE 2000; USBECK 1996b).

One-family houses are rare in Leipzig and other centres. Compared to western Germany where owner-occupied housing prevails with about 50 % of the total housing stock, East German figures revolve around one third. Instead three- to five-storey houses with smaller gardens dominate in the East. The areal demand of inhabitants varies between almost 40 square metre per tenant in the West in contrast to less than 35 m^2 in the East. (Amt für Statistik und Wahlen der Stadt Leipzig 2001; BBR 2001; KÜHN 1998, p. 500; PATZ & KUHPFAHL 2000; WIEST 2001).

After reunification a decline of population losses due to migration between 1990 and 1992 can be statistically proved (Stadt Halle 2000; Amt für Statistik und Wahlen der Stadt Leipzig 2001). Emigration to other federal states was severe at the beginning of this period of time, lessening in subsequent years. Since 1993 inner migrations within the city areas prevail, destabilising existing neighbourhoods (WIEST 2001). The natural population development is negative due to decreased fertility rates accompanied by stable death rates (Amt für Statistik und Wahlen der Stadt Leipzig 2001; KOWALKE 2000; PATZ & KUHPFAHL 2000). Due to increased emigration right after Germany's reunification and reduced population pressure suburbanisation processes are less severe in East Germany, though they span shorter periods of time.

4.3.4. Future Development Potentials

Forecasts for the next years predict no significant population growth for the new German states. In fact, the general trend of a declining population will continue in future according to a prognosis for 2010 (KOWALKE 2000; PATZ & KUHPFAHL 2000). Hence, public administration focuses on development within compact city boundaries. Renovation prior to new construction and careful reduction of pre-fabricated houses in the short-term are current trends to stabilise the housing market and to avoid an accommodation surplus. These objectives are established in the Saxony-Anhalt housing and urban planning policy, and the communal strategy concept for Leipzig (PÖTZSCH 1998; WIEST 2001).

According to KOWALKE (2000) and USBECK (1996a) the conurbation Leipzig-Halle has got the most promising development chances after Berlin compared to other East German metropolitan areas. However, compared to West German metropolitan areas, even the most promising areas in the East remain at a medium level concerning economic potential based on different indicators. Structural deficits are not yet overcome, and migration will prevail in areas with structural problems (BBR 2001; WIEST 2001).

Modern infrastructure in the North and East of the region encourage investments. The motorways A9, A14, and A38, as well as many important state-owned roads attract companies to build subsidies adjacent to these development axes. The internationally renowned fair, the airport Leipzig-Halle near Schkeuditz, the overall commercial and industrial power of the region, and current investment plans are very important location factors (see Table 1). Traffic infrastructure already accounts for more than 40% of the total area in the conurbation of Leipzig and Halle. (compare to Berlin and Munich 70%), whereas in the surrounding fringe values remain below 10-20% (BBR 2001). The current restructuring process leads to a disproportion of work space along the traffic routes, whereas the population is concentrated in the South and West of the cities. As a result, augmented commuting rates are to be expected in future.

On the other hand, a further spread of the urban edge can be hindered by reduced ground prices in the cities´ interiors, due to changes in funding of commercial sites. With the depletion of financial budgets cities are forced to give up plans for extensive land transformations in their surroundings. Some more aspects against the continuing trend of retail and commercial suburbanisation in future were gathered by SMUL (1999), USBECK (1996b) and USBECK (2000):

- Peak of companies has already left inner city locations since reunification
- Since 1995 subsequent reduction of site approvements
- Low utilisation degree of existing sites in the urban fringe
- Increased revitalisation of old industrial sites within the city
- Low ground prices in the cities´ interior
- Change in funding of new commercial sites
- Increasing financial problems of East German cities resulting in higher debts

Based on a treaty from February 1994 Saxony and Saxony-Anhalt agreed upon the establishment of an interregional space planning commission for the region. Its objective is the agreement on communal targets for spatial developments in the region. Areas of interest are traffic, housing, recycling of old-industrialised areas, and commercial settlement strategies (SMUL 1999; USBECK 1996). Because of the territorial border between the federal states of Saxony and Saxony-Anhalt planning authorities are faced with problems concerning cross border developments. Separate development plans neglect possible impairments of investments and infrastructural improvements in each other region. Because satellites are independent of administrative borders, and capable of dealing with large areas an application of RS techniques has been recommended by SCHÖNFELDER (1993) and STRUNZ & GÜLS (1999).

5. Data Material, Software, and Hardware

5.1. Landsat Data Characteristics

Landsat-4 has been launched on the 16th of July 1982, whereas Landsat-7 started off on the 15th of April 1999. The first carries a detector called Thematic Mapper (TM) with similar orbit, repeat coverage and swath width as its modern counterpart Enhanced Thematic Mapper Plus (ETM+) (LILLESAND & KIEFER 2000). Some properties of both detectors are listed in Table 2.

Table 2: Detector properties of TM and ETM+ (LILLESAND & KIEFER 2000).

TM		ETM+	
Band (µm)	Resolution (m)	Band (µm)	Resolution (m)
0,45-0,52	30	0,450-0,515	30
0,52-0,60	30	0,525-0,605	30
0,63-0,69	30	0,630-0,690	30
0,76-0,90	30	0,750-0,900	30
1,55-1,75	30	1,55-1,75	30
10,40-12,50	60	10,40-12,50	60
2,08-2,35	30	2,09-2,35	30
		0,520-0,900 (panchromatic)	15

5.2. Used Landsat TM/ETM+-Images

In this study, Landsat data of two different years were used to identify changes in landscape patterns. The first image dates back to 28th May 1992. It was scanned with the Thematic Mapper mounted on the Landsat-5 satellite. Its successor, the Enhanced Thematic Mapper Plus gathered data for the second scene, which was transferred to Earth by Landsat-7 on 19th June 2000.

Both sets were chosen because of their “clear” appearance, which means that shadows of clouds and haze do not impair the image. Moreover, a very narrow time span between both images (end of May to mid-June) was preferred to minimise phenological variations as recommended by MEINEL ET AL. (1997).

5.3. Additional Reference Data

Any interpretation of satellite data must be based on reference data and ground truth. Ground truthing means verifying remote sensing data by data gathered during field trips (VERBYLA 1995). Users tend to rely on topographic maps, aerial photos and other additional data because ground truth is difficult to obtain and expensive (MESEV 1997). In this study, digital biotope maps of Saxony and Saxony-Anhalt, topographic maps, airphotos, digital administrative borders, and census data of the two cities Leipzig and Halle were integrated (Table 3).

Table 3: Meta-information for the area of interest.

Source	Data/Scale	Application
Allgemeiner Deutscher Automobil Club - ADAC (Hrsg.) (2000): München.	Großraumstädteatlas Leipzig-Halle. 1:20000	Vector mask of urban areas
Landesamt für Umwelt und Geologie Sachsen (Hrsg.) (1994): Radebeul.	Digital biotope map of Saxony (CIR-Biotoptypen- und Landnutzungskartierung Sachsen). 1:10.000	Search for training sites Selection of traffic network
Landesamt für Umweltschutz Sachsen-Anhalt (Hrsg.) (1992): Halle.	Digital biotope map of Saxony-Anhalt (Katalog der Biotoptypen und Nutzungstypen für die CIR-luftbildgestützte Biotoptypen- und Nutzungstypenkartierung im Land Sachsen-Anhalt. H. 2). 1:10.000	Search for training sites Selection of traffic network
Amt für Umweltschutz der Stadt Leipzig (Hrsg.) (1999): Leipzig.	City biotope map (Stadtbiotoptypenkartierung der Stadt Leipzig). 1:10.000	Search for training sites
Landesamt für Landesvermessung und Datenverarbeitung Sachsen-Anhalt (Hrsg): Halle.	Topographic maps 1:50.000 L 4536 Halle (1996) L 4538 Landsberg (1996) L 4736 Merseburg (1997) L 4738 Leipzig-West (1997)	Verification of classification
Landesvermessungsamt Sachsen (Hrsg) : Dresden.	Topographic maps 1:50.000 L 4540 Eilenburg (1992) L 4740 Leipzig (1993)	Verification of classification

Hansa Luftbild GmbH: Münster.	False-colour airphotos 1:5.000. (12th August 1997)	Verification of classification
Hansa Luftbild GmbH: Münster.	True-colour airphotos 1:25.000. (26th June 1992)	Verification of classification
Usbeck-Wenninger GmbH (1997): Aachen.	Airphoto-atlas of Leipzig (Luftbildatlas Leipzig). CD-ROM	Verification of classification
Statistisches Landesamt des Freistaates Sachsen (Hrsg.) (2001): Kamenz.	Statistic yearbook of Saxony 2001 (Statistisches Jahrbuch Sachsen 2001)	Verification of classification
Statistisches Landesamt Sachsen-Anhalt (Hrsg.) (1997): Halle.	Statistic yearbook of Saxony-Anhalt (Statistisches Jahrbuch des Landes Sachsen-Anhalt)	Verification of classification
Amt für Statistik und Wahlen der Stadt Leipzig (1999): Leipzig.	Statistic yearbook 1999 (Statistisches Jahrbuch 1999)	Verification of classification
Amt für Statistik und Wahlen der Stadt Leipzig (Hrsg.) (2000): Leipzig.	Leipzig atlas 2000 (Ortsteilkatalog: Daten zu den Ortsteilen und Stadtbezirken der Stadt Leipzig)	Extraction of city quarter boundaries Population densities 1999
Stadt Halle an der Saale (Hrsg.) (2000): Halle.	Social atlas of Halle (Sozialatlas - Sozialberichterstattung 1992-1999. Beiträge zur nachhaltigen Stadtentwicklung)	Extraction of city quarter boundaries Population densities 1993 and1999
Umweltforschungszentrum Leipzig-Halle GmbH (UFZ) (Hrsg.) (1997): Leipzig.	Social atlas of Leipzig (Sozialatlas der Stadt Leipzig 1994).	Population densities 1993

Table 3 continued.

Firstly, the different biotope maps of Saxony and Saxony-Anhalt had to be adjusted to each other to allow for a simplified declaration of training areas in the classification stage. Later these thematic maps were used to select the traffic network for deriving landscape indices (see chapter 6). Additionally, the biotope map for Leipzig city called “Stadtbiotoptypenkartierung der Stadt Leipzig” from 1999 was consulted for the purpose of finding training sites.

Secondly, topographic maps, airphotos, and the CD ROM “Luftbildatlas Leipzig” aided in the declaration of training areas and assisted in the verification of the classified data. Moreover, the statistic references were applied for comparisons with the classifications.

The two separate digital city maps with information about official city quarters were aggregated and solitary identification numbers assigned (Figure 8). These were applied in context with census data (Figure 4) and for the generation of landscape indexes (see chapter 5). To get information on the official numbers and names of the city quarters refer to Table 15 in the Appendix.

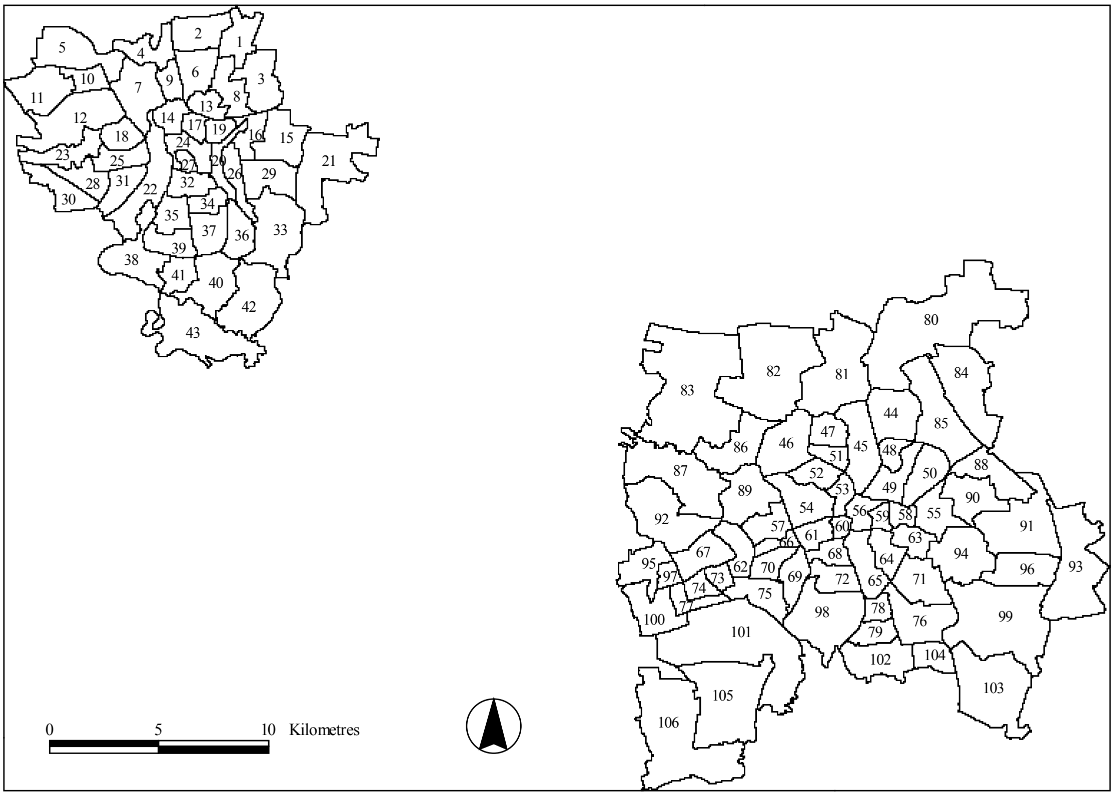


Figure 8: City quarters of Leipzig and Halle in 2000 (Stadt Halle 2000; Amt für Statistik und Wahlen der Stadt Leipzig 2000).

It must be noted that the area of Halle city remained unchanged over the period of time considered here (Stadt Halle 2000). In contrast, Leipzig city was enlarged by embedment of surrounding regions in a couple of communal boundary reforms. Here, the former quarters "Grünau-Süd", "Portitz" and "Großzschocher" now extend to larger areas than in 1995. "Grünau-Süd" was renamed "Lausen-Grünau", and "Portitz" and "Plaußig" were combined to form "Plaußig-Portitz". Moreover, many new quarters were appended in 1995. In the south "Rehbach-Knautnaundorf" was added, in the west "Miltitz" and "Böhlitz-Ehrenberg", in the north "Lützschena-Stahmeln", "Lindenthal", "Wiederitzsch", and "Seehausen", and in the east "Mölkau", "Engelsdorf", "Baalsdorf", "Althen-Kleinpösna", "Holzhausen", and "Liebertwolkwitz". Last but not least, "Burghausen-Rückmarsdorf" became part of the city on 1st of January, 2000 (Amt für Statistik und Wahlen der Stadt Leipzig 2000). This expansion can be seen in Figure 4 in which white areas indicate later enlargements. The only exception is the quarter "Gewerbegebiet Neustadt" in Halle. Nevertheless, the city boundaries of the year 2000, and not those of 1992, were applied to allow for comparisons for derived indexes.

5.4. Hard- and Software

The ERDAS Imagine 8.4 software package was used on a UNIX workstation (Sun-Solaris 2.5) to process and classify the images. For GIS purposes ESRI ArcInfo 8.2 was applied, facilitating the integration of vector data. The public domain programme FRAGSTATS (version 2.0, by Ma) calculated landscape indices. This tool is used as a standard, being in widespread application. To aid in data base management Microsoft Access 97 was used for linkage and queries of different data sets. Moreover, STATISTICA 5.5 for windows aided in the visualisation and analysis of generated indices. Finally, ESRI ArcView 3.2 came into use to demonstrate spatial results of landscape indices for both cities and their administrative quarters.

6. Classification and Change Detection

6.1. Pre-processing - Geometric Correction and Atmospheric Correction

Distortions or non-linearities result from variations in altitude, attitude, platform velocity, earth curvature, atmospheric refraction, relief displacement and irregular sweeps of the sensor. Geometric correction of satellite data is a prerequisite for map generation. The available data sets were already pre-corrected based on a reference image, a panchromatic SPOT scene of 1994 which was rectified with the aid of topographic maps. In an image-to-image rectification process 65 ground control points (GCP) were equally distributed all over the slave images, i.e. 28 May, 1992 and 19 June, 2000 (Figure 9).

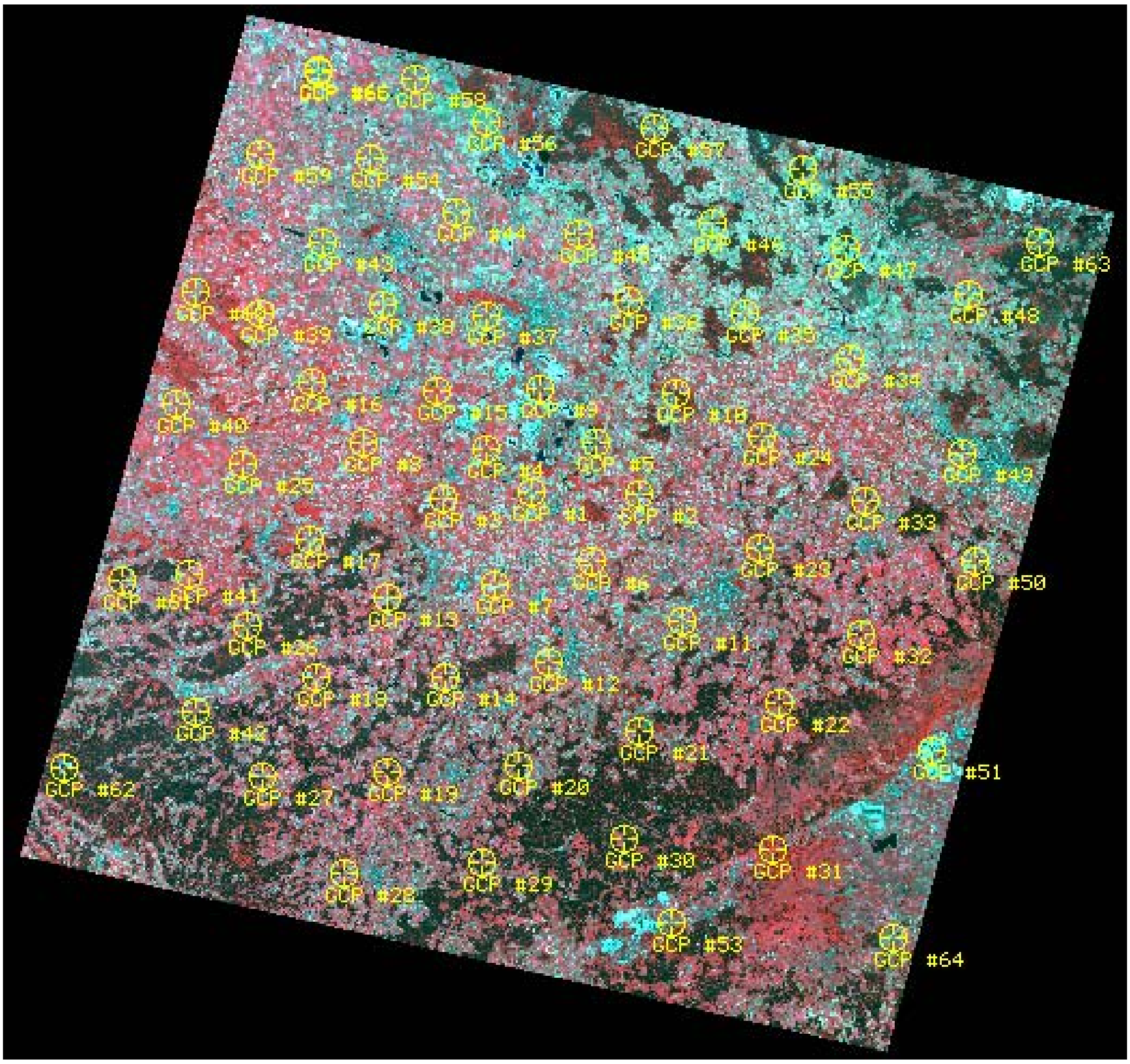


Figure 9: Distribution of GCPs in the scene 2000.

With a 2nd-order polynomial transformation the resulting route mean square (RMS) errors of both corrected slave images remained lower than 0,4 pixel. Nearest-neighbour resampling was applied in order to minimise alterations of DNs. The nominal spatial resolution of the output images was set to 25 m.

MAS (1999) and SONG ET AL. (2001) strongly recommend the application of absolute or relative atmospheric correction tools for classifications and change detection purposes. A Correction tool for atmospheric distortions was not available and could therefore not be applied. The images were chosen, because both appeared to have no visual obstructions like clouds or persistent haze.

6.2. Generation of Vegetation Indices

Vegetation indices aid in the identification of different objects in a satellite image. Normalised Difference Vegetation Index (NDVI) (4.1) is a ratio of two bands in a satellite image. Values range from -1 (black) to 1 (white) and demonstrate subtle differences in reflectance. Healthy vegetation is bright, soils are mid to dark grey and water and urban structures appear black. Vegetation indices aid in the detection of urban green (RICHARDS & JIA 1999). The NDVI is a ratio of

$$(NIR - Red)/(NIR + Red) \qquad (4.1)$$

For this study an NDVI layer was computed to facilitate the identification of the amount of urban green in the conurbation Leipzig-Halle. A differentiation of housing density classes or classes of sealing with this method is possible according to (MEINEL ET AL. 1997).

6.3. Classification

DONNAY ET AL. (2001) and JENSEN & COWEN (1999) suggest that low to moderate spatial resolutions are not sufficient to identify detailed land use classes in an image. On the basis of the US Geological Survey (USGS) land cover classification system level III classes can be identified with the help of 1 to 5 m spatial resolution, whereas for level II classes resolutions of 5 to 20 m are sufficient. For more information about the USGS land cover classification contact LILLESAND & KIEFER (2000).

Despite its enhanced spectral resolution no improvement in the separability of urban built-up can be found with SPOT data. Similar results for urbanisation processes with Landsat-TM data are possible according to HEINZ (1999). MASEK ET AL. (2000) and DONNAY ET AL. (2001) note that Landsat data sets appear to be appropriate for synoptic views of urban development studies, enabling an extraction of urban features and their separation from other land uses.

Therefore a multistage classification for Landsat data using an array of decisions to determine the correct class affiliation was performed because this was already successfully conducted for the area of interest Leipzig-Halle by HEINZ (1999) and LAUSCH (2000).

6.3.1. Multispectral Hierarchical Classification

In hierarchical classifications digital satellite images are subsequently partitioned and classified in a step-by-step process in order to achieve optimal classification results. Segmentation criteria might be spectral thresholds or other data sets. Applying thresholds two classes can be differentiated, e.g. urban versus non-urban land, which can be subdivided further into classes of lower integrity. According to HILDEBRANDT (1996) and RICHARDS & JIA (1999) the advantages of this method lie in a decreased time effort for computational operations and higher precision based on several subdivisions.

Due to the problematic differentiation between urban structures and open pit mines, urban structures were concealed with a binary vector mask in this investigation. The delineation was conducted with the aid of topographic maps and the "Großraumstädteatlas Leipzig-Halle" (ADAC 2000). This process resulted in a division of the data set into an urban and a non-urban part. The mask allows the classification of both resulting data sets separately as can be seen in Figure 10. (LAUSCH 2000; MORISETTE & KHORRAM 1996).

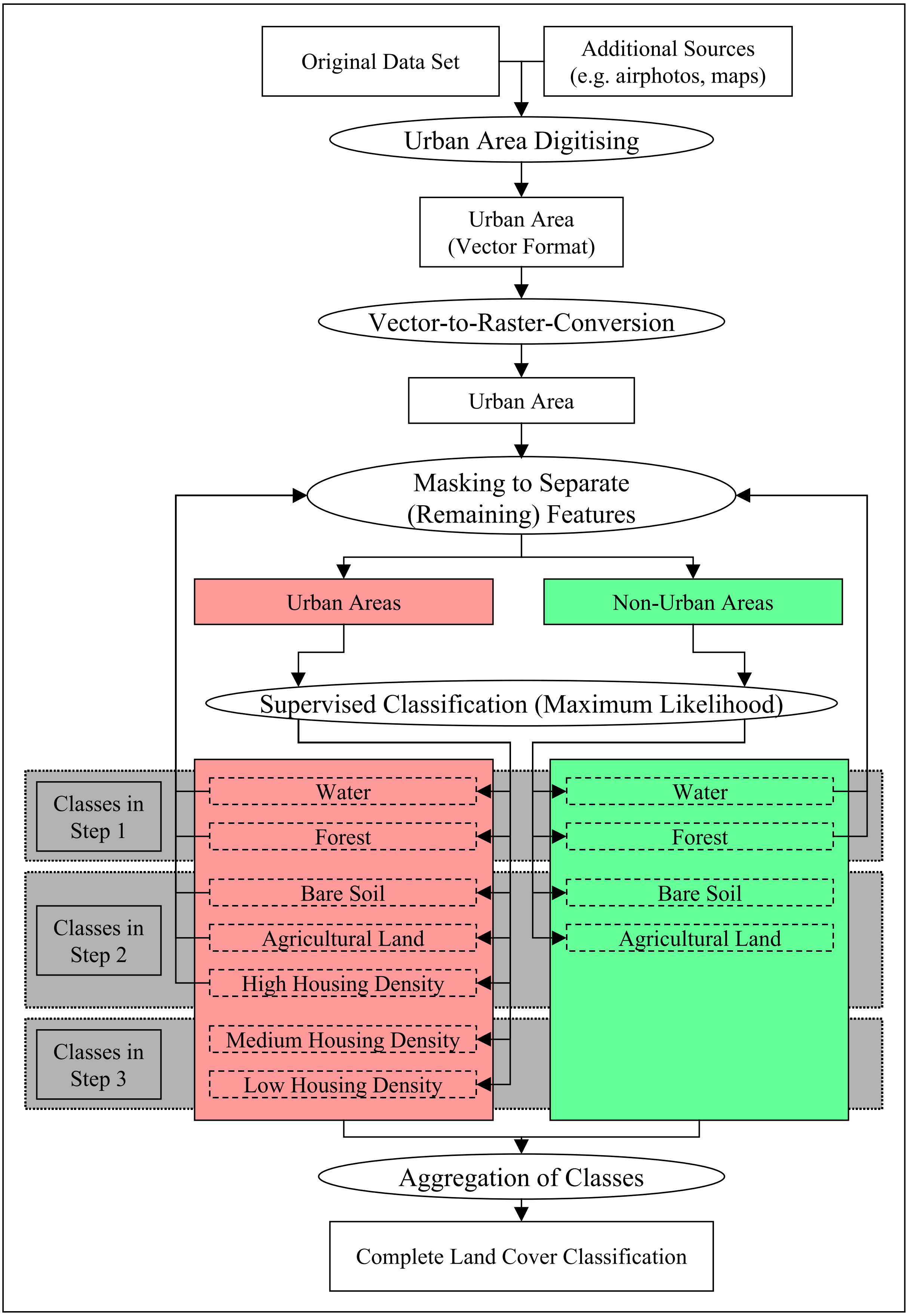


Figure 10: Classification steps.

