Urban ecosystem classification – land use based information for modelling, comparison and management

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Abstract. Different methodological procedures, scientific and practical questions concerning the urban environment require a common spatial work basis. The structuring of the city and its surrounding countryside into comparable, classifiable spatial areas (“urban structure types”) has been developed in geography in contact with the spatial planning and ecology as a practicable and appropriate method of the urban ecological research and management. The experiences of the landscape-ecological spatial dimensions were successfully transferred to the specific urban conditions.

It can be showed that land use related information can be used for urban landscape classification. This includes land use forms as well as utilization intensities and land cover in differentiated form. This allows interlinking science and planning in a successful way.

The classification system consists of urban structure types marking areas of physiognomic homogeneous development, those are predominantly characterized by clearly distinguishable characteristics in built up structures and open spaces (vegetation structure and soil sealing). They are to a large extent homogeneous concerning specific, density and portions of the built-up areas of various forms and of different developments of the open spaces (soil sealing areas, vegetation types and urban forest).

Substantial ecological characteristics of the urban landscape can be described by the land use form and the structural characteristic. Spaces with uniform structural equipment and the same land use form exhibit comparable habitat or landscape household function. Urban structural units/types allow statements to the habitat and vegetation structure, to the climate conditions, the soil, soil sealing intensity or the ground-water renewal. The urban ecosystem classification summarizes ecosystems of similar environmental condition.

The classification system allows comparing structural units in different cities – a task to understand the ecosystem functionality in science, to adopt ecosystem management to ecosystem conditions and to exchange relevant information between cities. Different to comparisons between cities with this tool different comparable ecosystem types can be compared in its consistency, functionality, maintenance etc..

Key words: urban land use, classification, land cover, structural vegetation types, types of built-up areas, comparison, structural and functional approach

Urban land-use - basic information on how human influence steers ecological features

Strong management of urban systems requires an understanding of the nature of the different landscape components, how the features of the components influence the processes within the area, and how the components interact to modify the influences or even create new ones. This section will outline two of the current
approaches to investigating the urban landscape, and a third method for describing landscape components which incorporates pattern and process.

Landscape components are currently described using the terms land-cover or land-use. These two terms are often used interchangeably, but this is incorrect as they represent fundamentally different aspects of the landscape component. The first term, land-cover, describes the physical attributes of the space (“existing material elements”), while the second term land-use describes how this space is being used by humans (“for what?”). Due to the fundamental difference between these two terms, it is important to clearly define which term is being used, and the reason for using it. The need for clear definitions is particularly important for comparative work as it will reduce communication problems, especially in the face of a wide variety of additional terms such as land-structure, actual use, spatial use, etc. For the purpose of this paper, land-use will be the main term used to define landscape components, as this term encapsulates more of the social processes occurring in urban landscapes, and therefore can provide greater insight into the social drivers which determine landscape structure and pattern.

Utilization is the fundamental process of the determination of space by humans. It means the utilization of technical and natural conditions of the environment by humans at the level of the individual, group or society. Utilization or land-use is not a condition, but a procedure. The available space can be subject to several requirements for utilization at the same time. This can be called multi-functional (targeting) utilization. Since land-use relates to procedures, there is also a temporal dimension composed of retrospective land-use (history) and projected land-use in planning (e.g. master plan). The utilization process itself is highly complex and in order to be modeled must be reduced to selected parameters. The basic positions, procedures and goals of this reduction must be explained in each case, since otherwise the term land-use can be misinterpreted.

The complex term land-use covers completely different things such as using open spaces or building use. However, there are general patterns of use which make it possible to classify general land-use types. Land-use varies over time and the term expresses the spatial orientation of utilization procedures (Richter 1989, Richter, Kugler 1972, Haase, Richter 1980a).

The development of ecological research in urban areas was also connected with the expansion of geographical landscape research, landscape ecology and ecological landscape planning in urban areas. The early research in the 1970’s was largely in the field of geographical landscape research, although it did not precede without influence from biology, in particular the vegetation science. In the 1980’s the need to incorporate spatially explicit locations for results from different research disciplines became a priority in an effort to gain a clearer understanding of the spatial distribution of ecological conditions within an urban area. Geographical landscape research tried to address this challenge drawing upon theories of landscape research from geography and landscape ecology which had already been well established from studies located outside of urban areas (Neef et al. 1961, Neef 1963). This focus gave rise to a wave of landscape-ecological work conducted in cities (Breuste 1985, 1986, 1989, Haase, Richter 1980b, Huelbusch 1982, Kaerkes 1985, 1987, Richter 1984, Schönfelder 1988), particularly through the implementation of habitat mapping. Land-use structures offered themselves as initial means for the differentiation of components within the urban cultural landscape.