Object Classes

Important rules for the establishment of groups or classes are described by ANTROP & SNACKEN (1999, p. 127):

- "the number of groups must be reasonably small to allow a synoptic view
- the differences between the groups should be maximal
- the differences between individuals within one group should be minimal".

In any supervised classification process classes are established according to their spectral separability in two-dimensional space. With the aid of a feature space image using band 4 (NIR) and 3 (red) seven different classes were established as follows.
"Water" and "forests" are most easily separated in a first step. All "agricultural land" is combined in one class due to phenological inseparability of pastures and plots of different crops (HEINZ 1999; MEINEL ET AL. 1997). The "bare soil" class comprises poorly vegetated areas (e.g. vegetation on sandy soils), construction sites and large open pit mining areas. With varying intensities of housing density three different urban land cover types were differentiated including "high housing density", "moderate housing density", and "low housing density". It must be noted that these classes do not reveal information about a specific use, i.e. residential, but are rather concerned with different degrees of surface sealing or the amount of vegetation respectively. In the first, inner city areas, industrial and traffic sites as well as 19^{th} century housing with a low degree of vegetation are aggregated. Pre-fabricated housing estates, as excluded by HEINZ (1999) in a separate class, are spectrally not separable. Thus, the second density group comprises core areas of towns and villages and pre-fabricated housing estates. The least dense are "green residential districts" such as allotment areas, villas, owner-occupied housing and other solitary houses in rural areas. The latter two of these categories showed manifold overlaps between either class. These findings are confirmed by MORISETTE & KHORRAM (1996) who state that large scale developed areas such as industrial sites or shopping malls can be reliably determined, whereas the separation of low to moderate housing density remains difficult.
In this study the categories "water" and "forest" could be easily differentiated with the help of a supervised classification in a preliminary step. Thereafter, "agricultural land" (also named "farmland"), "bare soil" and "high housing density" were determined in the training stage. The remaining two density classes had to be separated in a final step.

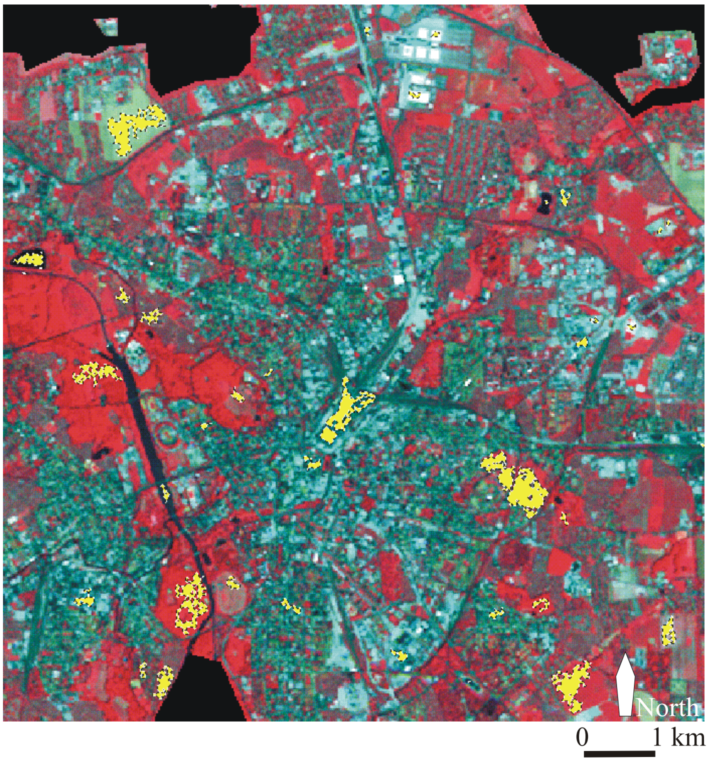
Definition of Training Areas

Training areas are representative samples of a certain cover type. It is essential to choose homogeneous areas to avoid mixed pixel that contain a mixture of various surfaces. This is due to the low spatial resolution of the detector (HILDEBRANDT 1996; KREMSA 1999, p. 94; VERBYLA 1995, p. 57). According to VERBYLA (1995) the establishment of training fields can be achieved by map digitising, on-screen digitising, and a seed-pixel approach.

The first method requires rectified airphotos to digitise training areas. For the second approach boundaries can be drawn manually, but this can result in an inclusion of isolated dispersed pixel of different categories. Finally, a seed pixel approach based on statistical criteria can be applied which was preferred in this study. For homogeneous areas, such as “water”, “forest” and “farmland” the Euclidean distance was set to eight, resulting in training areas that comprise more than 100 pixel. In contrast, a mathematical distance of 15 was chosen for all density classes and the class “bare soil” to allow for training areas to contain at least 25 pixel. One representative starting pixel was chosen for a further delineation of the training field. Subsequently, additional pixel of similar spectral reflectance in the neighbourhood were included into the field, whereas those that were not similar became rejected. The neighbourhood was formed by eight neighbouring pixel which completely surrounded the seed pixel.

According to LILLESAND & KIEFER (2000) at least 100 or more training areas are needed to reflect the spectral variability in an image. HILDEBRANDT (1996) suggests to find training areas with a minimum size of 50 pixel for heterogeneous fields and 100 for homogeneous areas. “Generally speaking, it is preferable to find 20 training areas per class with only few pixel distributed all over the image rather than a single training field with 1000 pixel” (LILLESAND & KIEFER 2000). This latter approach was adapted in order to include sparely distributed features like linear rivers and other waterways, and to allow for a separation of urban density classes. The training sites were distributed all over the images as exemplified for the scene of 2000 (see Figure 11 and Figure 12).

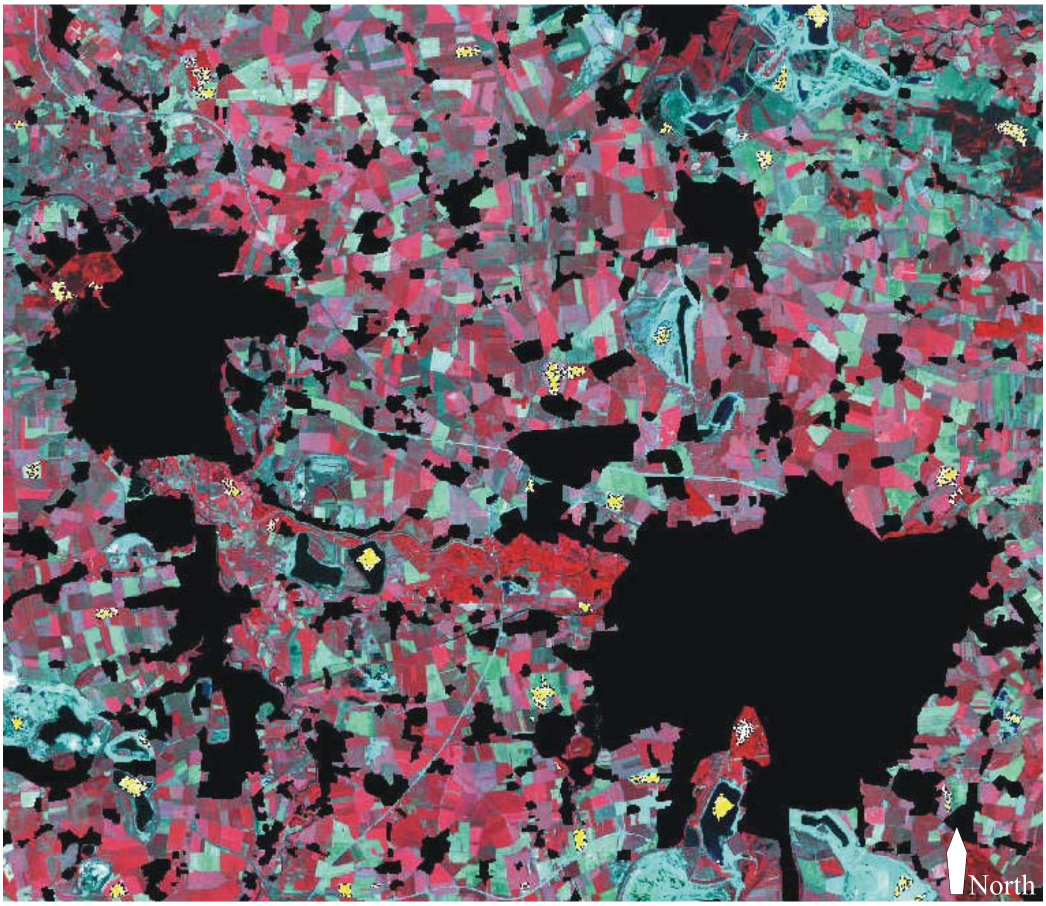
a) Training areas (yellow) in the centre of Halle. 1:1000



b) Training areas (yellow) in the centre of Leipzig. 1:1000

Background image: image 2000 (bands 4-3-2)
Black areas: non-urban mask

Figure 11: Distribution of training areas in the urban cores of Halle and Leipzig.



0 5 km
1:5000

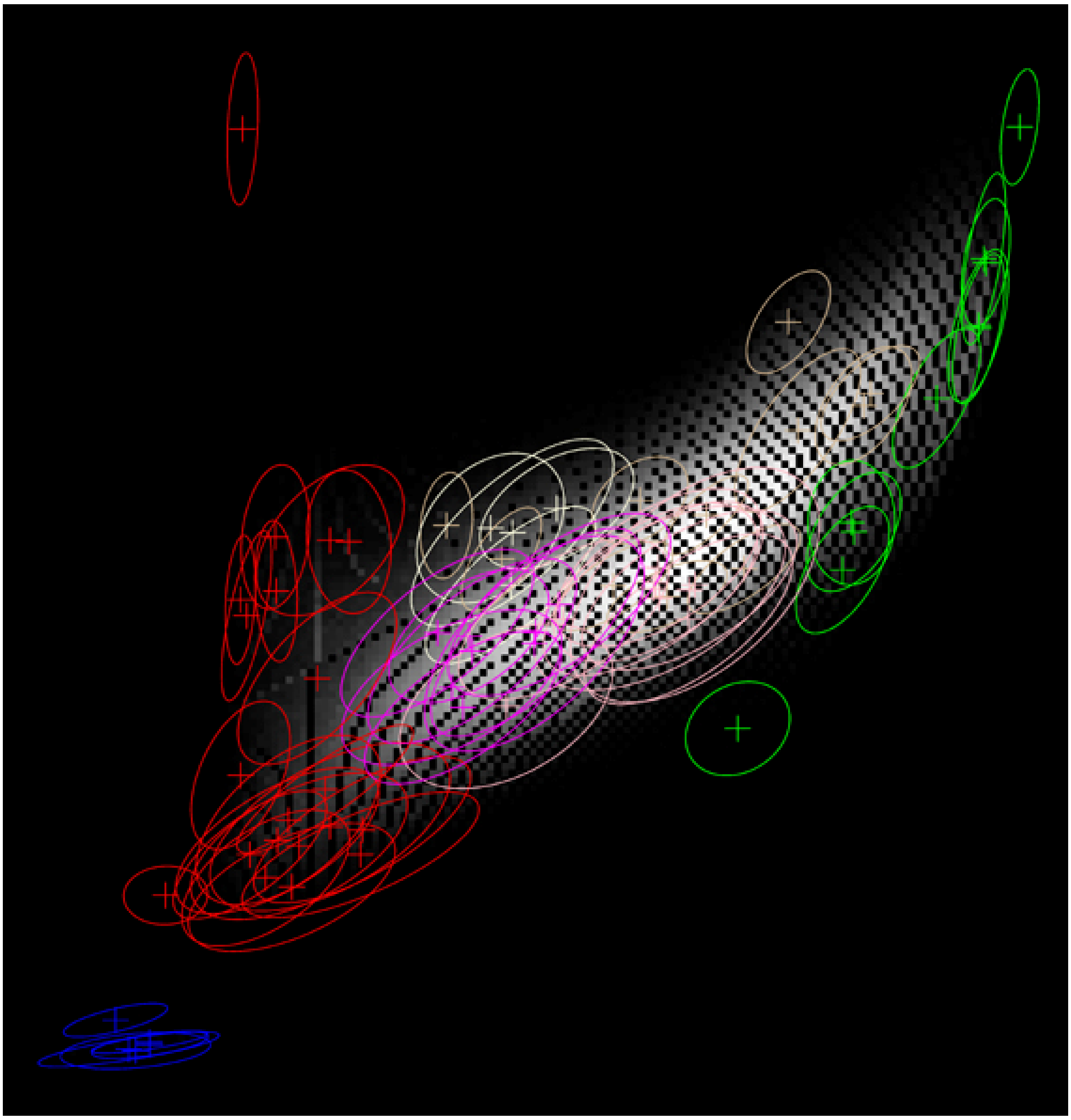
Training areas (yellow) in the countryside of Leipzig and Halle.

Background image: image 2000 (bands 4-3-2)
Black areas: urban mask

Figure 12: Distribution of training areas in non-urban areas.

Signature Analysis

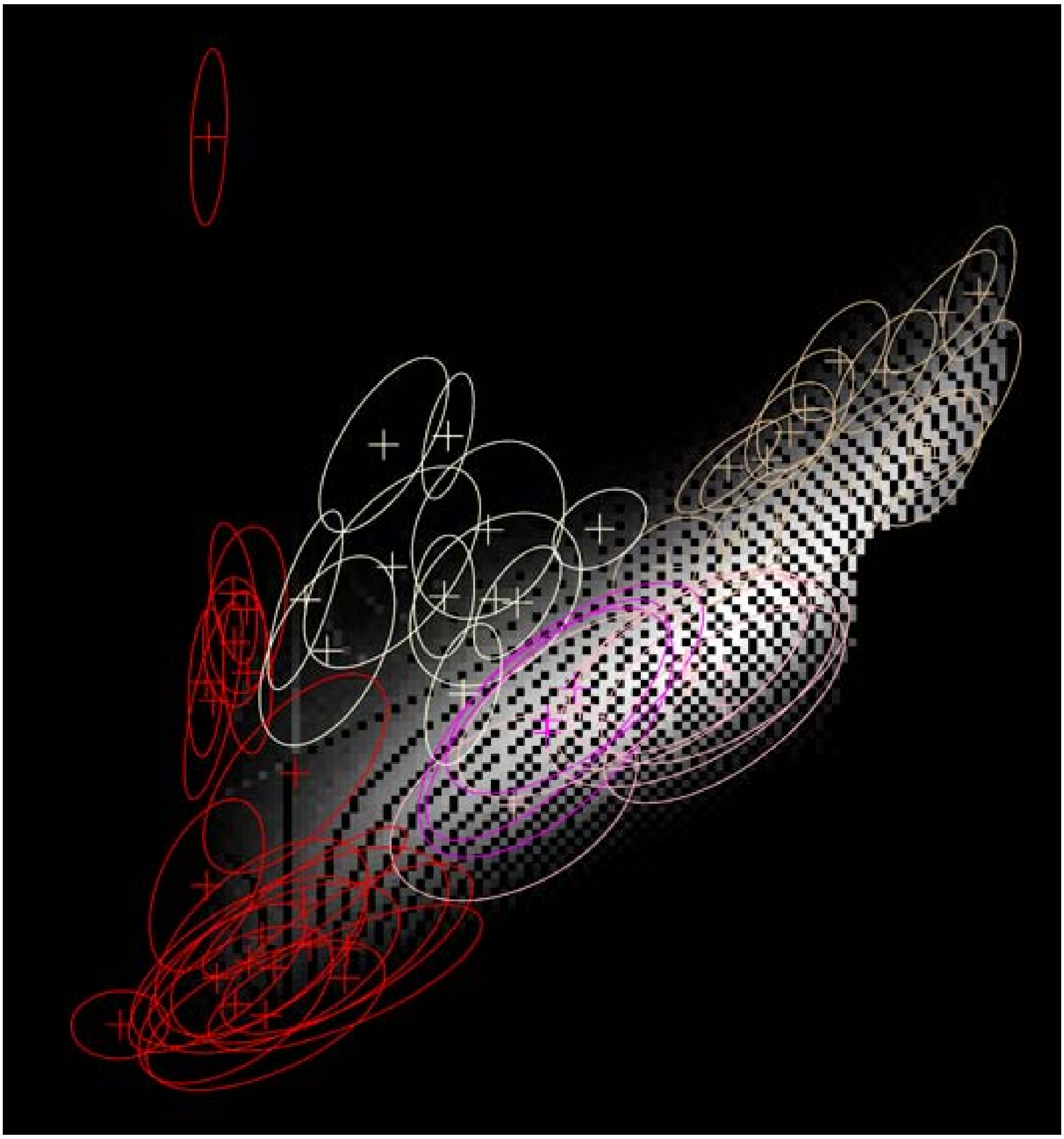
The overall quality of the classification is determined by the quality of training areas. Substantial reference data and a thorough geographic knowledge are prerequisites of the training stage. A signature analysis, also referred to as training set refinement, aims at assessing the radiometric separability of classes. Training sets containing other spectral classes can be identified and recompiled, and extraneous pixel can be excluded. Graphical representations such as histograms, spectral plots or scatter diagrams reveal overlaps between different categories (Albertz 1991; Lillesand & Kiefer 2000). Scatterplots or feature space images (band three and four) were favoured for this investigation with a threefold standard deviation. Because reflectance characteristics of both scenes were similar an example was chosen of the urban area in the year 2000 (see Figure 13 to 15).



Legend: Blue: Water; Green: Forest; Red: High density housing; White: Bare soil; Brown: Farmland; Purple: Medium housing density; Rose: Low housing density

Figure 13: Scatterplot of training areas for all classes of urban areas in 2000.

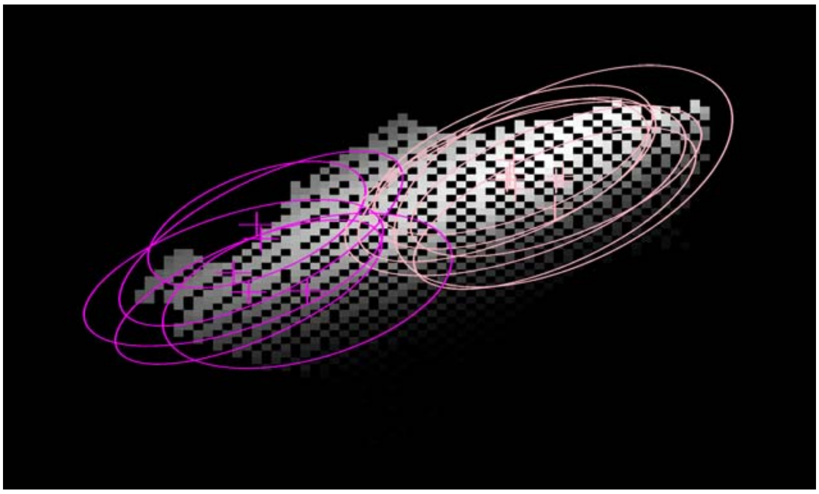
Obviously, many overlaps prevail in the centre of the image for the categories “medium housing density”, “low housing density”, “bare soil” and “agricultural land”. Thus, in a first step “water” and “forest” could be classified by supervised classification because no overlaps with other classes are apparent.



Legend: Red: High density housing; White: Bare soil; Brown: Farmland; Purple: Medium housing density; Rose: Low housing density

Figure 14: Scatterplot of training areas for selected classes of urban areas in 2000.

Secondly, “high housing density”, “bare soil” and “agricultural land” were classified in the next hierarchical step. The remaining two classes “medium housing density” and “low housing density” were still intensively intermingled. These were separated with the aid of Figure 15 in a final step.



Legend: Purple: Medium housing density; Rose: Low housing density

Figure 15: Scatterplot of training areas for the classes „low density housing“ and „medium density housing“.

Classifiers

After the training stage each pixel of the whole image can be classified according to its similarity to the spectral values of the training fields using a classification algorithm. Popular simple classifiers in widespread use are: minimum distance classifier, parallelepiped classifier, and maximum likelihood classifier (ML).

The frequently applied ML-algorithm was performed in this investigation to separate the classes from each other. Even though more computational effort is necessary, HILDEBRANDT (1996) states that the overall classification result using this algorithm is generally better. It is termed Gaussian ML-classifier, if a Gaussian distribution around the classes´ averages is considered. Mathematically means and covariance values for all digital numbers (DNs) are processed to obtain statistical probabilities for each pixel. A DN is then classified to one object class according to the highest probability values.

Having aggregated all classes further classification improvements must be applied to the obtained results.

6.3.2. Post-classification Smoothing

The salt-and-pepper appearance of any classified image can be smoothed using different filter techniques (GARCIA-RENDON 1999, p. 118; LILLESAND & KIEFER 2000, p. 566). In ERDAS Imagine a contiguity analysis can be performed to find groups of contiguous pixels of the same class. These are referred to as raster regions or clumps (ERDAS 1999, p. 397). Very small clumps do not only blur the overall output of the classification, but even spoil the generation of landscape metrics as stated by HUNSAKER ET AL. (1994, p. 216). Shape indices would be strongly influenced by the spatial resolution of solitary pixel and not by the complexity of a patch. Here, all clumps smaller than the user-defined minimum of five pixel have been replaced by values of surrounding larger clumps in an iterative process. Eight neighbours were considered in this process to gain the results on the following pages (Figure 16 and Figure 17).

Figure 16: Classification 1992.

Figure 17: Classification 2000.

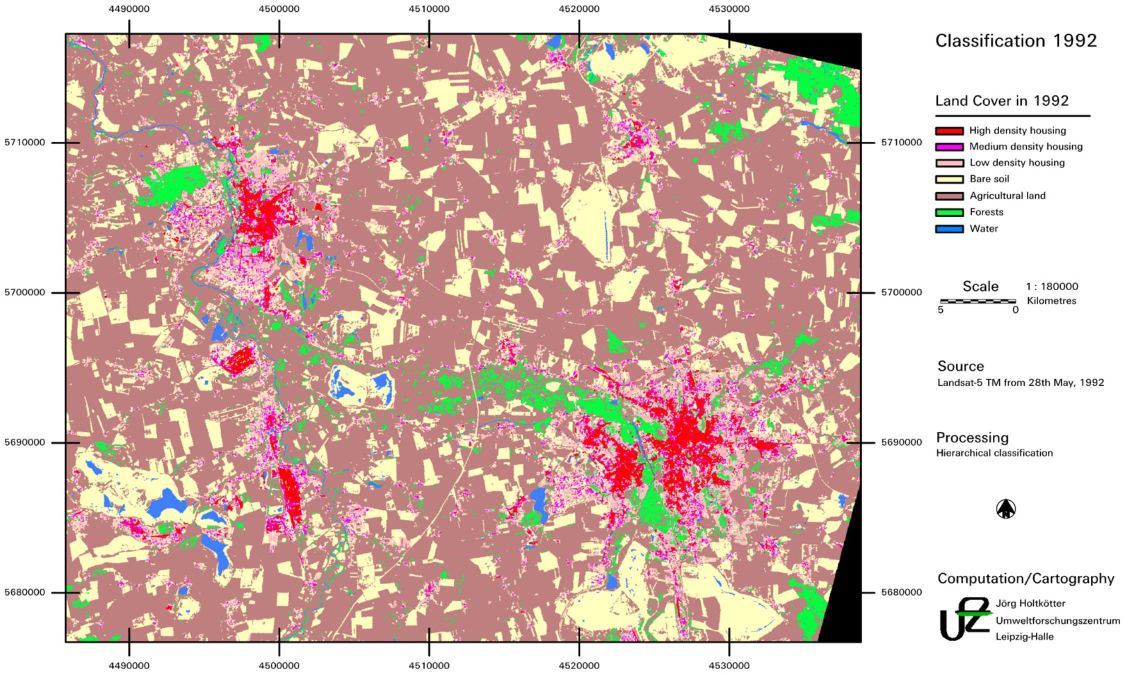
6.3.3. Quality of Results

The accuracy assessment aims at determining the degree of confidence of the classified data.

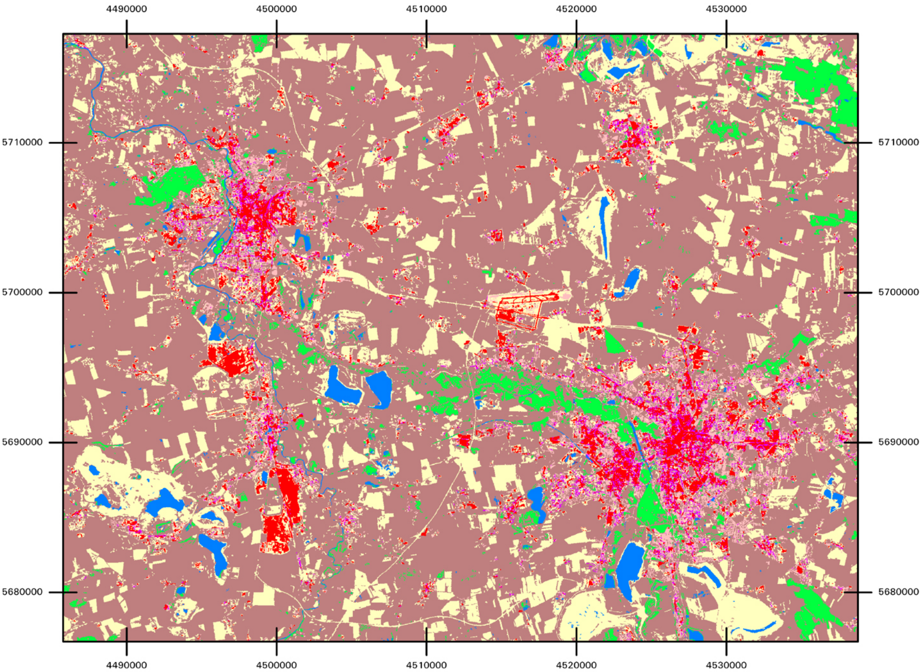
Accuracy Assessment

A couple of techniques to quantitatively assess separability of training areas are in use. Firstly, ERDAS Imagine software provides a separability listing containing two divergence measures, transformed divergence and Jeffries-Matusita distance. For all pairs of classes the statistical separability is compiled and expressed in a matrix. Transformed divergence (TD) is a “covariance-weighed distance between the category means” (ERDAS 1999, p. 239; LILLESAND & KIEFER 2000). Jeffries-Matusita distance (JM) can be similarly interpreted as TD. “However, it is not as computationally efficient as TD” (JENSEN 1996, cited in ERDAS 1999, p. 239; LILLESAND & KIEFER 2000).

Next pages – Figures 16 and 17: Classifications of 1992 and 2000.



Classification 1992
Land Cover in 1992
High density housing
Medium density housing
Low density housing
Bare soil
Agricultural land
Forests
Water
Scale
1 : 180000
Kilometres
5
0
Source
Landsat-5 TM from 28th May, 1992
Processing
Hierarchical classification
Computation/Cartography
Jörg Holtkötter
Umweltforschungszentrum
Leipzig-Halle
4490000
4500000
4510000
4520000
4530000
5710000
5700000
5690000
5680000



Classification 2000

Land Cover in 2000

- High density housing
- Medium density housing
- Low density housing
- Bare soil
- Agricultural land
- Forests
- Water

Scale 1 : 180000

5 0 Kilometres

Source

Landsat-7 ETM+ from 19th June, 2000

Processing

Hierarchical classification

Computation/Cartography

Jörg Holtkötter
Umweltforschungszentrum
Leipzig-Halle

Transformed divergence has a maximum value of 2000, JM only reaches a value of 1440. These values represent the greatest statistical distance between two classes. High values increase the probability of correct classification, values near zero indicate a lack of absolute separability. Subsequently, all generated TD- and JM-values were interactively compared with each other.
Secondly, and more important, is the sampling of test areas, i.e. representative, uniform land cover chosen in the neighbourhood of training sites. This process finally delivers an error matrix and overall accuracy values. Random sampling has the disadvantage of small classes possibly being underrepresented. Stratified random sampling can be a segmentation of the thematic map into a grid or, more appropriately, into every category. In this study stratified random sampling was applied with a search count of 1024 and a minimum of 12 samples per class to obtain classification accuracies ranging from 80 to 90% as recommended by RICHARDS & JIA (1999). Based on seven land cover classes 100 samples per image were obtained (50 are suggested by LILLESAND & KIEFER 2000).
The selection of samples from the thematic map can be verified by ground truth data, i.e. data gathered during field visits. Since these were only partly available, other reference data came into use (see chapter 3). With the results of this analysis being expressed in tabular form, the percentage of pixel erroneously addressed into every other class can be examined. This table is referred to as error matrix or, alternatively, confusion matrix or contingency table (LILLESAND & KIEFER 2000, p. 568; RICHARDS & JIA 1999, p. 266). The average of all correctly classified pixel is commonly named overall classification accuracy. Errors of omission or vertical errors are the result of those pixel from other classes that the classifier has failed to recognise (exclusion). They account for the producer´s accuracy value, whereas errors of commission correspond to pixel from other classes that the classifier has labelled as belonging to the class of interest (inclusion). These are expressed in the user´s accuracy value (RICHARDS & JIA 1999, p. 266).

Evaluation of Results

The ERDAS Imagine separability listing was used as a broad guideline to find errors in the classification. In the following text values of the year 2000 are put in brackets.

The results of the contingency analysis show that the overall accuracies of the classification of both images exceed 85% (Table 4). This value is sufficient compared to the studies of LAUSCH (2000) and WALZ (2001). Referring to Table 5 and Table 6 the erroneously addressed pixel can be determined.

Table 4: Accuracy totals and Kappa statistics.

	1992			2000		
Class Name	Producer´s accuracy [%]	User´s accuracy [%]	Kappa Statistics	Producer´s accuracy [%]	User´s accuracy [%]	Kappa Statistics
High density housing	85,71	100,00	1,00	58,82	83,33	0,80
Medium density housing	78,57	91,67	0,90	90,00	75,00	0,72
Low density housing	88,89	66,67	0,63	83,33	83,33	0,81
Bare soil	77,78	58,33	0,54	83,33	83,33	0,81
Agricultural land	76,92	76,92	0,73	78,57	84,62	0,82
Forests	100,00	100,00	1,00	100,00	73,33	0,70
Water	100,00	91,67	0,91	100,00	100,00	1,00

A producer´s accuracy of 85% in 1992 (<60% in 2000) for the class "high housing density" indicates that 85% of these areas have been correctly classified. On the other hand, 100% (83% in 2000) user´s accuracy means that more than 80% of all areas identified as "high housing density" actually belong to that category (LILLESAND & KIEFER 2000, p. 572; RICHARDS & JIA 1999, p. 266). The other density classes ("medium and low density housing") show lower values of more than 66% (75% in 2000) concerning the user´s accuracy, and values span to more than 90% with regard to the producer´s accuracy. Misclassifications between the two classes are due to similar spectral reflectance characteristics because an increasing proportion of vegetation is included in both of them. With regard to the error matrices (Table 5 and Table 6) the density classes are intermingled to a certain extent. In both years some of the pixel that should have been classified to a certain class were assigned to one of the other density categories.

The results of the class "agricultural land" were fairly good with a percentage of more than 75% for both accuracy types in 1992 (almost 80% producer´s accuracy and 85% user accuracy respectively). These can be compared to the values of the class "bare soil" which are quite similar besides a very poor user´s accuracy of <60% in 1992. Misclassifications between these two classes are common depending on the greenness of the vegetation cover. Hence, they are dependent on the phenological development in both scenes.

Good results were achieved for the classes "water", and "forest". Values range from more than 90% to 100% for both accuracy types and both years. Even though, in 2000 some of the forests were found to be classified to the classes "agricultural land" and "bare soil".

Table 5: Error matrix 2000.

	Training set data						
Classified data	HD	MD	LD	BS	AL	F	W
High density housing (HD)	10	1	1	0	0	0	0
Medium density housing (MD)	2	9	1	0	0	0	0
Low density housing (LD)	2	0	10	0	0	0	0
Bare soil (BS)	1	0	0	10	1	0	0
Agricultural land (AL)	1	0	0	1	11	0	0
Forest (F)	1	0	0	1	2	11	0
Water (W)	0	0	0	0	0	0	12

Table 6: Error matrix 1992.

	Training set data						
Classified data	HD	MD	LD	BS	AL	F	W
High density housing (HD)	12	0	0	0	0	0	0
Medium density housing (MD)	1	11	0	0	0	0	0
Low density housing (LD)	0	3	8	0	1	0	0
Bare soil (BS)	0	0	0	7	2	0	3
Agricultural land (AL)	1	0	0	2	10	0	0
Forest (F)	0	0	0	0	0	15	0
Water (W)	0	0	1	0	0	0	11

6.4. Change Detection Analysis

6.4.1. General Setting

Multitemporal image processing aims at finding differences between at least two images taken at two different times. This process is called change detection. MAS (1999) and SINGH (1989) provide a list of different techniques, including image differencing, image regression, image ratioing, vegetation index differencing, principal component analysis, and post-classification comparison.

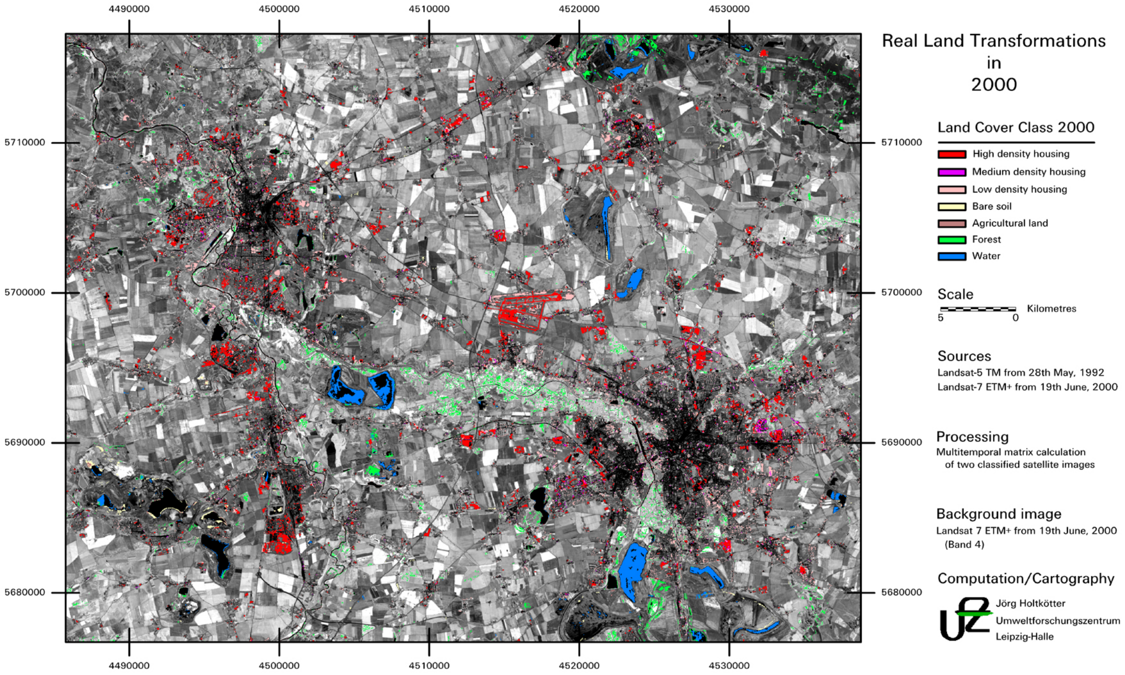
The latter approach is based on separately classified and rectified images. It has got the advantage that, in contrast to all the other techniques, no atmospheric correction must be carried through. The accuracy achieved depends on the accuracy of the independent classifications. Here, maps with different classifications were overlain to show changes in every direction, i.e. demonstrate which class undergoes what kind of transformation (GARCIA-RENDON 1999; MAS 1999; JÜRGENS 2000; LILLESAND & KIEFER 2000; SINGH 1989).

6.4.2. Results and Evaluation of the Change Detection Analysis

Statistically, the class “traffic” did not change over time because the traffic network stems from the 90s. Changes in the degree of urbanisation, i.e. surface sealing and fragmentation, can be visualised with the aid of Next page - Figure 18 (see next page). Transformations are mainly located in the urban fringe.

In January 1998 the airport Leipzig-Halle in Schkeuditz was extended north of the motorway A 14. The area under construction exceeded more than seven square kilometres (Flughafen Leipzig-Halle 16.01.02). Several commercial-industrial sites along the main motorways such as the modern Leipzig fair north of the city with more than 100 hectares (Leipziger Messe 27.09.01) and additional sites around Halle (Stadt Halle 27.09.01; Aeropark Oppin 27.09.01) must be mentioned, e.g. Halle-Oppin near the airfield (126 ha), Halle-Ost (120 ha), too. By means of airphoto interpretation all these areas were predominantly used for agricultural purposes or lay even derelict in 1992.

Next page - Figure 18: Real land transformation from 1992 to 2000.



Real Land Transformations in 2000
Land Cover Class 2000
High density housing
Medium density housing
Low density housing
Bare soil
Agricultural land
Forest
Water
Scale
5
0
Kilometres
Sources
Landsat-5 TM from 28th May, 1992
Landsat-7 ETM+ from 19th June, 2000
Processing
Multitemporal matrix calculation of two classified satellite images
Background image
Landsat 7 ETM+ from 19th June, 2000 (Band 4)
Computation/Cartography
Jörg Holtkötter
Umweltforschungszentrum
Leipzig-Halle
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Land transformation to “low and medium density housing” in 2000 are, if existent distributed in or in the surrounding of the cities. Some of the very densely sealed areas in 19th century housing districts have become refurbished and unsealed recently. The upgrading of urban districts is reflected in an increased amount of urban greenspaces in quarters such as Plagwitz, Reudnitz, and Stötteritz in Leipzig (GRUNDMANN 1996). One major building complex in the north-east of Leipzig was realised, comprising many multi-storeyed houses. Nevertheless, some of these changes are probably due to misclassifications, e.g. former agricultural plots were converted to extensive lawns alongside the new landing area of the extended airport.

Changes of the class “water” are mainly due to the infill of former lignite mines (class “bare soil” in 1992) in the area of interest. For example, lake Cospuden in the south-west of Leipzig was filled during the period of time under consideration to build a new leisure and water sports area. The extensive increase in number and size of artificial lakes led to a substantial decrease in derelict land.

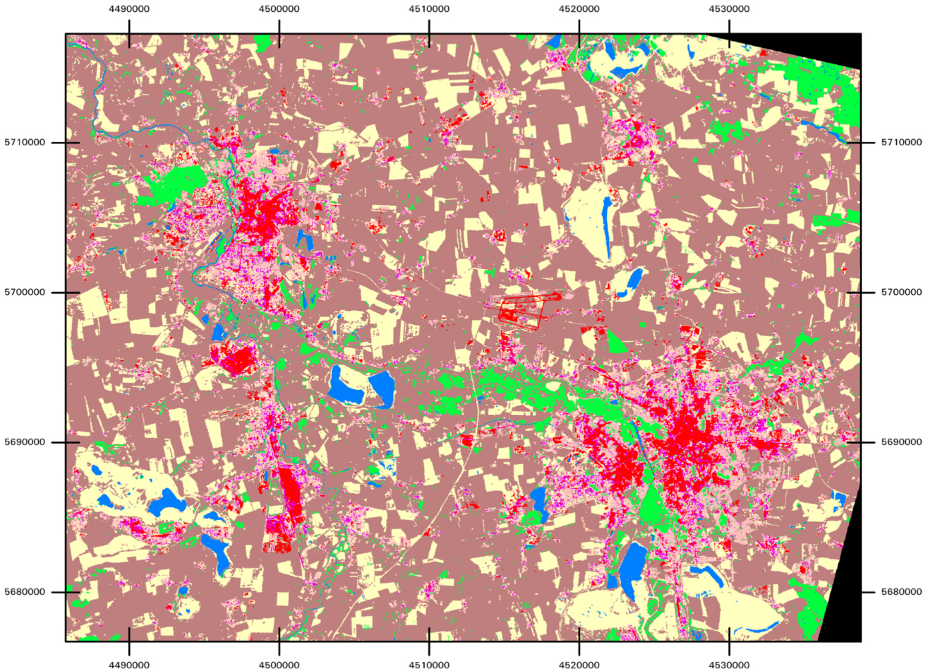
Other changes derived from the post-classification comparison are not long-lasting man-made modifications. Blurred results are partly due to RMS errors occurring during the geo-rectification and slightly different sensor characteristics. KREMSA (1999) states that real and apparent land use change must be differentiated. The latter is a result of phenological variations in biomass production of plants. These can be considered to be only short-term changes. According to STRUNZ & GÜLS (1999), “a correction of phenological influences in multi-temporal data is yet not possible”. Moreover, changes in crop cultivation must be taken into account. Though the overall accuracy was acceptable and the date of both satellite images is not very far apart, phenological variation and shifts in crop production certainly influenced the classification results. Especially the classes “agricultural land” and “bare soil” were affected, but also “forests”. These class changes needed to be verified separately using statistical data that lack spatial information. The statistics provided in the statistical yearbooks (see chapter 3) can confirm trends that are described with the aid of Figure 18. Thus, the correctness of transformation tendencies can only be proved with the aid of further information, e.g. maps and air photos.

The areal growth of forests in the agglomeration can be confirmed by statistics. Due to the very small proportion of forested area (see chapter 2) intensive reforestation programs were set up to increase the proportion of forests to at least 10% in the surrounding of Leipzig (Grüner-Ring-Leipzig 11.02.02). Main task is the development of a greenbelt, i.e. a network of greenspaces in the surrounding of the city of Leipzig. The changes within the flood plain woodlands appeared unusually high. Thus, true-colour and false-colour airphotos were applied to figure out the extent of change. In effect most of these alterations are apparently due to phenological changes.

Farmland percentages were very high before reunification. Since then losses evident in the matrix map could be statistically confirmed. The reason for the agricultural decline can be found in substantial changes in agricultural entrepreneurship. To avoid surplus production official programs started to fund the reforestation of agricultural plots. More importantly, reduced demand for farmland products led to a severe increase in fallow land. Thus, the classes "bare soil" and "forests" took advantage of the shrinkage of agricultural land. Another reason are the above mentioned suburbanisation processes which are severe in the whole agglomeration. In fact BREUSTE (1995) calculated land transformations due to retail, commercial-industrial and residential suburbanisation to be as large as 16.000 ha only for the city of Leipzig.

Most of the changes to either of the two classes "farmland" and "bare soil" are due to phenological variations and shifts in crop cultivation. This was ascertained with the help of airphotos. These particular alterations from one type to the other are not suitable for a monitoring and a calculation of landscape metrics. Therefore, LAUSCH (2000, p.80) recommends the generation of synthetic images for a monitoring with landscape indices. The changes in Next page - Figure 18 were draped over the image of 1992 to obtain a synthetic map for 2000 (see Figure 19). Then, an insertion of linear features is necessary to derive landscape indices of the synthetic map and the original classification of 1992.

Next page - Figure 19: Synthetic map.



Synthetic map

Land Cover

- High density housing
- Medium density housing
- Low density housing
- Bare soil
- Agricultural land
- Forests
- Water

Scale 1 : 180000
Kilometres
5 0

Source

Landsat-5 TM from 28th May, 1992
Landsat-7 ETM+ from 19th June, 2000

Processing

Synthesis of land covers derived from mono-temporal classifications

Computation/Cartography

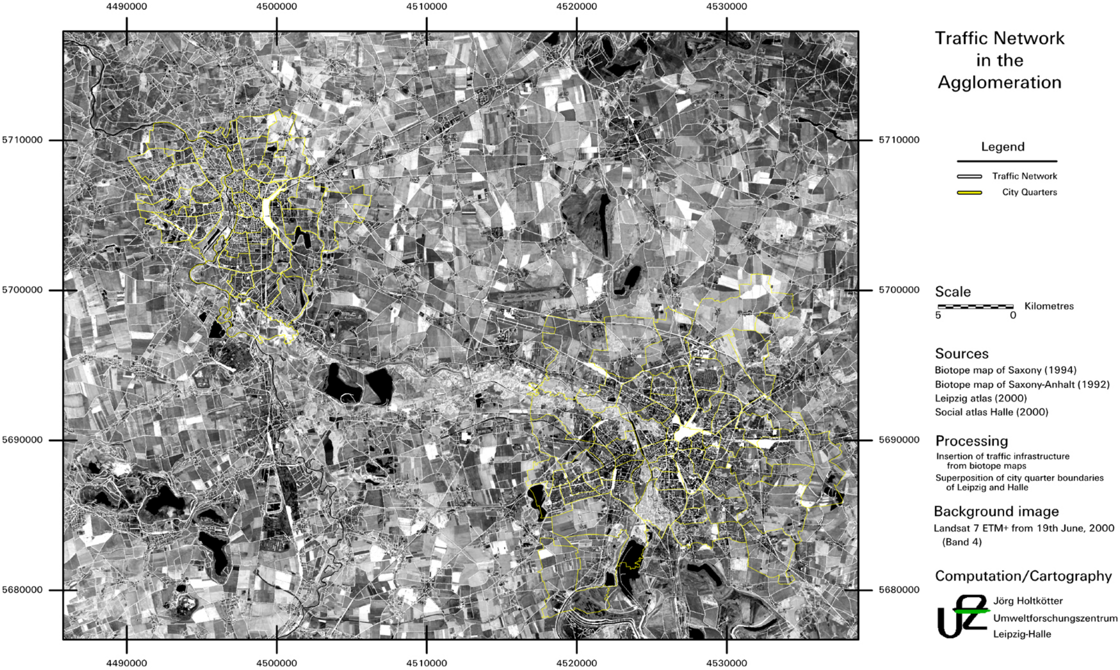
Jörg Holtkötter
Umweltforschungszentrum
Leipzig-Halle

6.5. Linear Structures

As stated by ANTROP & VAN EETVELDE (2000) an overlay of transportation infrastructure enhances the result of the supervised classification. In fact, the traffic network is a very important feature to derive landscape patterns and the degree of habitat fragmentation and connectivity. The mixed pixel problem results in an under-representation of linear features such as roads and railway tracks. Some of these can be represented in the image, if they are large (e.g. motorways), but most of them remain invisible to the sensor due to its low spatial resolution. The mathematical theorem requires a minimum extent of linear features of twice the diagonal length of one pixel (HABERÄCKER 1987, cited in LAUSCH 2000, p. 60). According to LAUSCH & MENZ (1999), the road and rail net must be implemented into the classified data set to allow for a proper measurement of landscape fragmentation.

Hence, the biotope maps of Saxony and Saxony-Anhalt were utilised for the selection of the roads and railway tracks in ArcInfo. These data were transformed to the same grid size than the classified image and could then be draped over it. Two drawbacks have to be mentioned in context with this layer. Firstly, the data is not up-to-date because the biotope maps stem from the early 90s. Secondly, the vector-to-raster conversion of the vector data results in an over-representation of linear structures in the matrix (Figure 20).

Next page - Figure 20: Traffic network selected from biotope maps.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5690000
5680000
Traffic Network in the Agglomeration
Legend
Traffic Network
City Quarters
Scale
Kilometres
5
0
Sources
Biotope map of Saxony (1994)
Biotope map of Saxony-Anhalt (1992)
Leipzig atlas (2000)
Social atlas Halle (2000)
Processing
Insertion of traffic infrastructure from biotope maps
Superposition of city quarter boundaries of Leipzig and Halle
Background image
Landsat 7 ETM+ from 19th June, 2000 (Band 4)
Computation/Cartography
Jörg Holtkötter
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7. Spatial Pattern Indices

7.1. Parameters of the Model

Basis for the quantitative analysis of the landscape Leipzig-Halle are the digital maps which processing is explained in chapter 4. The calculation of metrics was mainly carried through with the aid of FRAGSTATS software (version 2.0 by MCGARIGAL & MARKS 1994). The following model parameters were implemented into the programme for the compilation of landscape indexes (Table 7):

Table 7: Model parameter of FRAGSTATS.

Parameter	**Agglomeration Leipzig-Halle**
Data format	Raster format
Pixel size	25 m^2
Definition of the smallest patch	Besides vertically and horizontally neighbouring pixel also diagonal pixel are included into a patch
Search count for proximity distance	100 m
Maximum number of classes	Eight land cover classes including the integrated traffic network

7.2. Spatial Extent and Grain of Landscape Metrics

Scaling factors, i.e. extent and grain, are of primary concern in RS and quantitative landscape analysis (GUSTAFSON 1998; O´NEILL ET AL. 1996; TURNER ET AL. 1989; TURNER ET AL. 2001). Extent is referred to as the size of an area under investigation. In contrast, grain means the spatial resolution of the data, i.e. the pixel size. The pixel size is constant within this investigation, only the extent changes from broad, i.e. the whole agglomeration, to fine, as for the city quarters. The grain must be considered crucial in determining which feature becomes visualised and which feature will be lost during the classification stage (see mixed pixel problem in chapter 4).

In the past, the FRAGSTATS software package was only applicable for rather small scale investigations. A segmentation of landscapes with large extent into small pieces was inevitable. Most recently, an AML-file (ARC Macro Language) and a batch-file were created in order to automate the computation of landscape indices for many small subsets within a large area (WALZ 2001). The AML-file aided in a computerised segmentation of the whole area, whereas the batch-file was necessary to subsequently compile landscape metrics for each of these smaller subsets.

Generally speaking, it is either possible to generate regular-shaped grids with a rectangular form, or to use administrative and/or natural boundaries as a subset. An advantage of the former lies in the possibility to compare absolute landscape metrics because FROHN (1998) found that some indices are highly sensitive to arbitrary sampling geometries. Thus, in the second case, a comparison of indexes is not allowed.

Based on studies of HULSHOFF (1995) and HUNSAKER ET AL. (1994), a lattice of gridsquares was generated with ArcInfo with a grid size of 500*500 m^2 and northward orientation. This grid size in vector format was chosen because investigations on breeding birds in the region will be carried through in future. The resulting zone file, comprising 7696 labelled quadrates, was superposed on the final maps. After clipping the area of interest with this zone file, for each of the gridcells landscape indices were automatically generated with the batch file.

Nevertheless, for synoptic comparisons on the landscape level of both cities and their surrounding hinterland as well as on the variability of metrics within the city quarters the irregular-shaped, vector-based city quarter boundaries of Halle and Leipzig were draped over the final grid. By this method, values of different indices were related to to both cities. The internal city quarter boundaries divide some of the quadrates, i.e. in some cases one cell is shared by three and more adjacent quarters (see Figure 21). For statistic purposes it is necessary to define which landscape index belongs to which city quarter (or city), i.e. each square had to be allocated to one certain quarter (or city). Using the summary function in ERDAS Imagine simple statistics could be calculated, including the amount of different classes per square and the majority count. Based on a pixel size of 25 m^2 every quadrate in the zone file contains 400 pixel. With the majority count function it was possible to assign each square to a specific city quarter. Further explanations focus on the example of the allocation of landscape metrics to city quarters.

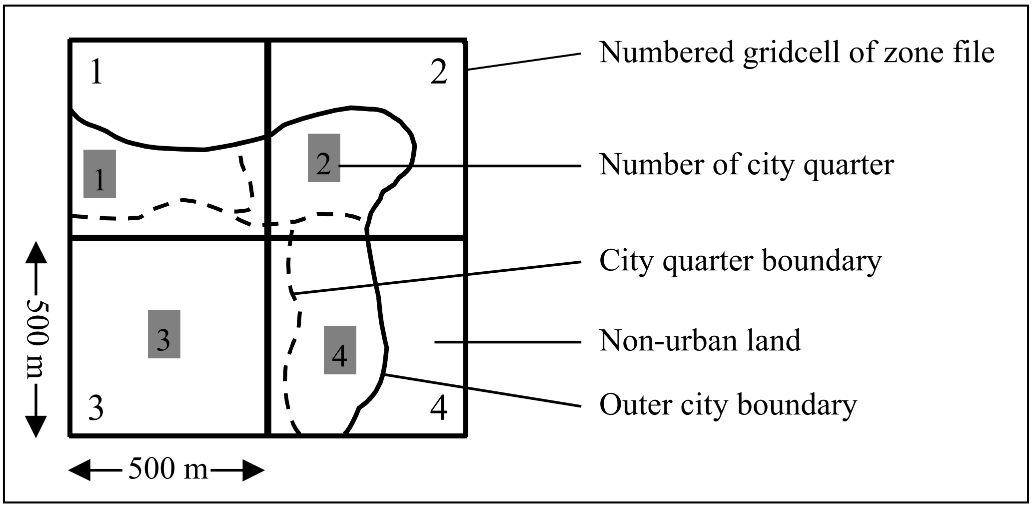


Figure 21: Division of one square/quadrate by linear boundaries.

In the example chosen in Figure 21, square one (large number in the corner of a square) comprises non-urban land and parts of three city quarters. Majority count results reveal that most of the pixel (25*25 m^2) belong to quarter one (small number with grey background in the middle of each quarter). Hence, the calculated landscape indices will be assigned to this quarter for statistical purposes. The city quarter number two in square two is significantly smaller than the background area. Even though the quadrate is allocated to this quarter, because the background value is ignored. The largest city quarter (number three) covers more than quadrate three. In this case the landscape indices can directly be assigned to it.

7.3. Definitions of Applied Landscape Indices

The majority of all publications on landscape indices is based on FRAGSTATS software. This software package, programmed by MCGARIGAL & MARKS (1994) in Oregon/USA, allows to analyse a landscape with the aid of numerous indices. A total of 94 indices can be compiled at three different levels as discussed in chapter 3.

Considerations about the relevance of the metrics for this investigation were necessary. These allowed a reduction on a few simple indices, though a redundancy of metrics could be helpful to prove results interdependently (RIITTERS ET AL. 1995; WALZ 2001).