If one peruses the geographical research on land-use, it becomes clear that it represents primarily a linkage of geography, biological sciences and spatial and regional planning. The geographical landscape research strengthened investigations into the utilization process and its relationship to natural components of the landscape. During the course of this research, it became apparent that the social function of areas was not of greatest importance for determining spatial landscape pattern, and the “process of the landscape influence and change” or “the degree of transformation of the natural balance of matter and energy of a landscape” (Schrader 1985, p. 24) became the centre of interest. On the basis of land-use types, spatial ecological units, urban landscape units, urban structure units of homogeneous physiognomic structure were developed for urban landscapes (e.g. Breuste 1985, 1986, 1989, Duhme, Lecke 1986, Duhme, Pauleit 1992, Leykauf et al. 1989). Landscape ecology operates at a broader scale that that used for habitat mapping, and can be used in situations which require a broader level of investigation and reflection.

In the 1980’s meso-scales were primarily used to provide an overview of the whole city or urban landscape. An example of this scale of research is the investigations of general urban climate and the urban heat
Urban ecosystem classification based on land use related information

The two previous methods outlined for use in classifying the components of urban landscapes have been widely used as a basis for modeling patterns within urban areas. However, while both of these methods are useful for describing patterns, they are less useful for examining processes due to their general definitions and broad applications. One method available when information is required at a finer spatial scale, is the use of "urban structural units". Urban structure types definite areas of homogeneous physiognomic development, which are predominantly characterized from each other by clearly distinguishable characteristics in built up structures and open spaces (vegetation and soil sealing). They are, to a large extent, homogeneous concerning the type, density and portions of the built-up areas of various forms and of different components of open spaces (soil sealing areas, vegetation types and urban forest) (Breuste 2006, p. 6). Urban structure types offer an opportunity to combine the structural information available from the soil sealing classification system, with the utilization processes associated with the land-use classification system. They therefore allow modeling of processes within the urban system at a finer level of detail than using the other methods, whilst maintaining the advantages of comprehensive and cost-efficient data collection.

Substantial ecological characteristics of a space can be described by the land-use form and the structural characteristics. Spaces with uniform structural equipment and the same land-use form exhibit comparable habitat or landscape household functions. In this regard urban structural units summarize spaces with similar complex environmental conditions. Therefore they can be used as the basis for collecting information on the ecological or landscape characteristics of urban areas, as each unit has a predictable type of habitat and vegetation structure, climatic conditions, soil structure, intensity of soil sealing and rate of ground-water recharge.
The main types of urban structural units found in urban areas are residential estates and areas of mixed use, industry and commercial areas, areas of specific use, traffic areas, leisure and recreation areas, agricultural areas, forest areas, water bodies, derelict lands and land-fills, quarries and disposal sites (Wickop 1997). These structural units can be further divided on the basis of more specific forms of development (Breuste 2006, p. 6). Function-oriented land-use types (maps, listings etc.) nevertheless lend themselves to planning applications because of their broad application as reference level in the urban planning, which allow them to be easily integrated into management recommendations. Indicator characteristics can be used to further differentiate the ecological conditions within urban structure types. Soil sealing as an indicator of human influence is currently far more advanced than the indicator vegetation structure. So far, data for the characteristics of the vegetation used in ecological urban spatial patterns, in particular habitat mapping, is often non-uniform and partly ambiguous. For the designation of this characteristic, the term “vegetation structure” (also called green areas) is frequently regarded as an indicator of utilization and maintenance intensity. It is also used as an indicator for different kinds of utilization and maintenance intensity of the areas outside of urban areas, with a cover of predominantly vegetation (Breuste 2006).


Due to the defining characteristics regarding utilization type and building structure there are direct relations between the scientific framework of the urban structure types and the instruments of urban planning (as master plan, zoning plan and site/property planning). They provide a crucial means for understanding the environmental development of cities, and their utility has been demonstrated in the cities of Munich (Blum 1991, Duhme, Pauleit 1992, 1994), Berlin (Stadt Berlin 1996), Leipzig (Kabisch et al. 1997) and Halle, where they have successfully used urban structure types for their environmental planning (Breuste 2006, p.6). Their monitoring has been facilitated by the development of new technologies, such as aerial photographs and satellite images and the advent of computer programs with the ability to combine existing maps and data (Breuste et al. 2002).
Table 1. Examples of types of vegetation structures used by working group on habitat mapping within urban areas (Arbeitsgruppe Biotopkartierung im besiedelten Bereich 1993).