In this study, nine FRAGSTATS metrics and one index derived with the integrated ERDAS Imagine summary function are used. In the following section indexes are explained with the aid of their mathematical algorithms. Depending on the hierarchy of interest (see chapter 2) the formulas are given either for class level (e.g. MPS_class) or landscape level (e.g. PR_land). Table 8 gives an overview of symbols and abbreviations used in the mathematical equations.

Table 8: Symbols and abbreviations of mathematical equations.

A =	Total landscape area (m^2)
a_{ij} =	Area of a p*atch* ij (m^2)
a_{ijs} =	Area of a p*atch* ijs (m^2) with a specific neighbourhood (m) of p*atch* ij
d_{ik}=	Weight factor of a p*atch* ik (dimensionless)
e_{ij} =	Total lengths of edges of a p*atch* ij (m)
E =	Total lengths of edges in the landscape (m)
E‘ =	Total lengths of edges in the landscape (m), including edges of the background without regard whether these are real edges
g_{ik} =	Number of boundaries between pixel and p*atch*type (class) i und k
h_{ij} =	Distance (m) of a p*atch* ij to the next neighbouring p*atch* of the same p*atch*type (class), based on an edge-to-edge distance
m =	Number of p*atch*types (classes) inherent in the landscape
N =	Total number of p*atches* in the landscape, excluding background p*atches*
N′=	Total number of p*atches* in the landscape with a neighbour of the same p*atch*type
n = n_i =	Amount of p*atches* in the landscape of p*atch*type (class) i
P_i =	Proportion of a pat*ch*type i (class) in the landscape
p_{ijk}=	Perimetre of a p*atch* ijk (m)
i = 1, ...,	m p*atch*types (classes)
j = 1, ...,	n p*atch*type
k = 1, ...,	m p*atch*types (classes)
s = 1, , n	*Patches* with a specific neighbourhood

7.3.1. Area Metrics

These quantify the configuration of all patches in the landscape.

Percent of Landscape (%LAND)

In absolute terms Class Area (CA) is used to evaluate the area in hectare for different classes. More appropriate for comparisons of different landscapes is %LAND which represents the percentage of the total landscape for a certain class as expressed by equation 5.1:

%LAND_class:

$$\%Land = P_1 = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100) \ [\%] \quad (5.1)$$

Patch Density (PD)

can be defined as the ratio of the number of patches of a class to the total number of patches in the study area (see formula 5.2):

PD_class:

$$PD = \frac{n_i}{A} * 10000 * 100 \ [\#/100 \text{ ha}]$$

PD_land:

$$PD = \frac{N}{A} * 10000 * 100 \ [\#/100 \text{ ha}] \quad (5.2)$$

Mean Patch Size (MPS)

refers to the average size of a patch and can be calculated as follows (5.3):

MPS_class:

$$MPS = \frac{\sum_{j=1}^{n} a_u}{n_i}\left(\frac{1}{10{,}000}\right) \ [\text{ha}]$$

MPS_land:

$$MPS = \frac{A}{N}\left(\frac{1}{10{,}000}\right) \ [\text{ha}] \quad (5.3)$$

Largest Patch Index (LPI)
The areal percentage of a certain class or the entire landscape by the largest landscape element can be expressed by means of algorithm 5.4:

LPI_class: LPI_land:

$$LPI = \frac{\max_{j=1}^{n}\left(a_{ij}\right)}{A}\left(100\right)\ [\%] \qquad LPI = \frac{\max_{j=1}^{n}\left(a_{ij}\right)}{A}\left(100\right)\ [\%] \qquad (5.4)$$

7.3.2. Edge Metrics

The increasing fragmentation due to human impacts on the landscape leads to a growth in patch number and edges being the boundaries of patches, respectively.

Edge Density (ED)
A simple measure would be the total edge length (TE) per class or per landscape. To allow for comparisons Edge Density (ED) values are generated with equation 5.5, giving a ratio of edge length and unit area (25 ha):

ED_class: ED_land:

$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}\left(10{,}000\right)\ [\text{m/ha}] \qquad ED = \frac{E}{A}\left(10{,}000\right)\ [\text{m/ha}] \qquad (5.5)$$

7.3.3. Shape Metrics

Rather natural environments show complex forms in comparison to artificial forms prevailing in surroundings affected by man. In the middle European landscape man-made lots of rectangular form affect remaining semi-natural ecosystems with irregular shape.

Landscape Shape Index (LSI)
is defined as the average perimeter-to-area-ratio for a certain class or for all patches in the landscape (5.6). A low value indicates a very compact form with small edge lengths, whereas higher values express more complex forms.

LSI_land:

$$LSI = \frac{0{,}25E'}{\sqrt{A}} \quad \text{[dim.]} \qquad (5.6)$$

7.3.4. Nearest-neighbour Metrics

These indices show the distance between the nearest edges of two patches of the same class in the landscape. This is ecologically relevant because it affects the dynamics of interrelations are affected. Species dispersal and migration are some important examples in this respect.

Mean Proximity Index (MPI)
measures the extent of isolation and fragmentation of the corresponding patch type. It takes into account the distance of all landscape elements within a class with reference to the applied search count (see Table 7) by dividing areal extent and the quadrate of distances. At the landscape scale the index is compiled by averaging the proximity index across all patches and patch types (formula 5.7):

MPI_class:

$$MPI = \frac{\sum_{j=1}^{n} \sum_{s=1}^{n} \frac{a_{ijs}}{h^2_{ijs}}}{n_i} \quad \text{[ha]}$$

MPI_land:

$$MPI = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{s=1}^{n} \frac{a_{ijs}}{h^2_{ijs}}}{n_i} \quad \text{[ha]} \qquad (5.7)$$

Mean Nearest-Neighbour Distance (MNN)
On class level, the average distance between the edges of two patches of one patch type is calculated with MNN. On landscape level however, only patches that actually have neighbouring patches of the same type are considered (5.8):

MNN_land:

$$MNN = \frac{\sum_{j=1}^{m} \sum_{j=1}^{n} h_{ij}}{n'i} \quad \text{[m]} \qquad (5.8)$$

7.3.5. Diversity Metrics

These measures are solely designed to quantify aspects of patch richness and patch evenness on a landscape level. Richness describes the amount of different patch types without regard to their spatial arrangement, whereas evenness refers to the distribution of patches in comparison to other patch types.

Absolute Patch Richness (PR)

The only metric calculated with ERDAS is absolute patch richness, meaning the number of cover types or classes present in a landscape (5.9):

PR_land:

$$PR = m \quad [\#] \qquad (5.9)$$

Shannon´s Evenness Index (SHEI)

quantifies the diversity of a landscape by measuring the distribution of an area among different patch types. Evenness is a ratio of observed diversity divided by the maximum possible diversity (5.10). If the evenness index is about zero, the landscape is dominated by a solitary patch type. As the evenness index approaches one, an almost perfect distribution of patch types is obtained.

SHEI_land:

$$SHEI = \frac{-\sum_{i=1}^{m}\left(P_i \circ \ln P_i\right)}{\ln m} \quad [\text{dim.}] \qquad (5.10)$$

8. Results and Discussion

All results are based on the regular grid approach as explained in chapter 5. Values for irregular-shaped city quarters and the two urban cores could be derived via database management with Microsoft Access and multivariate statistical analysis with Statistica for Windows. The assignment of a square to a polygon is displayed in Figure 21. Metrics were stored into ArcView GIS in order to demonstrate results spatially. Values on patch level were neglected in this investigation. Firstly, results on landscape level are presented, finally those for the classes. In the following chapter the order of landscape metrics stated in chapter 5 is going to be applied.

8.1. Results for the Cities Leipzig-Halle in Comparison to the Surrounding Countryside

8.1.1. Description of the Agglomeration Exemplified for the Year 2000 – Landscape Level

The extent of patch densities in the study area reveals that in urban cores values of above 80 prevail, in contrast to a rather rural surrounding with values of less than 40 patches per hectare (Figure 22). The maximum PD of more than 240 patches per hectare is located in the inner city of Halle. Obviously some of the grid cells in the hinterland are also characterised by higher PD values. This is true for smaller cities such as Merseburg in the south of Halle and Delitzsch north of Leipzig, as well as for other towns and villages dispersed all over the area of interest.

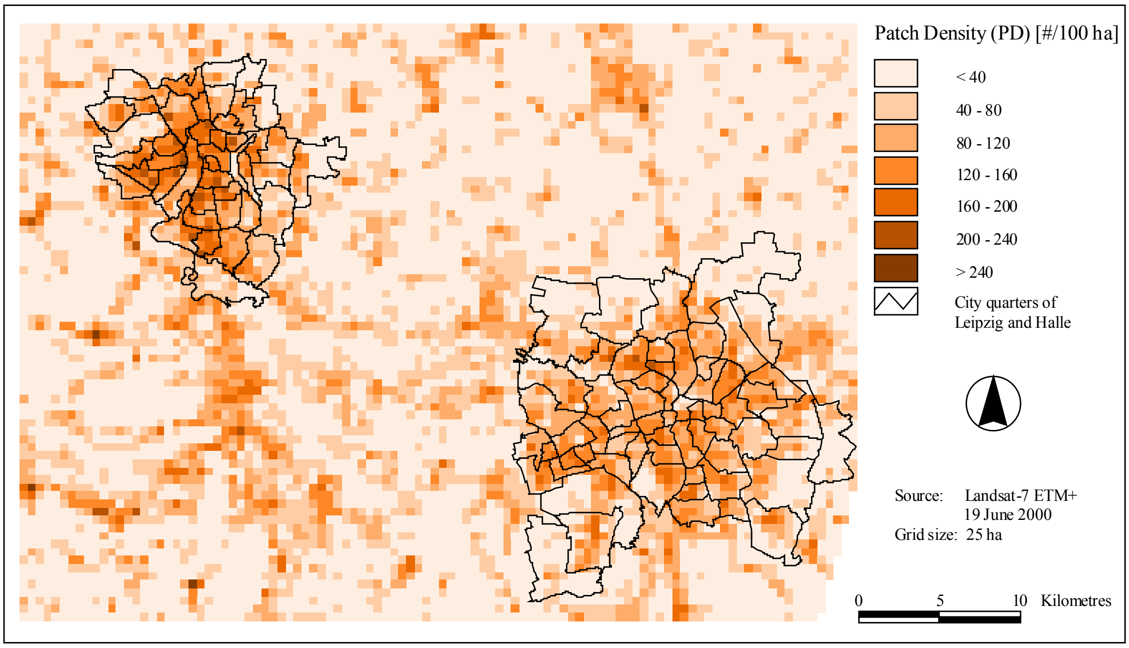


Figure 22: Grid-wide Patch Density–distribution.

The areal distribution of MPS values below 3,5 hectares is concentrated in the cities, whereas larger plots up to 21 ha and more can be found in the countryside (Figure 23). The latter are predominantly found in former lignite mines such as “Zwenkau” and “Espenhain” near Leipzig and “Breitenfeld” and “Delitzsch Südwest” in the south of Delitzsch. These areas are least fragmented by traffic routes.

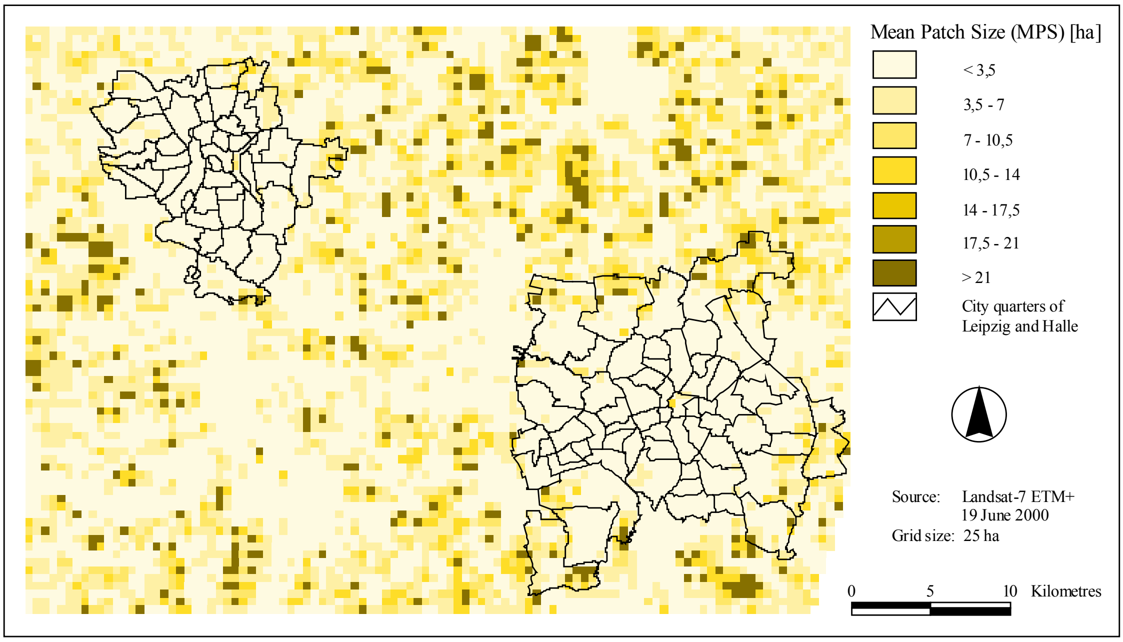


Figure 23: Grid-wide Mean Patch Size–distribution.

The areal LPI-distribution for 2000 is shown in Figure 24. In the urban areas LPI values are predominantly lower than 22%. The only exception are floodpain forests that separate the district of "Grünau" in Leipzig from the city core. In Halle this effect is less obvious and confined to the quarter "Planena". Values grower larger towards the outskirts and can reach more than 87% in rural areas, especially in large open pit mines or areas covered by water. This gradient from the countryside towards the city centres will be considered later in this chapter.

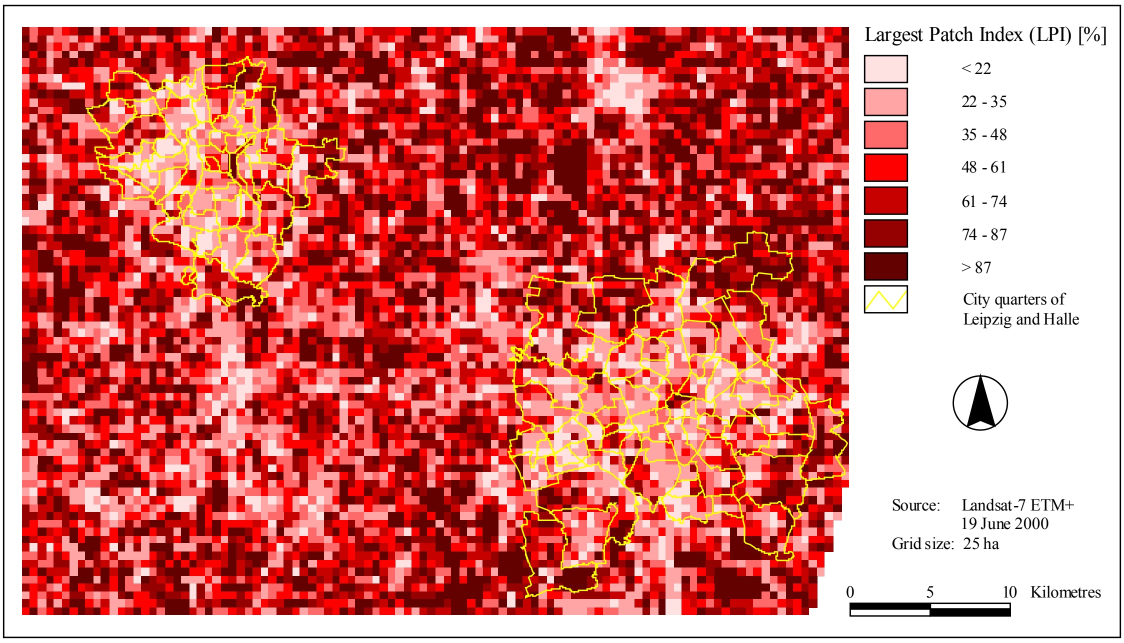


Figure 24: Grid-wide Largest Patch Index–distribution.

The total length of edges in the agglomeration can be demonstrated in Figure 25. Values of above 120 metres per hectare dominate in the cities. In the opposition, edge densities tend to decrease towards the periphery where values below 60 m/ha are common. Floodplain forests in the quarters of Leipzig "Connewitz", "Wahren", and "Leutzsch" exhibit very low ED values and seem to divide the city of Leipzig in two separate parts.

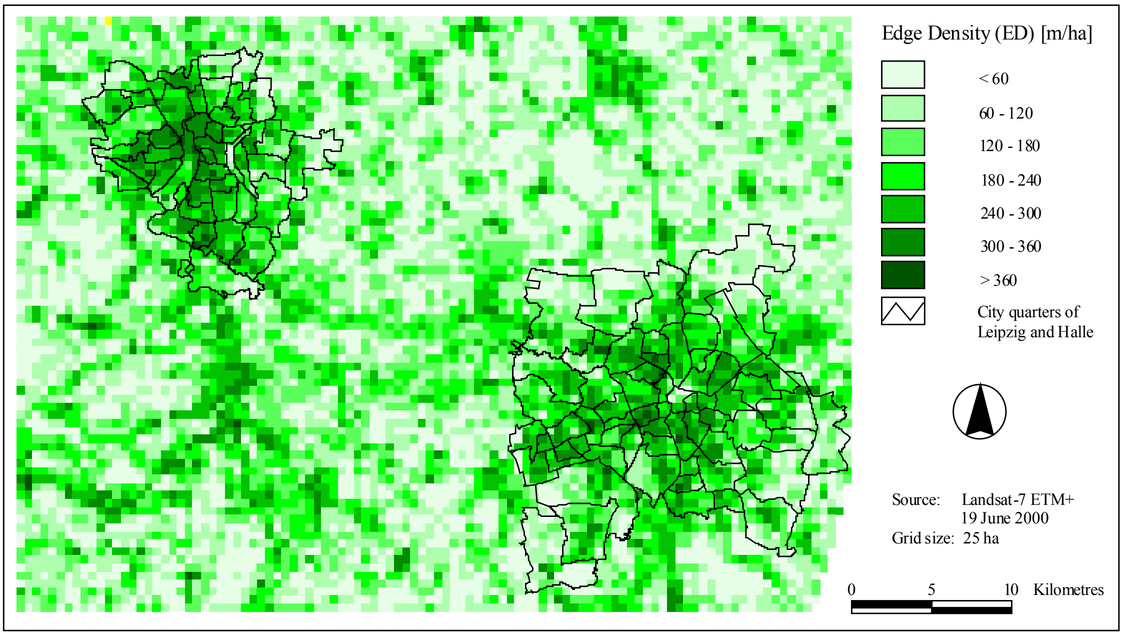


Figure 25: Grid-wide Edge Density–distribution.

The Landscape Shape Index expresses the perimeter-to-area ratio for the landscape as a whole (Figure 26). As expected, an LSI of below 1,75 is localised in the rural parts of the agglomeration. Large plots with relatively simple shapes prevail. In the contrary, values that are at least twice as large can be found in the cities. The shape of the patches tend to be more complex here. Comparing this index with ED both figures are nearly identical, making one of these measures redundant.

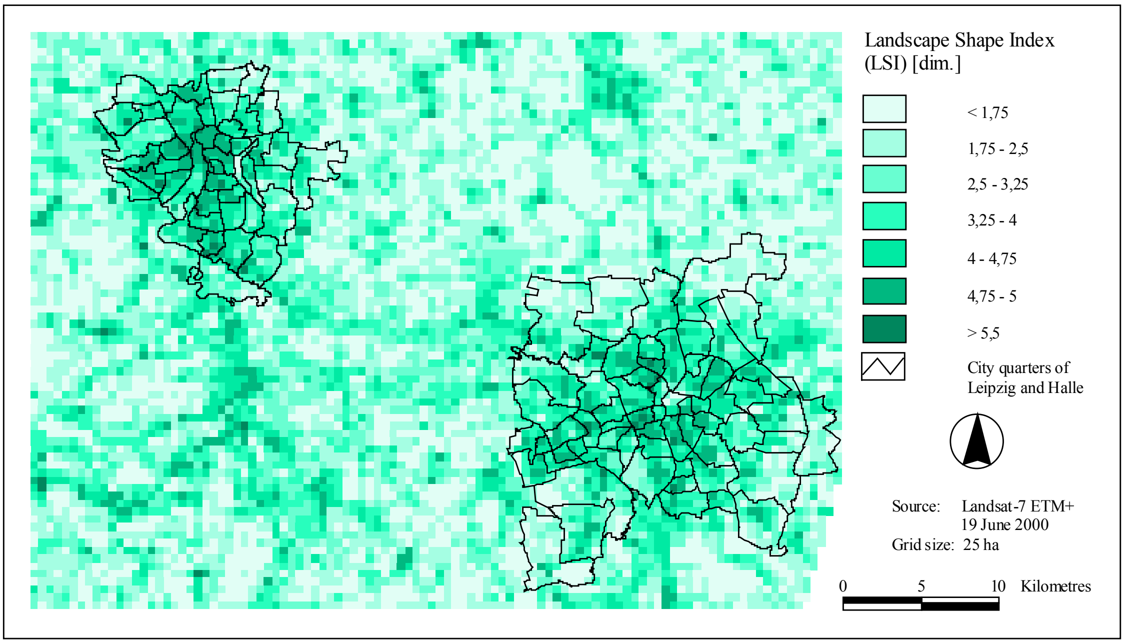


Figure 26: Grid-wide Landscape Shape Index–distribution.

MPI determines the degree of isolation of patch types and is used to supplement MNN (Figure 27). MPIs lower than 30 are widespread and dominate in the cities´ centres. In contrast, significantly higher values are located in the rural countryside, or in peripheral quarters within city borders.

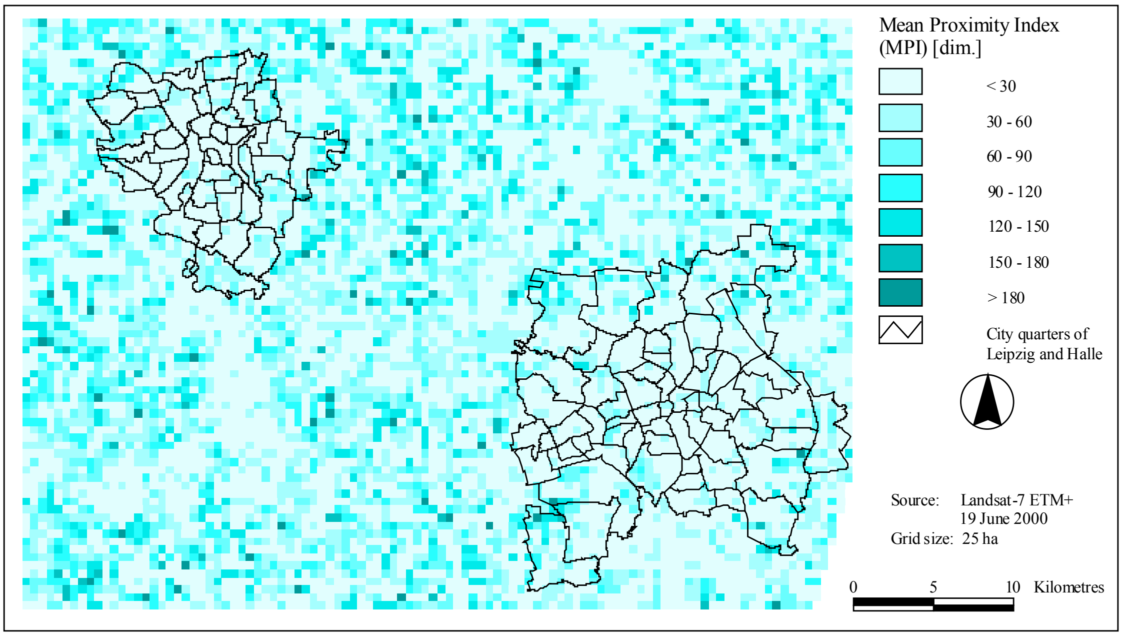


Figure 27: Grid-wide Mean Proximity Index–distribution.

The compilation of Mean Nearest-Neighbour distances of all patch types in a landscape are shown in Figure 28.

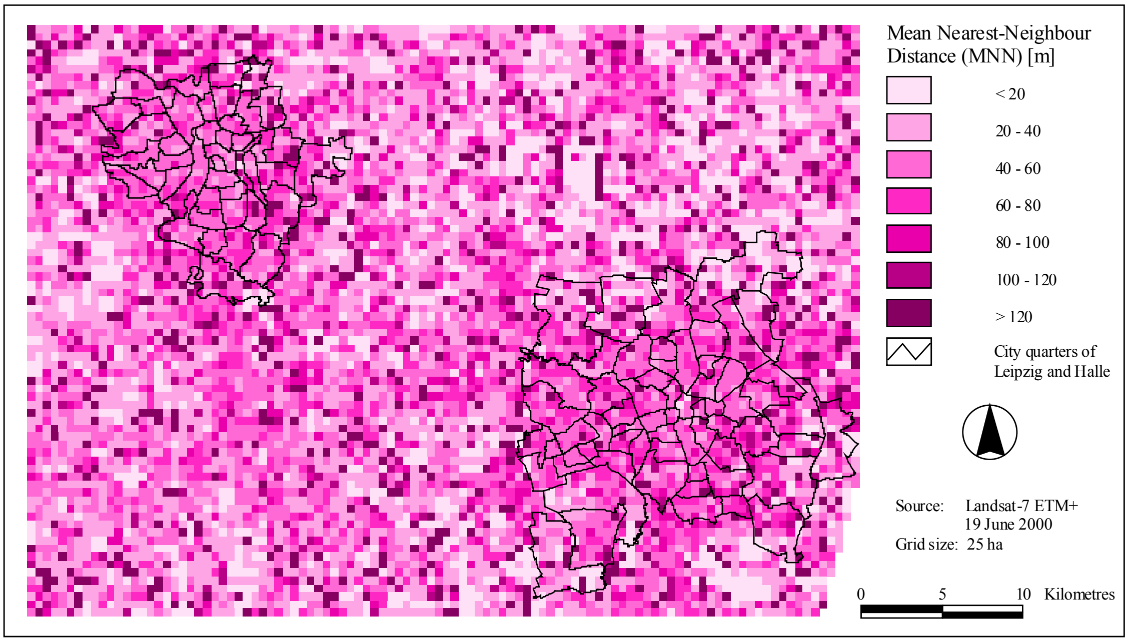


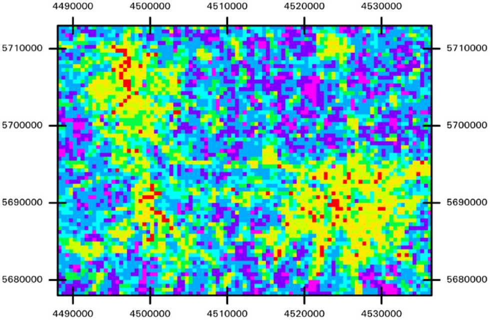
Figure 28: Grid-wide Mean Nearest Neighbour distance–distribution.

The computed distances are lowest in the rural areas with less than 20 m. Large open pit mines or lakes in former mining areas can distinguished by this means. Three times higher are heterogeneity values in the urban cores. Maximum numbers above 120 m can be observed around the settlement cores. This index seems to be more appropriate compared to its predecessor MPI.

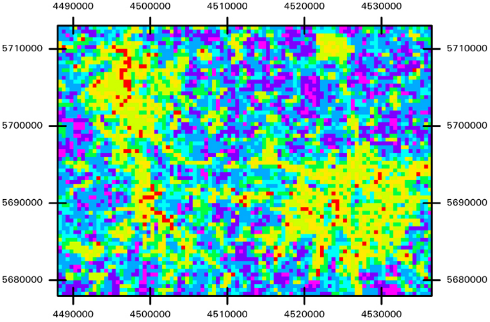
Considerations about the number of classes in every quadrate of the zone file confirm the distinction between the cities and rural periphery (see next page Next page - Figure 29 a and b). In the cities five to eight cover types coexist per raster, whereas for rural areas less than four classes prevail.

Next page - Figure 29: Grid-wide absolute Patch Richness distribution.

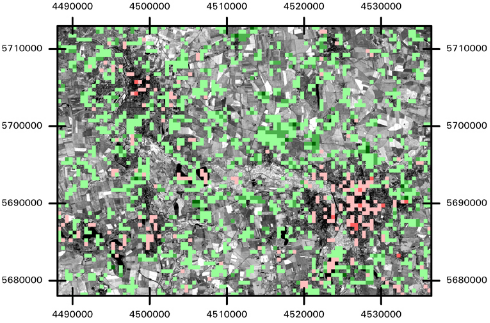
Absolute Patch Richness 1992-2000



a) Amount of Land Cover Classes in 1992



b) Amount of Land Cover Classes in 2000



c) Change Matrix

Legend for Figures a) and b)

- One Land Cover Class per 25 ha
- Two Land Cover Classes per 25 ha
- Three Land Cover Classes per 25 ha
- Four Land Cover Classes per 25 ha
- Five Land Cover Classes per 25 ha
- Six Land Cover Classes per 25 ha
- Seven Land Cover Classes per 25 ha
- Eight Land Cover Classes per 25 ha

Legend for Figure c)

- Major increase
-
- Minor increase
- Background - unchanged
- Minor decrease
-
- Major decrease

Sources

Landsat-5 TM from 28th May, 1992
Landsat-7 ETM+ from 19th June, 2000

Processing

a/b) Analyses of the amount of different land cover classes per 25 ha

c) Temporal changes of the amount of classes

Background image

Landsat-7 ETM+ from 19th June, 2000 (Band 4)

Scale

10 0 Kilometres

Computation/Cartography

Jörg Holtkötter
Umweltforschungszentrum
Leipzig-Halle

SHEI is very low (<0,14) in the rural surroundings (Figure 30). The quadrates are dominated by very few patch types. Large agricultural plots, former lignite mines and artificial lakes are responsible for these figures. In the cities values larger than 0,84 indicate an almost equal distribution of patch types which is due to a coexistance of urban structures and other patch types.

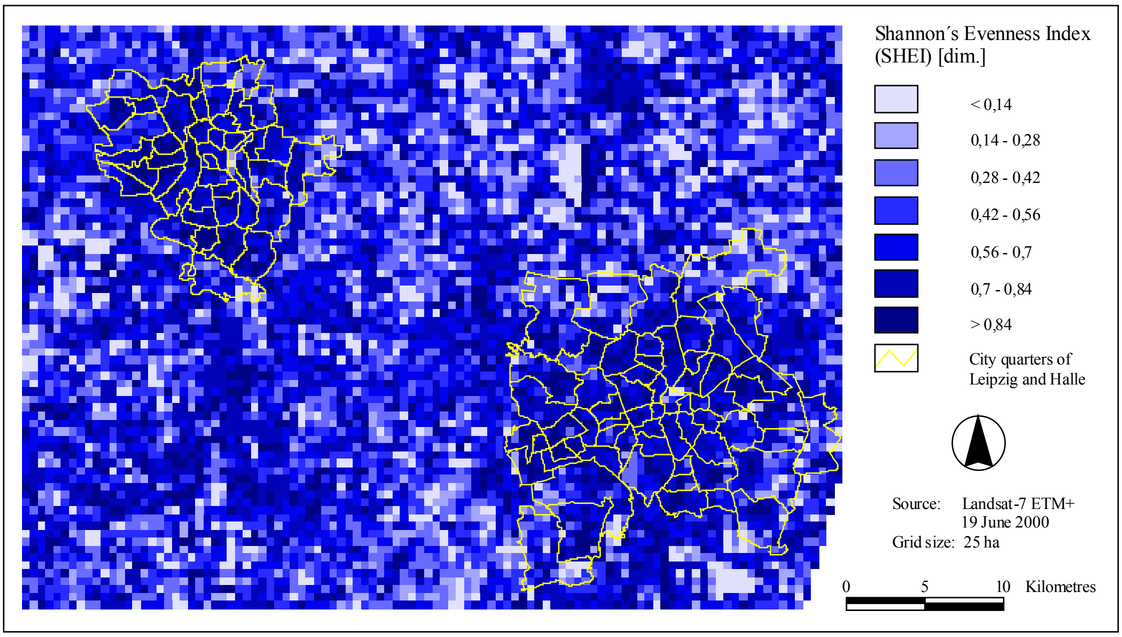


Figure 30: Shannon´s Evenness Index – distribution in the agglomeration.

Whether landscape metrics are capable of describing basic differences between urban and rural structures exemplified for the year 2000 in the conurbation Leipzig-Halle can be demonstrated with the help of Table 9.

Table 9: Assessment of discrimination of urban and non-urban structures:

	%LAND	PD	MPS	LPI	ED	LSI	MPI	MNN	PR	SHEI
urban		↑ +	↓ +	↓ +	↑ +	↑ +	↓ +	↑ +	↑ +	↑ +
non-urban		↓ +	↑ +	↑ +	↓ +	↓ +	↑ +	↓ +	↓ +	↓ +

Value		Assessment of discrimination	
↑	High	+	Positive
→	Medium	0	None
↓	Low	-	Negative

The discrimination of the urban and non-urban features in the agglomeration is successfully conducted with this set of different landscape indices. All of these reflect differences in pattern, i.e. the settlement cores obviously exhibit completely reversed values compared to their rural surrounding. In some cases a gradient from the city centres can be observed as in the case of PD, LPI, ED and SHEI. Moreover, some features such as floodplain forests, former lignite mines and artificial lakes can already be delineated by the applied grid.

8.1.2. Monitoring the Urbanised Landscape of Leipzig-Halle – Landscape Level

The following paragraphs focus on values derived for both cities in comparison to the rural hinterland in order to find changes over time on landscape level. Results of inner city dynamics will be dealt with later in this chapter. The assignment of landscape metrics of a quadrate to either city or the rural surrounding was explained in Figure 21. It must be noted that in the rural hinterland large urban plots are included, i.e. the city of Delitzsch in the north of Leipzig, Merseburg south of Halle, and many small urbanised villages and towns falsify purely rural values (see Figure 3). A Large Patch Index in the rural surrounding of 62% for example can be expected to be higher, if only a purely rural land cover is considered. Values compiled for the rural surrounding must be treated carefully and interpreted with respect to these distortions.

In Halle the number of patches per 100 hectares in 1992 account for almost 85, increasing to more than 90 in 2000 (Figure 31 a). A similar figure can be drawn for the city of Leipzig, though on a lower level of about 70 patches per 100 hectares compared to almost 75 in 2000. This difference can be explained with the large areal growth of Leipzig city by incorporating surrounding quarters with low population densities (Figure 4). In the rural hinterland values remain below 40 right after reunification. In 2000 a comparatively similar growth than that of both cities must be mentioned. This development supports the established trend of ongoing suburbanisation in the region.

Another area metric, the MPS, shows a similar graph (Figure 31 b). The mean patch size of Halle is lowest with two hectares in both years. The decline in 2000 is hardly visible. Leipzig´s value is slightly more than three hectares. The change over time can be neglected. A comparison with rural values delivers a difference of more than two hectares. The trend of smaller patch sizes in 2000 is obvious. The difference to 1992 reaches about 0,3 hectares. The decline can be attributed to increased construction of buildings and roads after reunification resulting in more fragmented landscapes.

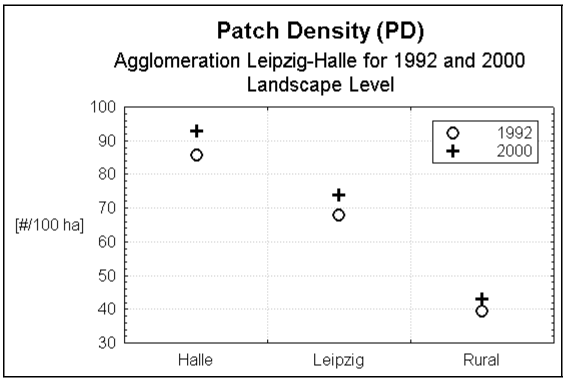
The LPI of Leipzig reaches about 50% in both years. It is even fairly constant for the city of Halle with 45% during the period of time 1992 and 2000 (see Figure 31 c). Compared to the surrounding hinterland which exceeds 62% both are substantially lower. This index does not reveal much more iformation than its predecessor MPS.

The measure Edge Density (ED) in Figure 31 d supports the already realised differences between urban and non-urban features. Edge Densities remain lower than 116 m/ha in both years, though a growth of four metres per hectare is observable in 2000. In Leipzig ED has been about 170 m/ha compared to 176 m/ha in 2000. The maximum growth must be stated for the city of Halle with eight metres per hectare to almost 210. The complex street pattern represented by a fine network in the cities is responsible for many small patches with large edge lengths.

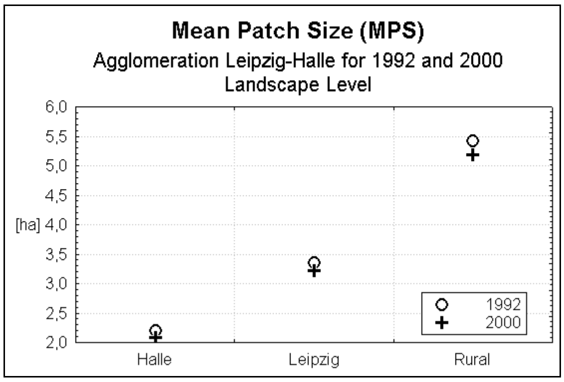
The Largest Shape Index (LSI) is highest in Figure 31 e. The maximum is achieved in Halle with 3,5 in 1992, for Leipzig it is only 3,1. For the rural surrounding less than 2,4 have been measured. The increase from 1992 to 2000 is in all cases less than 0,2 units. LSI appears similar, if compared to ED, and can thus be neglected in future analyses. This can be supported by HULSHOFF (1995) and LAUSCH (2000) who state that shape indices such as LSI are not capable of characterising form complexity over time

Mean Proximity Indices in 1992 remain lower than 28 in the urban partitions, compared to 33 in the non-urban hinterland (Figure 31 f). The increase lies between 7% in Halle and more than 11% in Leipzig. The maximum growth is attained in the non-urban surrounding with 57%! These changes can not be interpreted with respect to suburbanisation processes. It should have been more probable that values decrease in 2000 because lower MPI indicate smaller landscape elements which are further apart from each other.

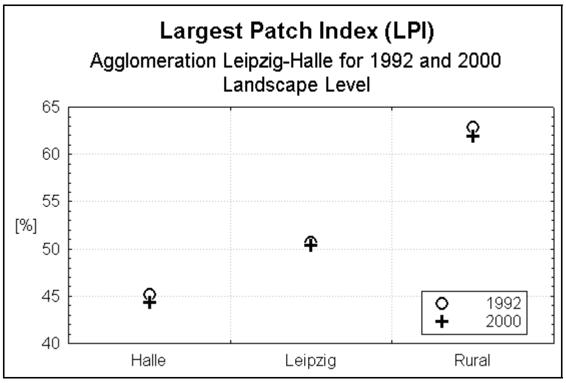
MNN is calculated to demonstrate nearest neighbour relationships between different patches on a landscape level (Figure 31 g). For the cities MNN values are higher than in their hinterland. The difference is six metres to Leipzig and more than eight to Halle. The changes over time are minimal in Leipzig, but can account for about two metres in Halle. With constant city borders as in the case of Halle, this nearest-neighbour metric must grow as a result of higher PD and ED values. The formerly compact city of Leipzig is less affected due to the administrative changes during the period of time 1992 to 2000.



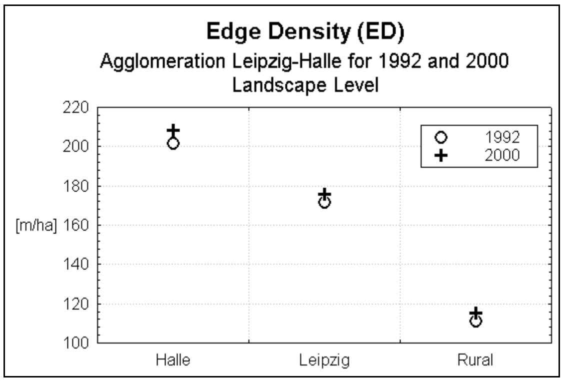
a) Patch Density (PD)



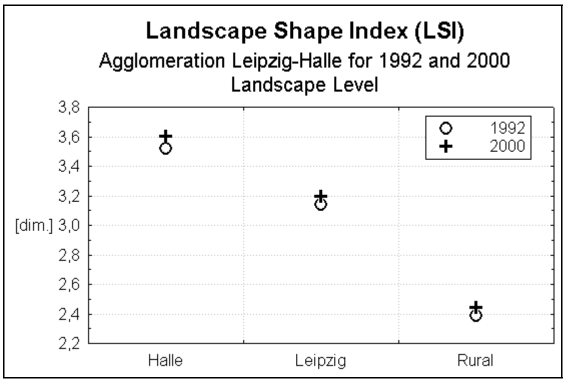
b) Mean Patch Size (MPS)



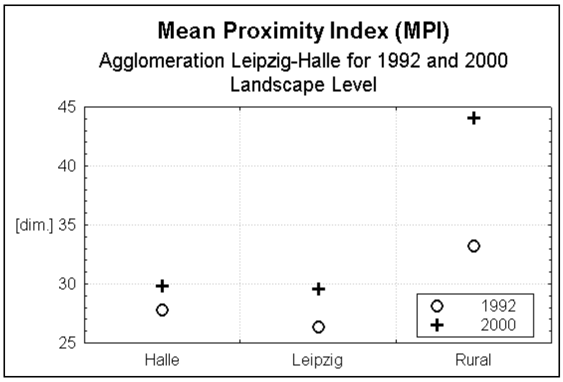
c) Largest Patch Index



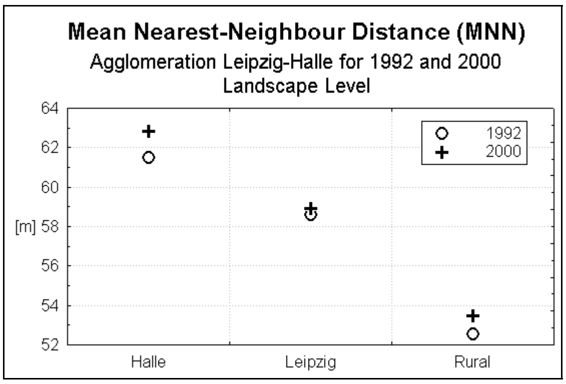
d) Edge Density



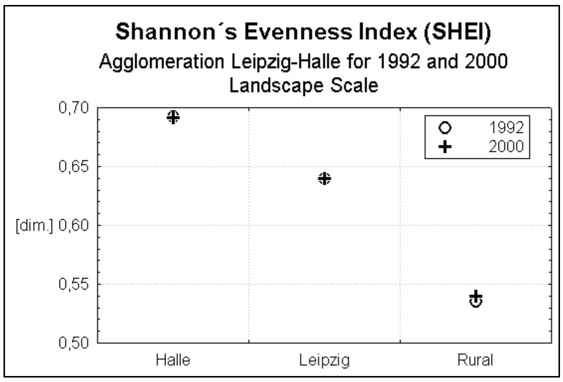
e) Landscape Shape Index (LSI)



f) Mean Proximity Index (MPI)



g) Mean Nearest-Neighbour Distance (MNN)



h) Shannon´s Evenness Index (SHEI)

Figure 31: Multivariate interactionplots of selected indices.

In order to visualise the change over time of absolute patch richness a change map (see Figure 29 c) was compiled . Green areas indicate an increase in the amount of classes, red colours a decrease. Roughly speaking, an increase in the number of classes can be stated for large parts of the landscape, whereas decreasing numbers are confined to the urbanised areas, or partly to artificial lakes in former lignite mines (e.g. Lake Cospuden). In case of the cities the fall can be traced back to sealing of remaining urban open spaces in their interior, especially in the centres (Stadt Halle 2000).

SHEI can be used to express the evenness in a patch distribution. According to Figure 31 h SHEI is below 0,53 in the countryside, compared with 0,64 in Leipzig and 0,69 in Halle. Thus, a domination of a solitary patch type could not be proved, but the compactness of Halle is once more been reflected in a slightly higher index number than of Leipzig.. The difference from rural to Leipzig is thus 20%, and even more compared to Halle. Temporal changes can be neglected in the cities, but it is evident in their hinterland. Here 0,54 are reached in the year 2000 which indicates a slightly increased evenness distribution in this part of the landscape. The construction of new motorways (A 38 and A 14) near Halle, commercial and residential suburban estates such as “Neu-Großkugel” and “Günthersdorf” outside the city boundaries result in a more complex pattern with additional patch types (BERKNER ET AL. 2001).

With this set of landscape indices it was possible to show how different urban and non-urban areas develop over time. Many indices support the view of ongoing fragmentation and surface sealing within the cities and their surrounding (Table 10). Suburbanisation processes are mirrored by generated indices. The ecological effect on species dispersal and migration is basically negative.

Table 10: Trend of selected indices between 1992 and 2000, and their assessment:

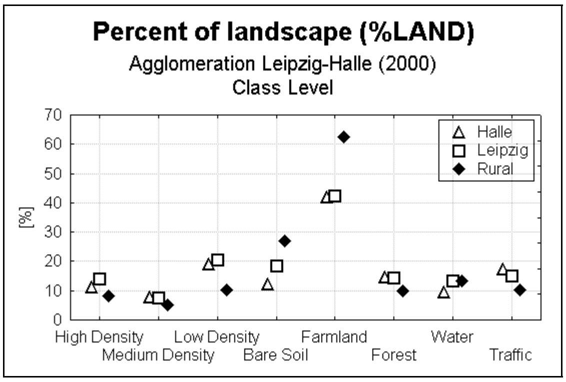
	%LAND	PD	MPS	LPI	ED	LSI	MPI	MNN	PR	SHEI
urban		↑ -	↓ -	↓ -	↑ -	↑ -	↑ -	↑ -		→ 0
non-urban		↑ -	↓ -	↓ -	↑ -	↑ -	↑ -	↑ -		↑ -

Trend		Assessment	
↑	Rise	+	Positive effect
→	None	0	None
↓	Fall	-	Negative effect

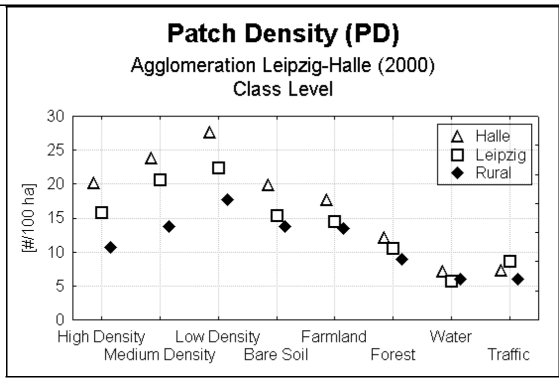
Bearing in mind the "blurred" results for the non-urban area as explained above, it must be stated that differences between both should be even more pronounced. The areal extension of Leipzig city during the time interval does affect generated indices.

8.1.3. Landscape Indices Describing the Agglomeration Leipzig-Halle Exemplified for the Year 2000 – Class Level

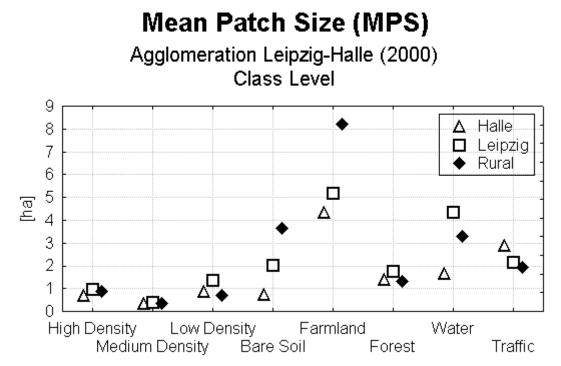
The index percentage of land (%LAND) can aid in emphasising the differences between urban and non-urban areas (Figure 32 a). The amount of built-up area is always higher in the cities for every category compared to the countryside. With pre-fabricated housing estates being limited "medium density" is least important with ~8% in urban areas, in contrast to roughly 5% in the non-urban parts. Between 12-14% are covered by almost completely sealed surfaces in the urban cores, whereas it is 8% in their surrounding. The largest areal extent of these is used by owner-occupied housing estates and allotmens or garden areas (class "low density") which is twice as large as in the periphery (KÜHN 1998). If the traffic class is taken into consideration almost 60% of all area is covered by urban structures. The land used for agricultural purposes is more than 20% lower in the cities than outside because more is converted to urban uses. The floodplain forests are much larger in both cities due to the riparian woodlands along Elster, Pleiße and Saale river. Water areas are of least importance in Halle, but may account for more than 12% as in the case of Leipzig because of "Lake Cospuden", "Auensee", and the "Elsterflutbecken". Comparisons to statisitical yearbooks of the states of Saxony and Saxony-Anhalt reveal that water areas and urban structures should be of minor importance. Settlement and traffic areas officially revolve around 40% of the total land area in both cities and water areas cover 4 to 6%. Forests account for 6-8% statistically in the cities and less than 3% as in the case of the "Saalkreis" that almost surrounds Halle. Farmland covering almost 60% in rural areas should also be higher compared to values of this district in which more than 80% are used by agriculture. Thus, compiled index values are much higher for these classes which is a result of the applied classification and change detection method. ANTROP & VANEETVELDE (2000) emphasize that the "method of thematic mapping largely determines the outcome" with regard to an interpretation of metrics. Unfortunately, the %LAND values do not resemble actual values as published in the statistical yearbooks. Even though, it must be pointed out that it is possible to demonstrate differences on class level between urban and non-urban areas.



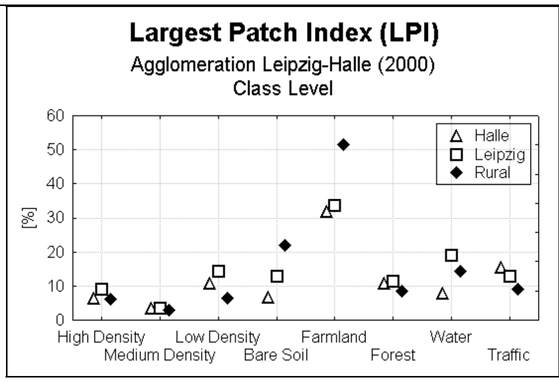
a) Percent of land (%land)



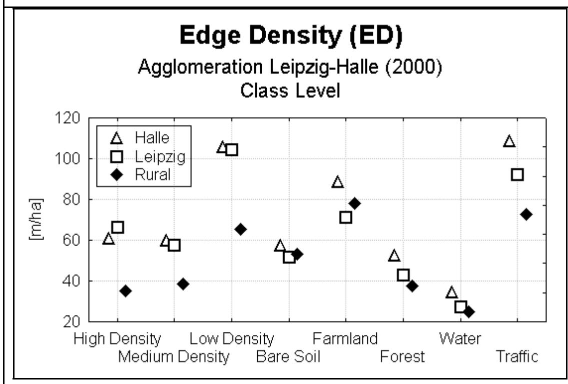
b) Patch Density (PD)

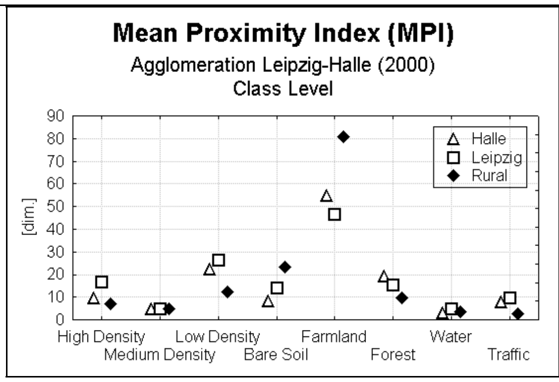


c) Mean Patch Size (MPS)



d) Largest Patch Index (LPI)





e) Edge Density (ED)	f) Mean Proximity Index (MPI)

Figure 32: Spatial differences of indexes on class level.

Comparing cities and their hinterland, patch densities are lowest in all classes in the countryside (except “water”) as expected (Figure 32 b). The differences between urban and non-urban areas are less pronounced (about one patch per 100 hectares) for semi-natural land cover categories such as “water”, “forest”, “agricultural land” and “bare soil”, but reach up to 10 patches/100 ha as in the case of Halle for sealed classes. The observed differences between Halle and Leipzig are due to extensive changes of the administrative boundaries of Leipzig, where relatively large rural areas were incorporated, whereas Halle`s borders remained unchanged (see chapter 3).
Mean patch sizes of the urban classes are lowest revolving around 1 ha without much variation (Figure 32 c). This can be compared to values derived by WALZ (2001) who investigated settlements in a rather rural setting in Saxony. However, the author used a vector based approach to subset the landscape which means that comparisons to values of this study cannot easily be drawn. MPS of “bare soil” ranges between 0,7 ha for Halle to almost 4 ha in the countryside. The same situation can be sketched for farmland, though on a higher level. Lowest values in the cities (Halle with ~4 ha; Leipzig ~5 ha) oppose the maximum of almost 8 ha in the fringe. The minor values of Halle city compared to Leipzig can be attributed to the areal extension of the latter during administrative reforms. Forest patches are 1,5 ha in all three cases. Water areas, twice as large as forests in the hinterland, are due to large artificial lakes. The maximum within this class in Leipzig can be explained by the large extent of Lake Cospuden in the South of the city and the “Elsterflutbecken” near its interior.
The Largest Patch Index compiled for the agglomeration in 2000 can be as low as 5% in the case of “medium density housing” or higher than 50% as for the category “farmland” (Figure 32 d). This maximum is located in the rural surrounding of Leipzig and Halle, whereas in the latter two only one third of the total area is comprised by the largest farmland patch. The magnitude of the “bare soil” class is slightly less pronounced, if rural and urban cores are compared. Obvious are lowest values for all three density patch types indicating higher heterogeneity. With regard to both major centres, values of semi-natural categories for Leipzig are always higher than for Halle, which must be related to the above mentioned extensions of Leipzig´s boundaries.