<table>
<thead>
<tr>
<th>Vegetation structure type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Decorative Green</td>
<td>Flower beds, small lawn patches, bushes, hedges etc. (well cared for)</td>
</tr>
<tr>
<td>Accompanying Green</td>
<td>Green strips along traffic lines or as addition to fill up the space between apartment blocks</td>
</tr>
<tr>
<td>Gardens/Parks</td>
<td>Urban open spaces, well maintained</td>
</tr>
<tr>
<td>Allotments</td>
<td>Privately used garden plots (allotments) territorially organized in groups 100 or more as closed-up area</td>
</tr>
<tr>
<td>Urban Lawns</td>
<td>Large open lawns regularly mown for recreational uses</td>
</tr>
<tr>
<td>Urban Forests</td>
<td>Forests as remnants of former seminatural landscape in the urban areas, used for recreation</td>
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Needs and content of urban ecological comparative studies

There is a strong need for the comparison of urban ecological studies world wide. This is necessary to separate local and individual results from broadly applicable general trends. On the other hand regional and local studies can only be valued if the spatial circumstances (natural and anthropogenic) are clearly defined. A formalized clear description of the spatial conditions of an investigation will allow for comparisons between research conditions and the associated findings. Also, the characteristics of the selected spaces can be compared between cities (for instance, residential estates in different countries) and even the spaces themselves. New and interesting knowledge on urban ecosystems can be expected from undertaking comparisons between different urban ecosystems (and their elements) and between different research results in various locations.

Comparison of general human influence on urban ecosystem on large spatial scale - land use as comparative factor

The main factor of human influence on urban ecosystem is land-use (see above). It makes sense to start comparisons by definition and typesetting of this factor. The target of this approach is to create categories which reflect different levels of human influence on urban ecosystems at a large spatial scale (urban ecosystems, cities etc.). Following this, comparisons between completely different urban ecosystems, such as Warsaw and Berlin, are possible by describing their land use structure and ecological relevant characteristics. The comparison can be made on small scale at a structural level (overview). The object of such comparisons can be the identification, qualification and quantification of areas representing different degrees of human influence. Different land use categories can be grouped to represent each of the categories high, medium or low human influence on ecosystem. This is an easy initial form of assessment, which offers a lot of possible interpretations and answers to questions. The following are examples of questions which can be addressed at the level of the entire urban ecosystem.

Comparison of human pressure on ecosystem: How much space (square kilometers, per cent of the space etc.) of the urban ecosystem is under high, medium or low human influence?
This allows an initial quantification of human input on the urban ecosystem as a whole.

Comparison of the spatial structure of the ecosystem: How can the urban patterns in general be described?
Where in the urban ecosystem are these areas located? What is the spatial structure of the landscape?
This allows for the comparison of structural information between cities. The description can be made by maps, by distance zone around the city centre (CBD) or even by mathematical methods (landscape metrics etc.).

Comparison of the speed of changes: How fast are the changing processes between these main categories?
Next to space, time is the most important factor for urban ecological changes. The time scale of ecological changes can be shown and compared.

Comparison of the quality of changes: Is the quantitative spatial growth connected with qualitative changes?
Urban growth is commonly measured as the expansion of urban land use. This information is not qualitative, whereas the altered configuration of land-use provides a more detailed and informative measure.

**Comparison of the intensity of human influence on urban ecosystem using selected indicators – example soil sealing indicating hydrological processes**

The research on selected human influenced processes in urban ecosystems as climatic, hydrological or ecological processes is of high relevance. More and more urban ecological studies are oriented towards understanding human influences on natural processes in order to improve their management or even to begin to manage them. These human influences must be investigated on small scale level by measuring the matter content (air, water, soil, vegetation etc.) and/or the fluxes of matter and energy. Most of these fluxes are influenced and regulated by the urban surfaces (“land cover”). To compare investigations, the description of the physical consistency of these surfaces as a transformer of energy and matter is necessary. One way to rapidly overcome this hurdle to information is to identify and assess the transformation properties of sealed soils (by different pavements). This can be done on all level of investigation, by summarizing information at a broad scale, by collecting structural information on a medium scale (ecological pattern) and by collecting detailed information on pavement types at a small scale, e.g. hydrological assessments.

Sealed soils are a relevant approach to urban ecological comparisons. They are typical for all cities, cover large areas in all cities world wide and they are an indicator for general “degradation/de-naturalization” of the urban ecosystem as well as a specific steering factor of water cycle, micro-climate, habitat conditions etc. This offers a lot of possible interpretations and answers to questions such as:

- **Quantitative approach on large scale:** How much area of a city is occupied by sealed soils? This allows a comparison between cities by using one main indicator which is widely applied world wide. A quantity in square kilometers or in percent of the total urban space can be given.
- **Growth rate of human pressure on urban ecosystem:** How fast are these areas growing?
- **Increasing pressure of human influence on urban ecosystem:** Which areas are changed into sealed soils? The location of newly implemented sealed soils shows which ecological units are most susceptible to land-use conversion pressure. It shows which habitats (part of the urban and peri-urban ecosystems) come under stronger urban influence and which are spatially reduced.
- **Soil sealing as internal factor of urban pattern:** What is the degree of soil sealing in different land use types? Which land use types have the highest degree of soil sealing?
- **Soil sealing as a factor of ecological differentiation between land use types:** It can show the extent of change to specific land use types and which of these land-use types are really comparable by the same degree of soil sealing (e.g. residential areas, commercial areas etc.).
- **Association of soil sealing:** With what other ecological relevant factors is soil sealing connected?