Edge Density of all three housing density classes is 20 to 40 m/ha higher in the cities, where differences between Leipzig and Halle are subtle in comparison to their rural hinterland (Figure 32 e). “Low density housing” in the cities has similarly long edge lengths compared to the class “traffic”. Because the latter is a network of coherent patches these maximum edge lengths could be expected. Why edge density is similarly high for the “low density housing” class can only be inferred from intensified residential suburbanisation. According to HEROLD & MENZ (2000) EDs of urban structures range form > 40 m/ha as in the case of commercial sites to less than 110 for residential areas. The other four categories do not vary much within either class, if urban cores are compared with their fringes. The edges of “water” and “forest” are lowest because only few patches of them exist in the landscape.

The dimensionless value MPI reveals information about the degree of patch isolation (Figure 32 f). Maximum values, i.e. a patch being surrounded by near-neighbouring patches of the same type, can be found for the category “farmland” in the rural setting, where large patches of meadows and cropland are least fragmented by traffic routes and urban structures. In the urban counterpart MPI remains significantly lower (~50) for this patch type because there urban land uses are intermingled with “farmland”. “Bare soil” values are also lower here in contrast to the fringe for the same reason. Astonishingly, rural forest patches are further apart from each other than urban ones. It has already been mentioned that the proportion of agricultural land in comparison to forests is extraordinary high in the area of investigation (see chapter 2). In Halle and Leipzig large plots of riparian woodlands exist within city boundaries which may be responsible for these figures. For all density classes values could be expected to be lower in rural areas than in the urban cores.

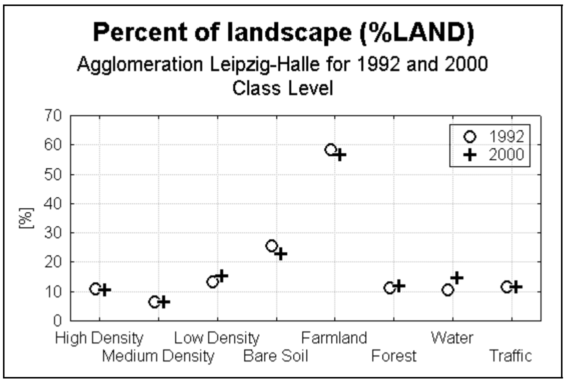
Summarising this chapter leads to the conclusion that Leipzig-Halle and surrounding can partly be characterised on class basis. The results of %LAND depend on the applied methodology and do not reflect actual land use. Even though, differences between urban and non-urban areas are evident. In the case of “medium density” and “water” MPS, ED and MPI of urban and rural values are almost identical. This leads to the question, whether the first should have not been separated from other urban classes in the classification stage. On the other hand, a perfect disticntion has been achieved in the cases of “low density”, “forest”, and “traffic”.

8.1.4. Temporal Changes in the Agglomeration – Class Level

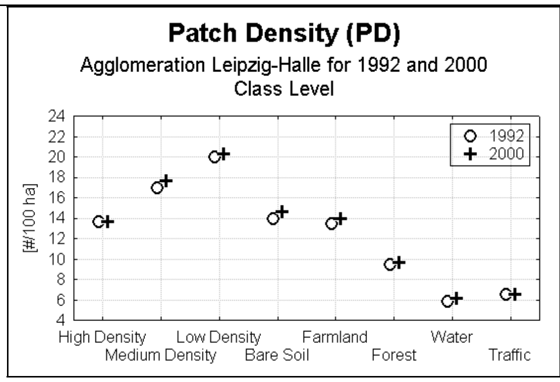
Variations of an area covered by a certain class in time are essential in monitoring urban sprawl (Figure 33 a). Almost stable remain the class “high density” and “medium density”, whereas the area of “low density” grew on average about 3%. The construction of residential, commercial and retail space since 1990 has mainly taken place outside of both major cities (see chapter 2). However, it is surprising that the class “high density” has not changed despite the erection of several industrial and commercial parks. This development has let to a decline in area used for farming purposes or patches that lay derelict. These findings are consistent with an investigation conducted by HULSHOFF (1995) who was able to show an overall increase of this metric for the urban land area in the human modified Dutch landscape, whereas other classes were faced with a decline. The slight change in the degree of forestation can be assigned to reforestation programs (SMUL 2000a). According to a press release of the SMUL (08.03.02) the forest area in Saxony is going to be extended to almost 30% of the total land area in future which means that more than 44.000 ha have to be planted with trees. The area covered by aquatic ecosystems such as lakes and rivers grew enormously (~4%) which is a matter of former lignite mines that recently became filled with water. According to BERKNER ET AL. (2001) this trend will continue in future because plans envisage 175 km^2 new water area in old mines until 2050 (see chapter 2).

Patch densities in the agglomeration range from 6 as in the case of “water” to more than 20 for the class “low density housing” (Figure 33 b). Average patch densities of about 13 to 14 were measured for the classes “farmland”, “bare soil”, and “high density housing”. As expected, relatively high PD values were obtained for the density classes. At a first glance, it must be somewhat surprising that the category “high density housing” is lower than the other two classes of surface sealing. With reference to the classification (Figure 16) this class is spatially confined to the cities´ interior, whereas the other two classes are rather dispersed around the urban cores. The trend of rising patch densities, though hardly visible, is present in all categories except “traffic”. The amplitude of change is less than one patch per 100 hectares. These results can be proved by the studies of HULSHOFF (1995) and SWENSON & FRANKLIN (2000) who also observed growing average numbers of patches per gridcell resulting in a rather heterogeneous landscape.

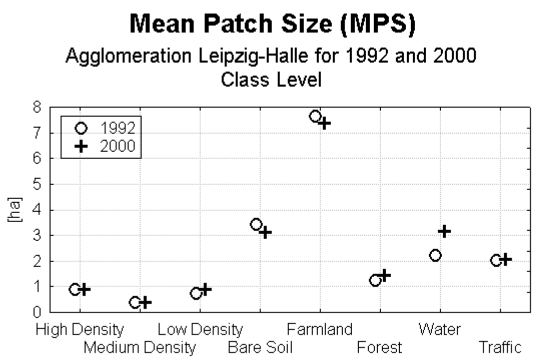
Growing MPS can be observed for the classes “low density”, “forest” and “water” (Figure 33 c). The latter two of them are found to be extended in size by reforestation and lake infill. “Low density housing” is larger then before because of residential suburbanisation spreading around the cities. The categories “bare soil” and “agricultural land” decrease of about 0,3 ha, both of which are threatened by the construction of traffic routes and other urban features. HULSHOFF (1995) found smaller MPS for all classes but “urban”.



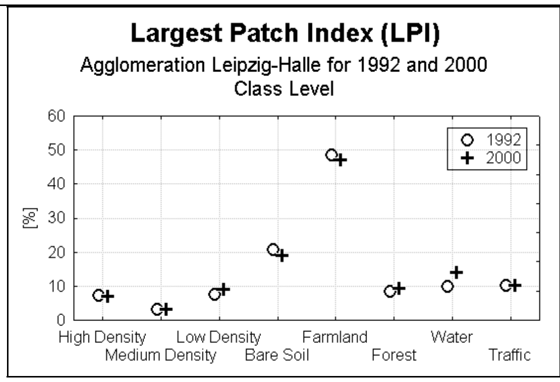
a) Percent of land (%land)



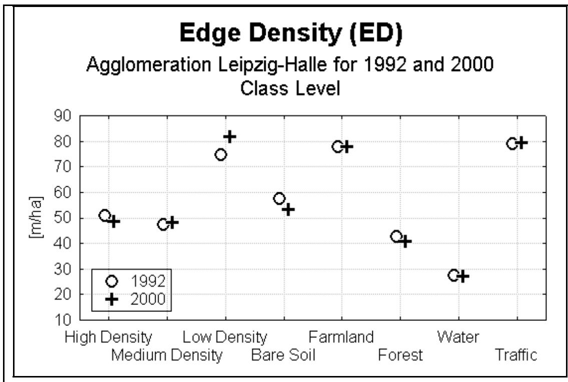
b) Patch Density (PD)



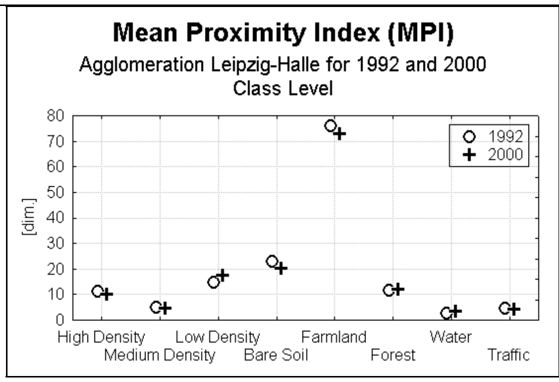
c) Mean Patch Size (MPS)



d) Largest Patch Index (LPI)



e) Edge Density (ED)



f) Mean Proximity Index (MPI)

Figure 33: Temporal changes of landscape indexes on class level.

Temporal changes of LPI can be considered to be low for the conurbation (Figure 33 d). Classes such as “high density housing” and “medium density housing” remain unaffected, only “low density housing” grows slightly due to residential suburbanisation. The transformation to urban uses of land formerly used for other purposes is manifested in changes of “bare soil” and “agricultural land”. The class “water” became substantially larger (roughly 5%) which can be traced back to the flooding of former lignite mines.

Changes of ED over time range from an increase of about 10m/ha for the class “low density housing” to a decrease of roughly 5m/ha for “bare soil” (see Figure 33 e). A decline of 2 m/ha is observed for the class “high density housing” in contrast to the value of “medium density housing” that raised by 1. “Water”, “farmland”, and “traffic” edge densities tend to be fairly untouched. For the latter increased fragmentation by an increased areal demand for roads should result in growing ED for this class as suggested by SWENSON & FRANKLIN (2000). Because the transportation network has been selected from the digital biotope maps, no change can be found for this index.

Temporal variations of MPI reflecting effects of urbanisation are demonstrated in Figure 33 f. The changes in the classes “water” and “forest” can be neglected, although reforestation programmes and the infill of pits with water led to an areal growth. More obvious are changes in “farmland” and “bare soil” due to the construction of roads and other urban features. A maximum decline of about 5 can be noticed for both categories. An extreme growth of “low density housing” is apparent, whereas “high density housing” values decreased. This might in part be due to the ecological upgrading of city quarters by refurbishment as well as the demolition of artificial structures.

Preceding paragraphs have dealt with changes of landscape indices for the agglomeration as a whole and can be summerised in Table 11.

Table 11: Changes of landscape indices on class level.

	%LAND	PD	MPS	LPI	ED	MPI
High density housing	→ 0	→ 0	→ 0	→ 0	↓ +	↓ +
Medium density housing	→ 0	↑ -	→ 0	→ 0	→ 0	→ 0
Low density housing	↑ -	↑ -	↑ +	↑ +	↑ -	↑ -
Bare soil	↓ -	↑ -	↓ -	↓ -	↓ -	↓ -
Farmland	↓ -	↑ -	↓ -	↓ -	→ 0	↓ -
Forest	→ 0	→ 0	↑ +	→ -	↓ +	→ 0
Water	↑ +	→ 0	↑ +	↑ +	→ 0	→ 0
Traffic	→ *	→ *	→ *	→ *	→ *	→ *

Trend

- ↑ Rise
- → None
- ↓ Fall

Assessment

- + Positive effect
- 0 None
- - Negative effect
- * Not evaluated

The class "traffic" has not changed at all which is due to the unchanged transportation network from the biotope maps. Therefore, it will not be evaluated. In contrast, indexes of "low density" always rise. From an ecological point of view, more land has been transformed to urban uses which is detrimental to semi-natural processes and ecosystems. The high density of patches and edges indicate increased fragmentation for the class "low density housing", on the other hand MPS and LPI prove decreased heterogeneity. The classes "farmland" and "bare soil" are faced with increased fragmentation and surface sealing. In contrast, aquatic ecosystems have become more important concerning their land area, and have grown in size as indicated by MPS and LPI. From these values can be inferred that artificial lakes have become more important recently.

8.2. Landscape Indices Describing Urban Structures in City Quarters

8.2.1. Situation Within City Quarters in 2000 - Landscape and Class Level

An analysis of landscape indices for city quarters is attempted by focussing on three characteristic quarters of each city, which are not only distinguishable by their population densities but also by different degrees of surface sealing and functions. Furthermore, gradients from the centre to the outer quarters are demonstrated with a couple of indices.

Firstly, Halle and Leipzig city centres are densely populated with almost 3.000 inh./km^2 in the latter and 6.000 inh./km^2 in the first. Both are characterised by only few open spaces due to high ground prices that led to the construction of many buildings for various purposes. The population density is considerably lower in “Leipzig Zentrum” because of the domination of the tertiary sector in this area. During the time of the former GDR, Leipzig was a world-wide renowned fair location and many of the old trade houses still exist in the inner city (GRUNDMANN 1996). Secondly, an analysis of pre-fabricated housing estates follows. The examples “Westliche Neustadt” in Halle and “Grünau-Mitte” in Leipzig have population densities that exceed 10.000 inh./km^2. These quarters mainly serve the purpose of accomodation with high-rise building blocks surrounded by short-mowed lawns. Finally, two quarters with population densities below 1.000 inh./ km^2 are investigated. These are located towards the outer border of both cities. “Kröllwitz” in the NW of Halle and “Probstheida” in the south of Leipzig are examples of the “low density” category with higher proportions of urban green between predominantly solitary owner-occupied houses with gardens and extensive allotments.

The percentages of different land cover classes (%LAND) in all three examples of city quarters reveal that in the centres of Leipzig and Halle more than 95% of the area are confined to urban uses (Table 12). The classes ”traffic” and “high density housing” dominate, whereas the other two classes of surface sealing can almost be neglected.

Table 12: Indices compiled for the city centres of Leipzig and Halle on class level

City Quarter	Land Cover Type	%LAND		PD		MPS		LPI		ED		MPI	
		1992	2000	1992	2000	1992	2000	1992	2000	1992	2000	1992	2000
Halle Altstadt ID = 27	High Density	27,50	30,25	89,33	88,00	0,32	0,34	6,92	7,50	212,67	223,00	22,50	22,12
	Medium Density	8,25	8,00	41,33	40,00	0,19	0,19	2,08	2,17	75,67	73,67	4,12	3,79
	Low Density	6,67	7,00	29,33	21,33	0,23	0,56	3,08	4,50	51,67	49,33	6,69	4,45
	Bare Soil	5,13	1,13	16,00	4,00	0,32	0,29	2,38	1,13	38,50	7,50	4,60	0,00
	Forest	1,75	1,50	4,00	6,00	0,44	0,31	1,75	1,38	11,50	9,00	0,00	1,00
	Traffic	53,00	53,00	6,67	6,67	8,80	8,80	51,67	52,08	275,33	273,67	71,17	71,17
Leipzig Zentrum ID = 60	High Density	48,50	51,25	30,00	30,00	2,00	1,88	29,63	28,50	200,50	195,00	71,44	68,78
	Medium Density	4,75	4,50	24,00	28,00	0,20	0,16	1,63	1,50	42,00	44,00	2,36	1,86
	Low Density	3,00	3,00	8,00	8,00	0,38	0,38	1,75	1,75	30,00	32,00	1,20	1,20
	Bare Soil	1,75	0,00	8,00	0,00	0,22	0,00	1,38	0,00	14,50	0,00	1,78	0,00
	Forest	2,00	2,50	4,00	8,00	0,50	0,31	2,00	2,00	16,00	20,00	0,00	0,56
	Traffic	42,50	41,50	18,00	18,00	2,41	2,34	38,13	37,63	227,00	222,00	75,51	57,83

In case of the pre-fabricated housing estates the land used by urban features accounts for about 65%. The “high density” values do not exceed 11% (see Table 13) and, in contrast “medium density” and “low density” are more important here. The class “bare soil” also exceeds 10% due to the extensive lawns between the high-rise building blocks. Traffic infrastructure, occupies between 20% of the land in Leipzig and 28% in Halle.

Table 13: Indices compiled for pre-fabricated housing estates on class level.

City Quarter	Land Cover Type	%LAND		PD		MPS		LPI		ED		MPI	
		1992	2000	1992	2000	1992	2000	1992	2000	1992	2000	1992	2000
Halle Westliche Neustadt ID = 28	High Density	2,32	7,19	6,86	19,00	0,32	0,36	1,68	3,78	18,71	47,25	0,79	4,29
	Medium Density	11,72	12,84	28,00	31,00	0,40	0,39	5,78	6,09	76,88	84,88	8,14	7,75
	Low Density	20,53	24,06	51,00	51,50	0,43	0,52	7,75	9,38	138,75	154,88	12,26	18,67
	Bare Soil	18,03	11,59	36,50	34,50	0,50	0,34	7,41	4,84	108,88	85,13	12,82	4,76
	Farmland	18,56	15,53	33,00	33,00	0,57	0,48	6,38	5,22	109,50	98,75	9,86	7,08
	Forest	1,83	1,50	6,67	6,67	0,19	0,16	0,92	0,83	14,67	12,67	3,04	1,67
	Traffic	28,44	28,22	8,00	7,50	4,93	5,55	25,78	25,66	132,63	133,63	23,61	12,64
Leipzig Grünau-Mitte ID = 74	High Density	3,35	10,60	9,60	18,40	0,40	0,53	2,00	6,10	28,00	63,40	1,26	9,35
	Medium Density	18,40	23,50	33,60	43,20	0,54	0,56	10,20	12,25	120,00	144,80	11,62	15,84
	Low Density	24,55	26,75	40,00	43,20	0,68	0,65	12,50	12,75	139,40	158,00	27,60	28,03
	Bare Soil	24,05	10,35	28,80	22,40	0,95	0,53	18,35	7,85	113,40	74,80	41,64	10,18
	Farmland	8,55	7,40	16,00	16,00	0,56	0,47	4,75	4,25	48,40	45,40	2,79	1,67
	Forest	2,00	3,50	4,00	4,00	0,50	0,88	2,00	3,50	10,00	13,00	0,00	0,00
	Traffic	20,70	20,70	14,40	16,00	1,47	1,27	13,50	12,60	113,20	114,60	16,68	14,84

In the examples representing a low degree of surface sealing, “Kröllwitz” and “Probstheida” urban structures (~55%) cover the least amount of land compared to the other examples (Table 14). Traffic routes vary between 23% in Kröllwitz with and 15% in “Probstheida”. Here, the classes “high density” and “medium density” are of minor importance. A domination of “low density” structures supports the view that these districts are characterised by a larger amount of urban green and open spaces.

Table 14: Indices compiled for “low density housing” estates on class level.

City Quarter	Land Cover Type	%LAND		PD		MPS		LPI		ED		MPI	
		1992	2000	1992	2000	1992	2000	1992	2000	1992	2000	1992	2000
Halle Kröllwitz ID = 7	High Density	3,22	6,50	10,67	14,91	0,39	0,55	2,14	4,34	24,44	39,27	1,77	3,29
	Medium Density	2,75	2,73	16,00	15,67	0,21	0,20	1,35	1,27	25,75	26,67	1,30	1,30
	Low Density	20,34	25,28	29,89	34,74	0,75	0,83	9,46	11,43	113,89	132,47	22,38	30,26
	Bare Soil	9,04	6,19	18,67	18,22	0,48	0,36	5,11	3,32	55,17	44,44	7,17	3,98
	Farmland	28,28	25,26	27,58	29,26	1,21	0,95	20,32	17,62	121,79	113,74	43,30	39,00
	Forest	16,97	13,96	21,50	18,67	0,84	0,83	10,19	8,96	83,94	69,39	15,93	12,95
	Water	7,14	7,29	8,00	7,33	1,01	1,03	5,29	5,42	35,29	34,67	2,39	2,94
	Traffic	22,63	22,58	11,79	12,00	2,56	2,86	18,09	18,20	162,53	162,05	16,90	12,09
Leipzig Probstheida ID = 76	High Density	3,05	5,65	11,20	13,85	0,37	0,49	2,10	3,96	24,70	36,08	1,14	2,62
	Medium Density	4,48	4,72	13,60	13,87	0,49	0,49	2,63	2,62	36,40	38,73	3,06	3,03
	Low Density	24,31	33,63	23,40	23,80	2,29	2,60	17,06	25,01	105,05	124,85	15,42	37,70
	Bare Soil	7,81	5,72	14,00	15,06	0,53	0,37	4,38	2,87	48,06	42,12	4,40	4,02
	Farmland	36,66	30,15	21,20	22,60	4,54	3,12	27,95	23,53	97,80	89,15	18,05	27,48
	Forest	18,65	13,25	18,13	16,94	1,54	1,73	13,15	11,12	74,73	50,88	17,32	11,11
	Water	2,30	3,38	4,80	6,00	0,56	0,67	2,25	2,75	18,60	33,00	0,30	2,75
	Traffic	14,76	14,76	9,41	10,82	1,76	1,63	13,07	12,71	93,12	92,65	14,90	19,80

Comparisons to official statistics of the city of Halle (Stadt Halle 2000) yield different coverages of urban uses for each quarter. In the case of Halle “Altstadt” the coverage is roughly 85%, of “Westliche Neustadt” 81%, and only 40% in the case of “Kröllwitz”.

On landscape level patch densities can be visualised with the help of the following figure (Figure 34). The legend exhibits maximum values of above 153 patches per 100 ha, and in the opposition least dense areas with less than 57 patches. Halle´s city centre´s PD of more than 153 is higher than its counterpart in Leipzig (57-89/100 ha). This result can only be explained by a thorough investigation of the street layers selected from different sources. In the case of Halle the street network appears very finely structured (Figure 20). In Leipzig many empty spaces can be seen which are due to the poor data quality of the biotope map of Saxony. This leads to smaller and fewer patches in contrast to Halle. To support this view additional values on class level were investigated (Table 12). The MPS of the class “traffic” is more than tree times larger in Halle than in Leipzig centre. The area covered by streets is about 10% larger in the former city centre compared to the Saxonian counterpart. Traffic routes dominate in Halle with reference to LPI and exhibit much higher ED (>50m/ha) values. The pre-fabricated housing estates Halle “Westliche Neustadt” and Leipzig “Grünau-Mitte” are also characterised by extremely high PD based on the very fine street network comparable to that in Halle centre. In the quarters Kröllwitz and Probstheida PD are already much smaller indicating a lower degree of fragmentation. In the former 121-153 patches/100 hectare were found, in the latter 89-121.

The gradient of declining patch densities towards the periphery in more or less concentric circles from Halle centre except for “Halle-Neustadt” in the west and the area of German Railway (DB) to the east is also visible. In the latter case an almost solitary rail track dominates which is responsible for this very low value. Lowest densities are located in the “Dölauer Heide”, which is predominantly covered by extensive forests, “Ortslage Lettin”, “Tornau”, “Seeben”, “Mötzlich”, “Reideburg”, and “Planena” where agricultural uses prevail. In Leipzig least dense quarters are also remote from the urban core. In contrast to Halle, high values (121-153 patches per 100 hectares) are not localised in the city centre, but in surrounding areas. “Gohlis”, “Schönefeld-Ost”, “Sellerhausen-Stünz”, “Neustadt-Neuschönefeld”, “Reudnitz-Thonberg”, “Zentrum-Südost”, “Zentrum-Süd”, “Zentrum-West” have to be mentioned.

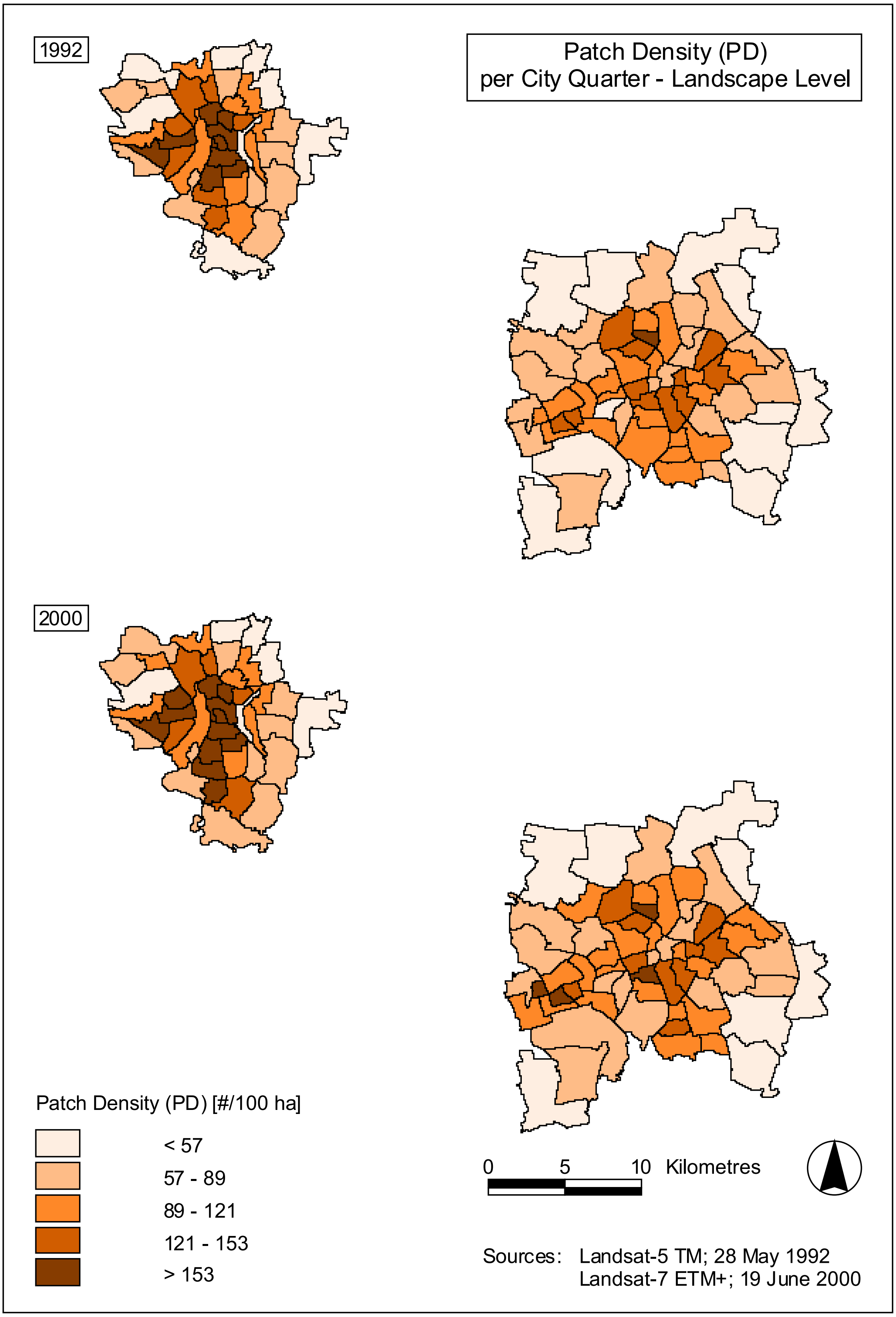


Figure 34: Patch Density– Distribution in Leipzig and Halle.

Low densities in the city centre and Zentrum-Ost must be noted. Taking the selection of the street layer from the biotope map into account these are not very surprising. The quarters of “Schleußig” and “Plagwitz” need to be considered also. In “Schleußig” the railway station with extensive track area is responsible for the poor PD. “Plagwitz”, being highly monofunctionally structured, evolved in the 19th century. Industrialisation led to a development of mixed housing and industrial uses GRUNDMANN (1996). During the classification process both have been categorised as high density housing.

On class level (Tables 10-12), a comparison of PD for both centres reveals that in all classes values are completely different from each other city. PD is almost three times higher in Leipzig than in Halle indicating a higher degree of fragmentation in the western city. In fact, PD of other classes tend to be larger, here. For the pre-fabricated housing sites this trend can also be observed which can only be attributed to the street layer selection from the different biotope maps. In contrast to the former examples of city quarters largest PD do not prevail in the categories of urban built-up, but can be found for “bare soil”, which is a result of remnant patches of lawn in front of the high rise buildings. In Halle “Kröllwitz” and Leipzig “Probstheida” PD are similar for the patch type “traffic” (11-12). Maximum PD are observed for the category “low density” and “farmland” indicating their importance within these quarters.

Mean patch sizes are very low in both cities (<2,1 ha) and over all three different examples of quarters chosen (Figure 35). Larger mean patch sizes can only be found in the cities interior in quarters dominated by the German Railway (DB) as in Halle “Gebiet der DB” and Leipzig “Zentrum-Ost”. Other quarters adjacent to the outer border of both urban cores exhibit large MPS numbers due to an increased amount of agricultural plots.

The above stated gradient within Halle can also be demonstrated because average MPS (3,7-5,3 ha) are found in “Seeben”, “Tornau”, “Mötzlich”, “Reideburg”, and in “Planena”. Smaller sizes can be observed in “Böllberg/Wörmlitz”, “Gewerbegebiet Neustadt”, “Dölauer Heide”, “Dölau”, “Ortslage Lettin”, “Kanena/Bruckdorf”. In Leipzig the largest mean patch size (>6,9 ha) is to be found in “Seehausen” and “Rehbach-Knautnaundorf”. The next category is located in “Lindenthal” and “Althen-Kleinpösna”. Average values of 3,7-5,3 ha as in “Plaußig-Portitz”, “Lützschena-Stahmeln”, “Großzschocher”, “Liebertwolkwitz”, “Holzhausen”, “Baalsdorf”, also near the urban fringe. These numbers reflect the intensity of urban fragmentation. It is least in remote quarters and grows successively to the city centres.

On class level, differences in PD are reflected by variations of MPS (Tables 10-12). In the centre of Leipzig high PD of the class “traffic” results in a low MPS (<2,5 ha), whereas for Halle centre the situation is reversed with a low PD value contrasting a high MPS of 8,8 ha. In the remaining classes MPS is below 0,6 ha. The only exception is “high density” in Leipzig with 1,9 ha. Again, MPS of the centres resemble those values of the pre-fabricated housing areas. MPS of <0,6 ha are common in both areas with two exceptions. The forested area is slightly larger and MPS of the traffic network is at its maximum of 5,5 ha in Halle and 1,3 ha in Leipzig. The last two city quarters, “Kröllwitz” and “Probstheida”, are characterised by increased mean patch sizes for many categories compared to the other examples except the class “traffic”. For this class values range from 1,6 ha as in Leipzig to 2,9 ha in Halle being partly a result of the decreased area covered by roads (see %LAND in the same table). In both areas in Leipzig and Halle, though on a lower level compared to the other city quarter types, large MPS appear for the classes “low density”, “farmland” and “forest”.

Largest patch indices can be found to be very high in the quarters adjacent to the urban fringe (Figure 36). The differences between both city cores in PD are also existent for LPI values. This is due to the reduced importance of traffic routes in Leipzig. The LPI for the pre-fabricated building quarters reaches a minimum of <30% indicating high fragmentation. Halle “Kröllwitz” has a very low LPI that can be explained with the greater importance of streets than in “Probstheida”. In the latter LPI belongs to the middle class (44-58%).

In the city centres the LPI of the class “traffic” in Leipzig covers 38% and in Halle more than 52% of the total landscape area (Tables 10-12). The trouble with the traffic layer has already been mentioned. This cause can be made responsible for the high percentage of land covered by the class “high density” which is almost four times larger in Leipzig (~29) than in Halle (~8). All other classes remain very low (LPI <5%). In Neustadt and Grünau most of the quarters are sealed with traffic routes (see %LAND). The largest patch of Leipzig is only half the size of that in Halle which can be traced back to the error of the street layer. No apparent domination of another class can be reported. In “Kröllwitz” and “Probstheida” the LPI is conform with values of %LAND, that means very large patches are apparent for the classes “low density” and “farmland”.

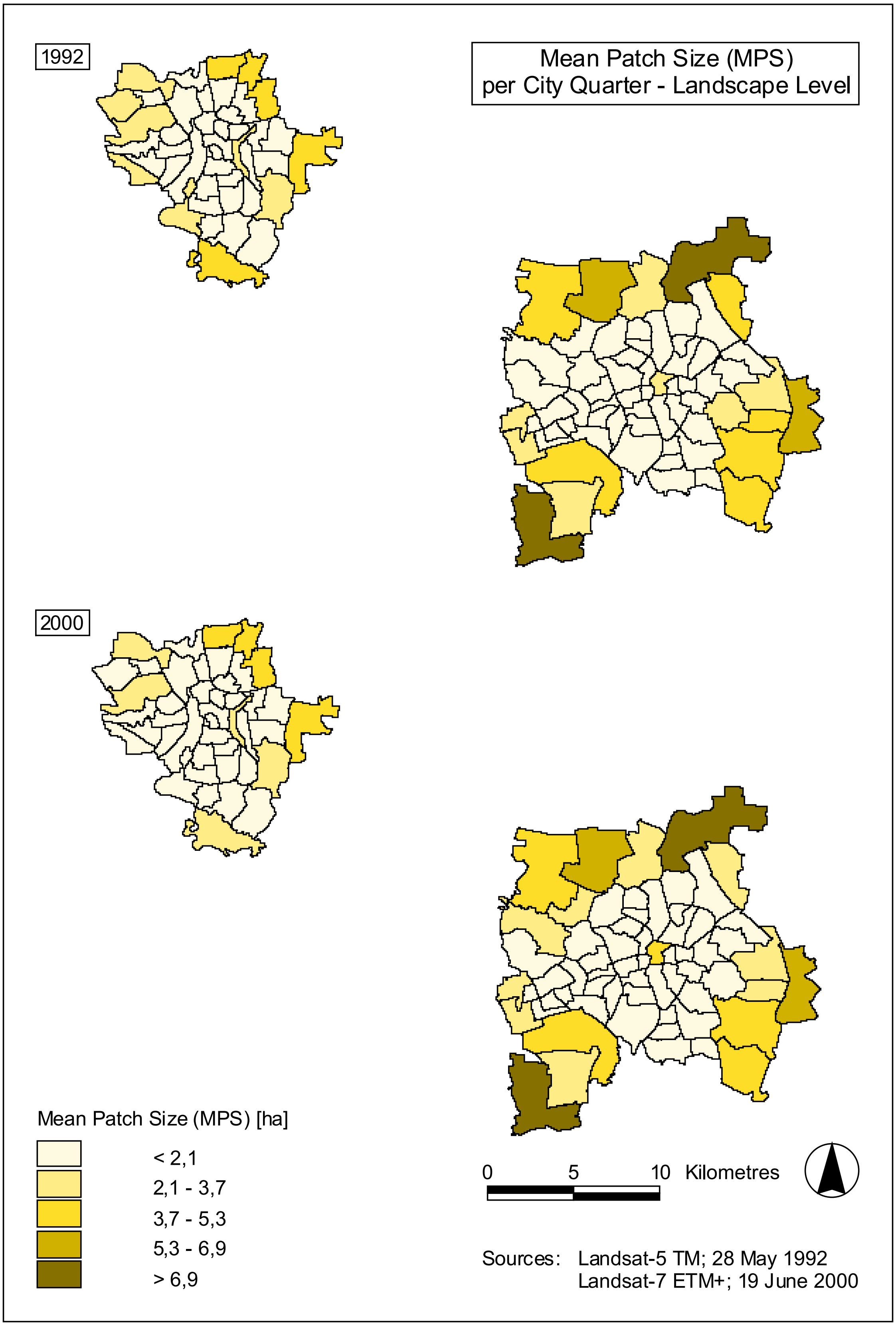


Figure 35: Mean Patch Size – Distribution in Leipzig and Halle.

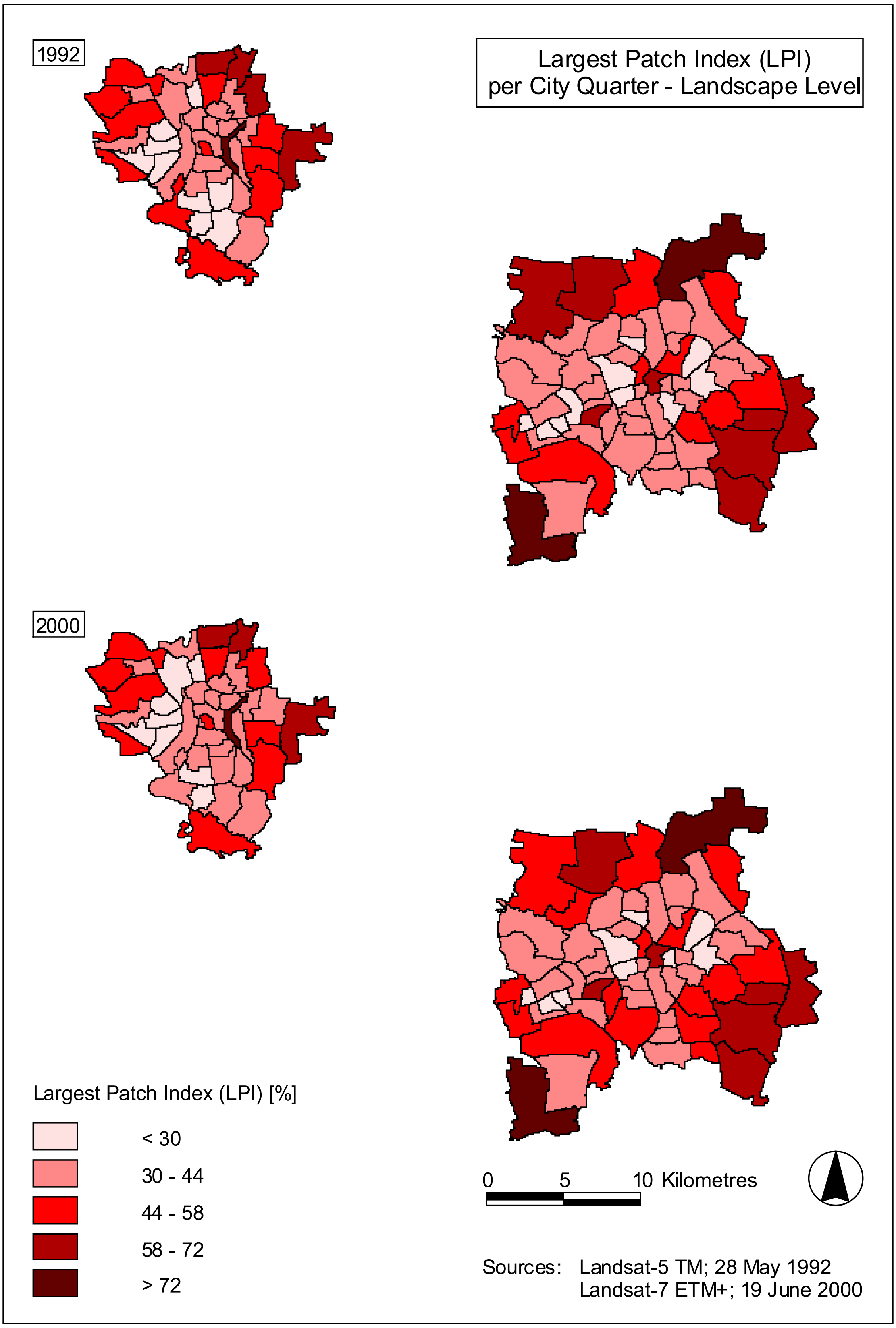


Figure 36: Largest Patch Index - Distribution in Leipzig and Halle.

The lengths of edges per unit on landscape level range from <136 m/ha to more than 304 m/ha (see Figure 37). While the least dense quarters concerning ED are located near the urban fringe, the reversed situation is true for the cities´ interiors. This gradient corresponds to the results of PD and MPS. Taking the two city centres into account differences from Halle (>304 m/ha) to Leipzig (192-248 m/ha) can be reasoned with the differing data quality of both traffic layers. On a city-by-city basis the values of the pre-fabricated site and “Kröllwitz” in Halle are one grade higher than in the reference quarters in Leipzig. The edge length per unit in “Neustadt” for example is larger than 304 metres per hectare, but slightly shorter in Leipzig “Grünau-Mitte” (248-304 m/ha). The measure of ED is related to PD and MPS because with an increasing amount of patches and/or larger MPS the ED value rises. Thus, on class level, the trend of ED is similar to that one of PD (Tables 10-12).

The dimensionless LSI has only been calculated on landscape level to evaluate the form of patch types. Because of its dependeny on the lengths of edges the existing trend can be compared to the one of ED (Figure 38).

The MPI is a dimensionless measure for the isolation of landscape elements on landscape level (Figure 39), and suggests that a patch type is further away from a patch of the same type in Leipzig than in Halle at least for two examples of city quarters. The average proximity in the centre of Leipzig exceeds that one in Halle by one grade, which is also true for Leipzig “Grünau-Mitte” in comparison to Halle “Westliche Neustadt”. These findings are consistent with respect to MNN later in this chapter. The differences might only be due to selected class intervals. If the value of Leipzig does not exceed 26 by far, whereas MPI of Halle is almost 26, this would lead to a split into two separate grades.

On class level (see Tables 10-12) MPI can be very small (<5), if patches are very far away from each other or reach >70, if they are nearly clumped together as in the case of the class “traffic” in the city centre of Halle. This high value means that patches are further apart from each other, whereas in Leipzig its viceversa. For all other classes proximity almost reaches zero, i.e. many small and distant patches are distributed in these quarters. Quarters such as “Neustadt” and “Grünau” are quantified by a maximum range of 28. This indicates rather sparse distribution of smaller landscape elements. If “Kröllwitz” and “Probstheida” are analysed, a more compact arrangement of patches is evident in the classes “farmland” and “low density” for Leipzig (27 to 38) and Halle (39

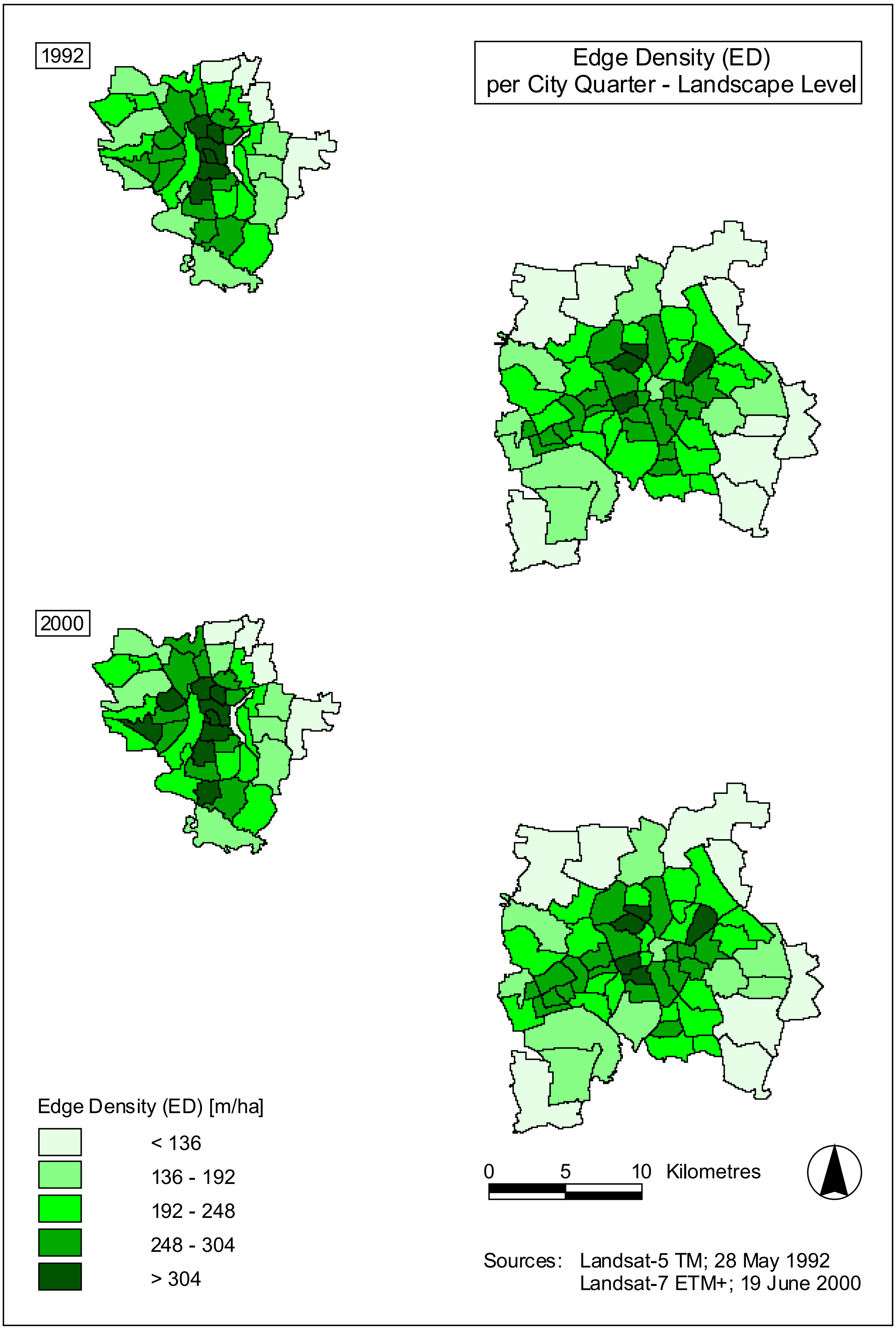


Figure 37: Edge Density – Distribution in Leipzig and Halle.

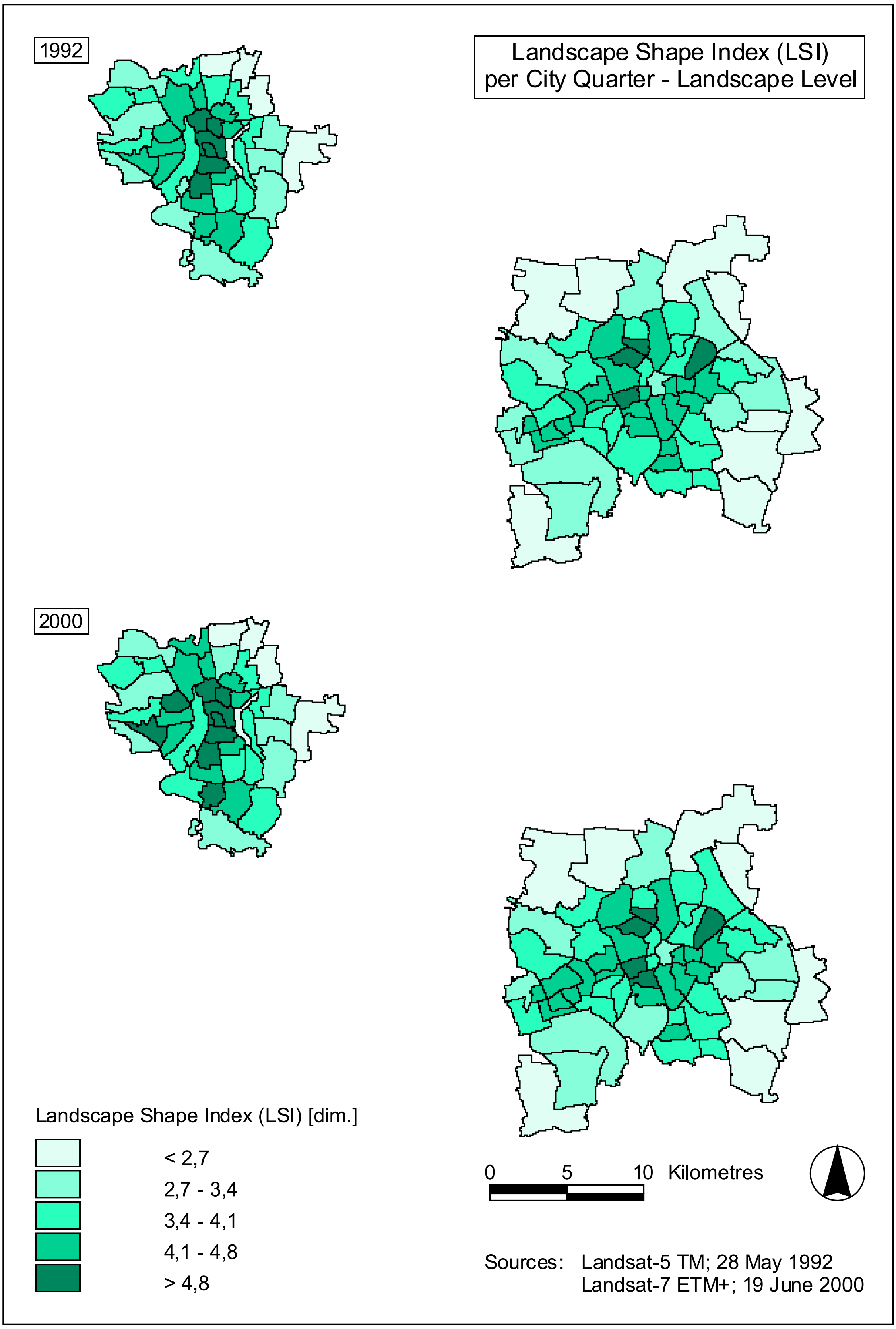


Figure 38: Landscape Shape Index – Distribution in Leipzig and Halle.

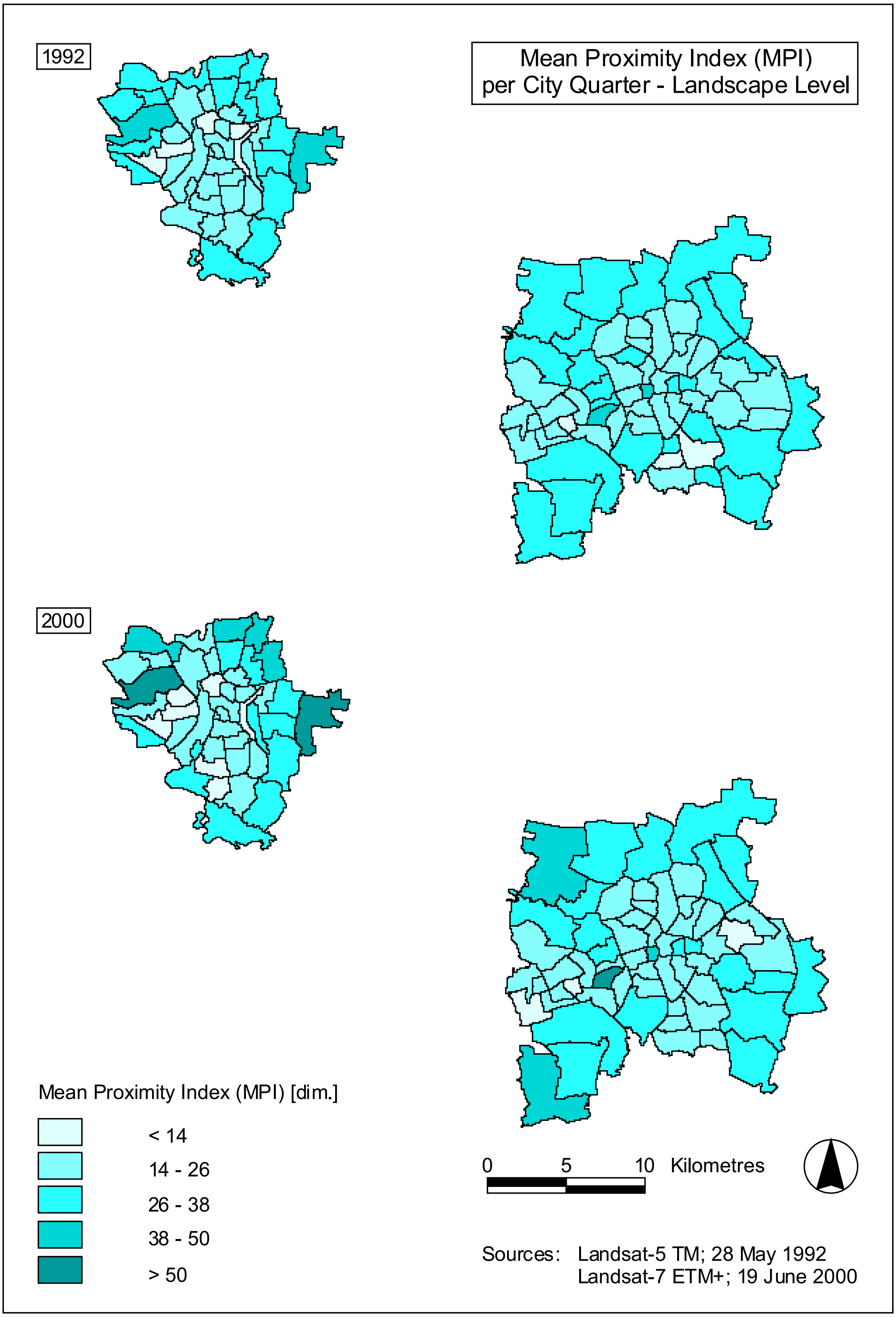


Figure 39: Mean Proximity Index – Distribution in Leipzig and Halle.

to 30). Which is consistent with %LAND. Classes of minor importance exhibit small MPI numbers because patches are small and distances between them large.

MNN is another index for quantifying near-neighbouring patch types on landscape level. All patches in any kind of city quarters are intensively intermingled because MNN is less than 84 m which is the second lowest grade (Figure 40). In fact, for the examples of intensive urban built-up (classes "high density" and "medium density") MNN belongs to the grade below 57 m. Unfortunatly, this index can hardly be interpreted in this respect because most of the quarters belong to either of these two grades.