To understand how soil sealing is connected with other human factors (i.e. economy, income groups of population, age of built-up structures etc.) can be an important point of comparison between cities. This comparison can highlight the interactions between socio-economic and ecological factors.

**Determination and comparison of urban pattern qualified by process indication**

A relevant and accurate possibility to compare ecological conditions of cities is to define urban structural units (USU) in each investigated city. It allows a direct connection for data on land use and land cover, indicating natural processes. This process is well established in medium scale research in addition to small scale investigations. It allows the assessment of not only a general degree of human impact on the urban ecosystem but also a detailed spatial view, which includes the assessment of relevant human influenced natural processes (such as climate, hydrological and ecological processes etc.). Especially the definition of additional characteristics.
of land cover (soil surfaces) as sealed soil types, building types and types of vegetation can give a clear view on the main ecological factors of an area as representative of a spatial type. This can be used for a sharp and clear comparison of many other further characteristics and even allows an assessment of the structure and components of the urban ecosystem. This offers a lot of possible interpretations and begins to address such questions as:

**Structural approach:** How differentiated are the land use classes in an ecological sense? Which ecological types of urban structural units are useful to define?

The identification, mapping or use of urban structural units in GIS allows the characterization and assessment of its (internal) characteristics in different directions. This can even be used for a detailed and complete overview of the urban ecosystem.

**Stability approach (internal changes):** Which USU are in its characteristics generally stable over many years and which are rapidly changing their characteristics?

The urban transformation is not only connected by external growth but also by strong internal changes of urban ecological characteristics. These changes can be quantified in terms of changes to the characteristics of the urban structural units. It can be shown which of them are stable over many years. This provides important information on ecological conditions and allows the ecological stability of cities to be evaluated.

**Growth approach (external growth):** Which USU are the most important in the urban growth process and which ecological consequences are connected with them?

When it can be identified which urban structural units are consistently constructed on large newly created areas in the urban fringe zones of cities, a qualitative assessment of the growth process and its elements is possible. This allows an increased understanding of the urban growth process.

**Comparison of detailed small scale investigations:** Which are the ecological circumstances characterizing detailed local investigations (often by measurements) of climatic, hydrological, ecological etc. factors to compare the results between cities?

A very important question is the comparison of detailed studies, for example on urban climate, distribution of plants and animals, pollution of water, soil or air etc. Previous studies in different cities have not sufficiently described the conditions under which they had been undertaken. Even where the description is more detailed, a comparison with other studies is not possible because of the singularities of the locations. The use of urban structural units would facilitate urban ecological investigations and their comparison between cities.

**Conclusion**

The landscape-ecological modeling of urban landscapes has grown substantially over the past 35 years, yet there is still room for further improvement. While the monitoring methods are now largely automated (e.g. utilization of the remote sensing techniques), there is still the need for substantial research focusing on modeling process rather than structure. This research is not necessarily to the detriment of structural models, as these two types of research are intricately related. Progress in the ability to model processes will also help to refine the structural models of urban landscapes. Categories of land-use in urban landscapes continues to be an important criterion for the demarcation and characterization of ecologically homogeneous areas.

The contribution that land use makes in terms of acting as major influence on ecological systems in urban areas and indicator of associated processes is confirmed in a broad sense. However there is still only limited research into the utility of this system as an indication of process. It is important to use and further develop the existing methods of landscape research and to adapt them to urban conditions. The existing and wide spread application of land-use based modeling is only partly effective, and should be extended by the addition of further characteristics. Depending on the questions being addressed, a further differentiation of the existing land-use based urban ecological structures may be recommended, using the methods for creating urban structural units.

It is also important to remember that the urban landscape is not strictly separated from other cultural and natural landscapes. Thus models need to include and further examine natural characteristics which can be used to refine the methods for quantifying landscape pattern. There are currently methodological deficiencies in using general
landscape-ecological methodology and with the current system of selecting, differentiating and evaluating the ecological characteristics of the urban landscape. These deficiencies have far-reaching consequences beyond those associated with the practical planning process, so it is important to obtain accurate and scientific results. Nature protection and eco-urban development will benefit from the further development of comprehensible landscape-ecological methods of analysis and evaluation of the urban landscape structure.

References