Absolute patch richness (PR), meaning the absolute number of patch types in a quarter, can aid in measuring diversity (Figure 41). In this context, the inner city quarters Halle "Altstadt" (5-6) and Leipzig "Zentrum" (3-4) appear least diverse. The difference between both is due to a domination of fewer land cover classes in Leipzig than in Halle based on missing urban greenspaces. In the remaining two city quarter types PR is maximum with an average of more than six patch types per quarter indicating a more balanced diversity pattern.

These figures can be confirmed with the help of SHEI in Figure 42 which considers the distribution of inherent patch types. An almost equal distribution is achieved in the quarters "Neustadt" and "Grünau" (>0,8), followed by the least sealed quarters "Kröllwitz" and "Probstheida" (0,7-0,8). Leipzig city centre also belongs to this grade, whereas 0,6-0,7 can be found in the centre of Halle. Hence, this quarter is rather dominated by fewer classes which can be proved by Table 12 because some of the classes are completely missing (e.g. "water", "farmland") here.

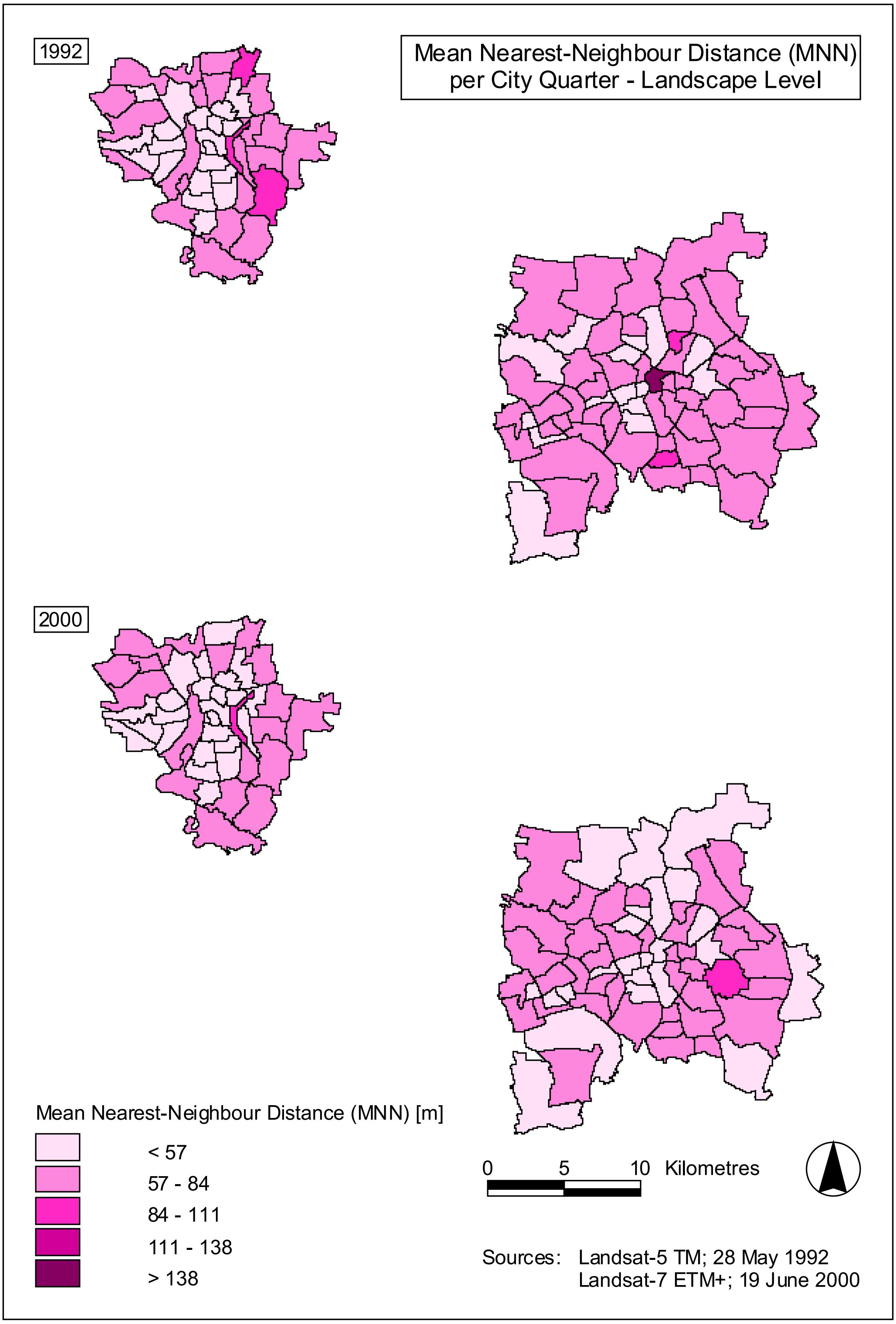


Figure 40: Mean Nearest-Neighbour Distance – Distribution in Leipzig and Halle.

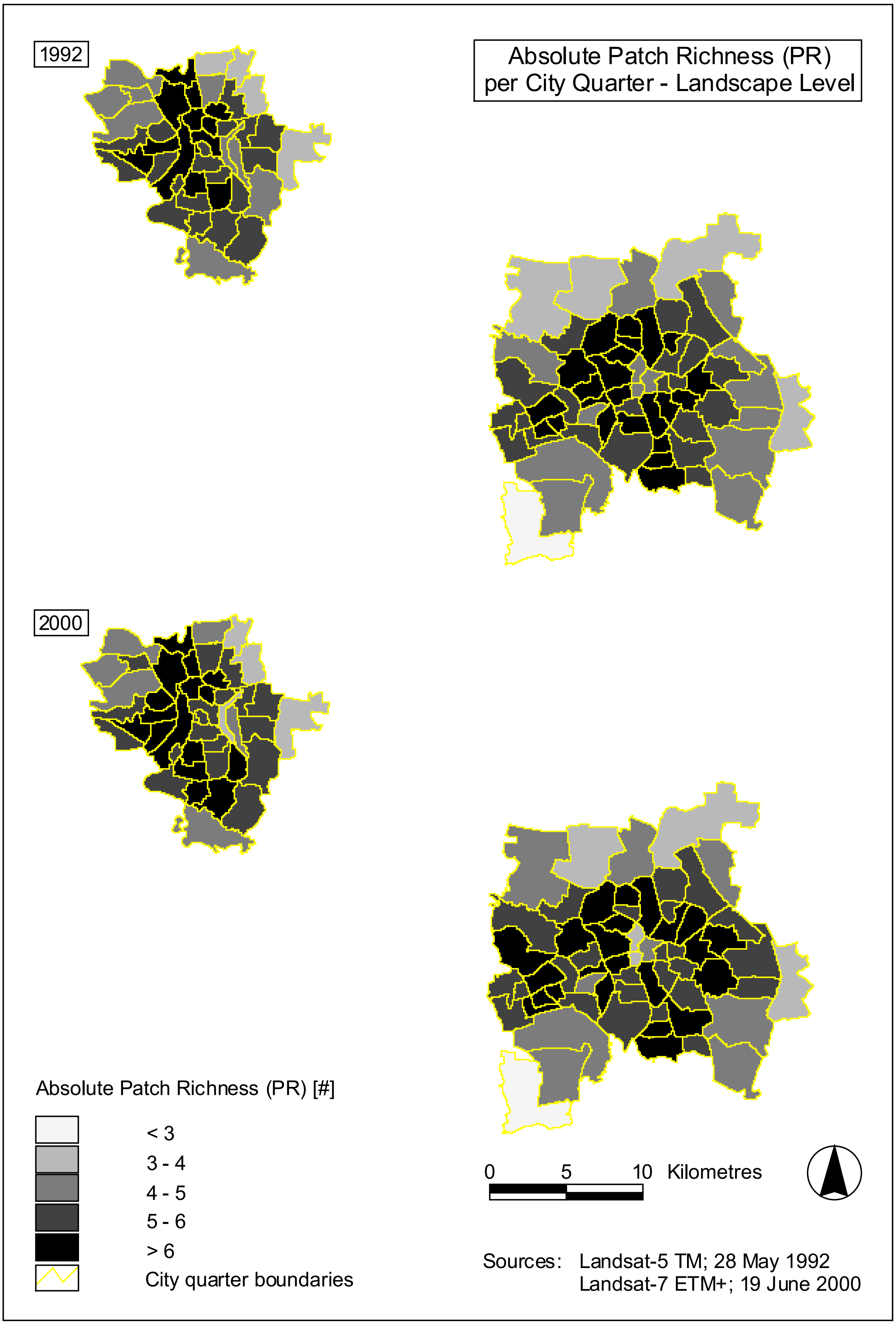


Figure 41: Absolute Patch Richness - Distribution in Leipzig and Halle.

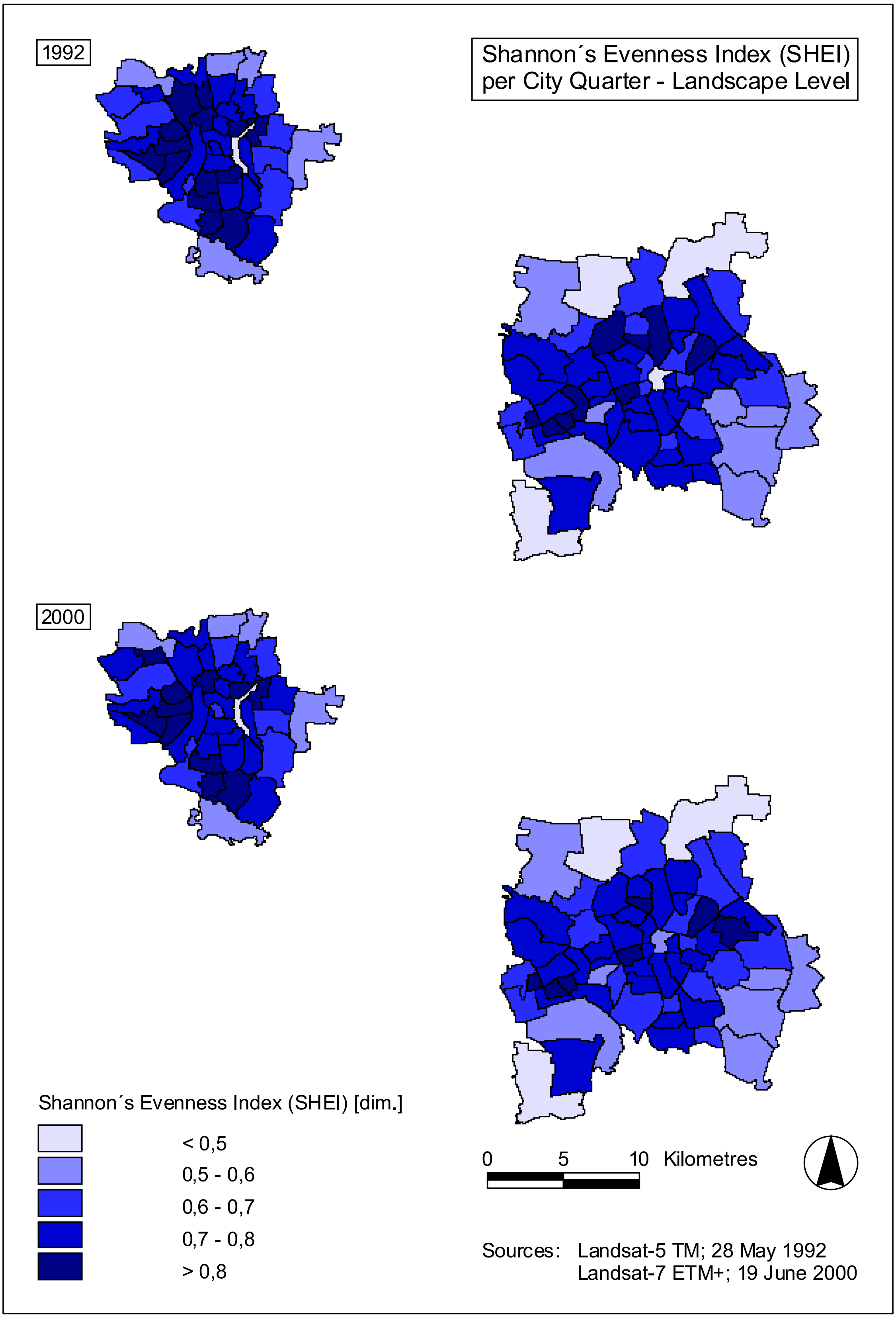


Figure 42: Shannon´s Evenness Index – Distribution in Leipzig and Halle.

8.2.2. Temporal Changes Within City Quarters

The political change in 1989 led to a change in land use and land cover. In the following chapter, an analysis is carried through on the basis of different city quarters in each city to monitor changes in the degree of urbanisation and fragmentation.

In Halle centre, the class „high density" grows almost 3% from 1992 to 2000 because development strategies have envisaged the construction of new buildings on sites where dilapidated houses had to be pulled down right after unification (%LAND). These locations have lain bare in 1992 and have subsequently been reconstructed resulting in a decrease in the class "bare soil". This development is also true for Leipzig centre. Other classes tend to be less affected. In Leipzig "Grünau-Mitte", the class "medium density" grows 5,1%. This development can hardly be explained. On the contrary, it would have been more probable that some of the high-rise buildings have been pulled down for social and ecological upgrading of this quarter leading to smaller partitions claimed by the class "medium density". The class "high density" rises to more than 10% of the total area due to the construction of the "Allee-Centre" in 1996. This secondary centre meets demands of modern shopping and recreation. Lower percentages of the class "bare soil" are not only due to the construction of this shopping centre but also due to an increased demand for traffic facilities, especially parking lots (GRUNDMANN 1996). A similar trend in Halle Neustadt can be reported without the distortions found in Leipzig concerning the class "medium density". In Halle "Kröllwitz", the areal coverage of the class "high density" has grown about 3%, which can be compared to Leipzig "Probstheida". In both quarters the construction of commercial parks is responsible for this rise. Even more important is increased residential suburbanisation as indicated by larger percentages of %LAND in both quarters. In Halle the growth is less than 5%, in Leipzig more than 9%. Consequently, classes such as "farmland" and "bare soil" are faced with high losses of about 3 to 6,5%.

Changes of PD on landscape level are only visible for the quarter of "Grünau" in Leipzig. On class level, PD of urban built-up classes in the inner city areas tend to remain unchanged. The only class experiencing very high losses is "bare soil", whereas an increase in PD can be reported for "forests". Actually, former construction sites ("bare soil") have become transformed into other patch types, e.g. parks, in order to enhance the attraction of the centres. In Halle "Neustadt" and Leipzig "Grünau" PD of all urban classes has risen. The growth of "high density" is most severe because of the construction of modern retail space and recreational facilities in both quarters. In “Kröllwitz” and “Probstheida”, the PD rise of the category “high density” can be traced back to an increase of commercial areas in these quarters. Changes in the category “low density” are only apparent in Halle “Kröllwitz”, whereas fragmentation is less severe in Leipzig “Probstheida”. Increased PD values have also been observed for the class “farmland” in both quarters and “bare soil” in Halle “Kröllwitz” indicating a more fragmented urban landscape.

No changes of MPS are obvious in both cities on landscape level. On class level, MPS values of both city centres do not exhibit a particular trend. In Halle centre, MPS of the urban classes grows or remains unchanged, whereas in Leipzig slightly declining values prevail. A loss of urban green can be observed in both cases with decreasing numbers of forest patches. A decline of urban green can be ascertained by statistics of the city of Halle (Stadt Halle 2000). On the other hand, the quarters “Westliche Neustadt” and “Grünau-Mitte” are characterised by increasing values for most urban classes. They are faced with losses with regard to “bare soil” and “farmland”. The importance of urban categories has increased, which is detrimental to remnant semi-natural space. The same situation can be observed for Kröllwitz and Probstheida. Increases in urban categories oppose decreases in “bare soil” and “farmland”.

On landscape level, LPI values have remained unchanged in both city centres and the pre-fabricated housing estates. LPI of Halle “Kröllwitz” has fallen to less than 30% indicating a more equal distribution among classes. In contrast, the share of the largest patch has risen to more than 44% in Leipzig “Probstheida”. On class level, urban categories become more important in Halle´s centre, where increased numbers are present, whereas reduced values have been measured in Leipzig´s city core. In the pre-fabricated housing estates as well as the less densely populated quarters “Kröllwitz” and “Probstheida”, LPI grows in all urban categories over both cities. Reduced LPI values have been found in the class “agricultural land” and “bare soil”. This is in accordance with findings concerning MPS earlier in this chapter.

On landscape level, EDs of all quarters in Leipzig have not been altered. The only quarter with changes at all is Halle “Westliche Neustadt”. Considering changes on class level, numbers are not consistent if both city centres are compared: the class “high density” grows in Halle but falls in Leipzig, and for the other two urban classes it is vice versa. The decline of the class “bare soil“ can be explained with the disappearance of construction sites in both quarters. In the pre-fabricated housing estates, ED rises in all urban classes and for both examples chosen, which explains the spread of urban features, here. On the contrary, ED of “bare soil” and “agricultural land” fall in accordance to their decreased areal extention. These findings can be transferred to the quarters “Kröllwitz” and “Probstheida” where a similar trend is apparent.

MPI on landscape level is constant except the quarter “Probstheida” in Leipzig. There, an increase can be observed as a result of intensified urban sprawl and landscape fragmentation, respectively. With reference to the city centres, MPI on class level drops to zero for the class “bare soil”, which can only be true if the class is not present at all as in the case of Leipzig, or if the class is comprised by a solitary patch without any neighbours as in the case of Halle. The MPI values of urban categories also decrease indicating a slightly decreased compaction within the city cores. In the pre-fabricated housing quarters, MPI of most urban categories is increased, i.e. patches have become larger and distances beween them have declined. The opposite is true for the patch type “bare soil”and “agricultural land” meaning that patches have got smaller and are further away from each other. In “Kröllwitz” and “Probstheida” similar numbers have been obtained.

Inner city dynamics comprise surface sealing processes in rather peripheral quarters and increased frragmentation of large semi-natural space. Soil sealing has been proved with the index %LAND. All other metrics deal with aspects of fragmentation and landscape heterogeneity. Semi-natural areas become successively smaller (MPS, LPI) due to a spread of urban features and are also faced with increased PD and decreased MPI respectively. The reverse is true for urban categories.

9. Final Summary

Analysing settlement structures and the fragmentation of the agglomeration Leipzig-Halle was the main goal of this work. Suburbanisation continues in the area of interest bearing ecological problems such as increased rain water runoff and climatological impairments. On the other hand, the construction of transportation infrastructure leads to highly fragmented landscapes, in which only specialist species survive. A combination of RS techniques and landscape metrics aided in inferring information from land cover structures present in the area of interest and their change over time. Two Landsat images of different dates were classified and superposed by linear features (transportation network) derived from digital biotope maps of Saxony and Saxony-Anhalt. The public domain software FRAGSTATS was applied to compile landscape metrics for areas subset in a lattice with square grid cells. Furthermore, city and city quarter borders were overlain in order to assign values from these quadrates to certain administrative areas. Indices have been compiled with the help of database management and multivariate statistics and can be summarised as follows:

- Geometric resolution of applied satellite data, the mixed pixel problem, misclassifications, and the elimination of small patches (post-classification smoothing) affect the generated landscape metrics.
- Data quality of the biotope maps is essential in determining landscape indexes for the class “traffic”.
- Grid cells allow for comparisons of various indices but are not relevant for planning purposes. Thus, indexes have been assigned to different administrative areas (cities of Halle and Leipzig and their city quarters) by statistical means.
- Differences between Leipzig and Halle are mainly the result of successive enlargements of the administrative area of Leipzig, whereas Halle`s city border has not been altered between 1992 and 2000.
- Results are distorted to some extent because non-urban land outside both cities′ boundaries comprises smaller urbanised villages and even cities, which have been amalgamated with other semi-natural features in the landscape.
- For various land cover classes differences between the cities and their hinterland have been successfully measured despite the class “medium density housing”.

- A gradient from the cities´ interior towards peripheral quarters has been observed that nearly reflect current population densities.
- The form index LSI should not be used in future analyses because the shape of semi-natural patches in human modified landscapes is highly dependent on artificial patch types.
- Changes over time can be successfully monitored using this set of landscape indexes, particularly on landscape level. Ongoing surface sealing, i.e. a spread of urban land uses, has been proved with the index %LAND. Inner city quarters are characterised by compaction of existing urban structures because of a loss of urban green, which leads to increased homogeneity. On the opposite, increased heterogeneity has been measured for the categories “farmland” and “bare soil” in remote city quarters.

Though drawbacks have to be taken into account, RS data can facilitate a monitoring of areas with large extent. Generated landscape metrics successfully quantify and characterise landscape patterns of the agglomeration Leipzig-Halle. A small set of different common indices is suitable for a monitoring of landscape structure.

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12. Appendix

Table 15: City quarters and population densities.

Quarter-ID	City	Name of city quarter	Population density [Inh./sq.km]	
			1999	1993
1	Halle	Tornau	108	121
2	Halle	Seeben	349	201
3	Halle	Mötzlich	120	98
4	Halle	Industriegebiet Nord	169	297
5	Halle	Ortslage Lettin	236	209
6	Halle	Gottfried-Keller Siedlung	622	605
7	Halle	Kröllwitz	951	904
8	Halle	Frohe Zukunft	1161	1194
9	Halle	Ortslage Trotha	5005	5582
10	Halle	Heide-Nord/Blumenau	5740	6989
11	Halle	Dölau	860	618
12	Halle	Dölauer Heide	2	6
13	Halle	Landrain	2081	2087
14	Halle	Giebichenstein	4661	4317
15	Halle	Dautzsch	470	341
16	Halle	Diemitz	694	739
17	Halle	Paulusviertel	8542	9183
18	Halle	Heide-Süd	421	120
19	Halle	Am Wasserturm/Thaerviertel	753	865
20	Halle	Gebiet der DB	55	112
21	Halle	Reideburg	295	268
22	Halle	Saaleaue	55	49
23	Halle	Nietleben	824	793
24	Halle	Nördliche Innenstadt	5395	5963
25	Halle	Nördliche Neustadt	9570	12278
26	Halle	Freiimfelde/Kanenaer Weg	1393	1758
27	Halle	Altstadt	6429	6731
28	Halle	Westliche Neustadt	10196	13619
29	Halle	Büschdorf	758	465

Quarter-ID	City	Name of city quarter	Population density [Inh./sq.km]	
			1999	1993
30	Halle	Gewerbegebiet Neustadt	16	0
31	Halle	Südliche Neustadt	8769	10873
32	Halle	Südliche Innenstadt	9003	9937
33	Halle	Kanena/Bruckdorf	239	240
34	Halle	Lutherplatz/Thüringer Bahnhof	5881	6319
35	Halle	Gesundbrunnen	5068	5292
36	Halle	Dieselstraße	260	261
37	Halle	Damaschkestraße	3556	3996
38	Halle	Böllberg/Wörmlitz	397	438
39	Halle	Südstadt	8677	10257
40	Halle	Ortslage Ammendorf/Beesen	1720	1800
41	Halle	Silberhöhe	13036	18062
42	Halle	Radewell/Osendorf	322	279
43	Halle	Planena	7	6
44	Leipzig	Mockau-Nord	2703	3695
45	Leipzig	Eutritzsch	2333	2664
46	Leipzig	Möckern	2546	3201
47	Leipzig	Gohlis-Nord	4308	5029
48	Leipzig	Mockau-Süd	3188	3919
49	Leipzig	Schönefeld-Abtnaundorf	3330	4192
50	Leipzig	Schönefeld-Ost	3235	3670
51	Leipzig	Gohlis-Mitte	9192	11860
52	Leipzig	Gohlis-Süd	5544	6680
53	Leipzig	Zentrum-Nord	4450	4815
54	Leipzig	Zentrum-Nordwest	1397	2147
55	Leipzig	Sellerhausen-Stünz	2665	3389
56	Leipzig	Zentrum-Ost	1588	1694
57	Leipzig	Altlindenau	4479	5568
58	Leipzig	Volkmarsdorf	8000	10346
59	Leipzig	Neustadt-Neuschönefeld	8947	10483
60	Leipzig	Zentrum	2750	3161
61	Leipzig	Zentrum-West	4074	5576

Table 15 continued.

Quarter-ID	City	Name of city quarter	Population density [Inh./sq.km]	
			1999	1993
62	Leipzig	Neulindenau	2111	2773
63	Leipzig	Anger-Crottendorf	4177	5787
64	Leipzig	Reudnitz-Thonberg	7741	8460
65	Leipzig	Zentrum-Südost	2936	3464
66	Leipzig	Lindenau	4692	5095
67	Leipzig	Schönau	1772	2084
68	Leipzig	Zentrum-Süd	5045	6082
69	Leipzig	Schleußig	3957	4394
70	Leipzig	Plagwitz	4941	5573
71	Leipzig	Stötteritz	3229	3663
72	Leipzig	Südvorstadt	6710	8421
73	Leipzig	Grünau-Ost	8970	11183
74	Leipzig	Grünau-Mitte	13411	16504
75	Leipzig	Kleinzschocher	2508	3139
76	Leipzig	Probstheida	981	797
77	Leipzig	Grünau-Siedlung	2584	2280
78	Leipzig	Marienburnn	5006	5743
79	Leipzig	Lößnig	6318	7423
80	Leipzig	Seehausen	120	
81	Leipzig	Wiederitzsch	702	
82	Leipzig	Lindenthal	449	
83	Leipzig	Lützschena-Stahmeln	199	
84	Leipzig	Plaußig-Portitz	350	610
85	Leipzig	Thekla	840	1113
86	Leipzig	Wahren	1319	1058
87	Leipzig	Böhlitz-Ehrenberg	999	
88	Leipzig	Heiterblick	1089	225
89	Leipzig	Leutzsch	1845	1876
90	Leipzig	Paunsdorf	4197	5215
91	Leipzig	Engelsdorf	843	
92	Leipzig	Burghausen-Rückmarsdorf	244	
93	Leipzig	Althen-Keinpösna	190	

Table 15 continued.

Quarter-ID	City	Name of city quarter	Population density [Inh./sq.km]	
			1999	1993
94	Leipzig	Mölkau	1005	
95	Leipzig	Miltitz	654	
96	Leipzig	Baalsdorf	279	
97	Leipzig	Grünau-Nord	13257	18266
98	Leipzig	Connewitz	1834	1810
99	Leipzig	Holzhausen	469	
100	Leipzig	Lausen-Grünau	4632	19162
101	Leipzig	Großzschocher	552	626
102	Leipzig	Dölitz-Dösen	1024	987
103	Leipzig	Liebertwolkwitz	517	
104	Leipzig	Meusdorf	1938	2020
105	Leipzig	Knauthain-Hartmannsdorf	532	454
106	Leipzig	Rehbach-Knautnaundorf	43	

Table 15 continued.

Hiermit erkläre ich, dass ich diese Arbeit sebständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Alle sinngemäßen und wörtlichen Zitate sind kenntlich gemacht.

Leipzig, 12. März 2002