THE MAPPING OF URBAN HABITAT AND ITS EVALUATION

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This discussion paper traces changes in approaches to habitat, land-use and biotope mapping in the built environment and, in a non-technical manner, provides a series of examples that demonstrate the limitations and value of these different approaches.

It might seem axiomatic that planning decisions concerning the future should be based on comprehensive information and appraisal of what already exists. It is evident, however, that in many towns and cities, and on many occasions, decisions that greatly affect the urban fabric, the urban landscape and urban quality of life have been made, and continue to be made, on incomplete, inappropriate, marginally relevant or partial data. Urban planning in general, environmental planning in particular, and nature conservation and amenity planning most of all should demand a comprehensive, frequently updated set of relevant information. Much of this information needs to be given a spatial framework, including distributions and distributional interrelationships. In a word, the information needs to be mapped. And these maps need to be in a format that can be accessed, reviewed, interpreted and used. We therefore not only need mapped information but also a team of people who can undertake these tasks and who can then provide decision-making non-experts, who may hold the purse-strings and political authority to allocate resources, with a cogent set of options and opportunities.

In order to use the green environment as a component in the decision-making process in urban planning and, reciprocally, in order to use the planning process as an opportunity and tool in the enhancement of the green environment it is necessary to know what actually exists, what the planning and conservation goals are, and what the options are for achieving these goals. The green environment itself must be seen as including biodiversity, habitat type (biotope), habitat quality, and the structure and pattern of the landscape. Together, these components provide what might be thought of as the ‘green capital’ of the city, and we must seek ways of using this capital as an investment for the future in such ways as to yield profit on that investment – profit in the sense of an enhanced quality of urban life for people, plants and wildlife.

This green capital ranges from the presence of common and abundant species to the rare and restricted; from relict ancient woodland to small manicured lawn; from large semi-natural vegetation to tiny wasteland plots; and from integrated green networks to isolated green islands. Quantifying and mapping the green capital is essential for identifying, monitoring and assessing the consequences of planning decisions, bearing in mind that urban form and function are both inherently dynamic. Mapping has increasingly become dependent on geographic information systems (GIS), and many of the tools of landscape ecology have been usefully applied to issues of green planning, whether in terms of methodology or pattern analysis.

The changing pattern of urban land use reflects the on-going human processes of planning, building and, often, neglect, and influences the ecology of the built environment: ecological processes in the city are usually more or less constrained by what humans do and have done. There is a need to develop appropriate management tools for the conservation, enhancement and management of biodiversity and the green environment. These tools are often GIS-based or use expert systems such as CMS (Conservation Management System – see www.esdm.co.uk/default.asp) and can enable decision-makers such as a local authority to set out appropriate goals, identify realistic choices, implement suitable environmental impact assessments, and monitor results.

One problem with classifying and mapping urban habitats is that most show important differences in content, structure and disposition compared with their non-urban equivalents. Many examples of ‘classic’ vegetation types such as deciduous woodland, scrub and unimproved grassland fall awkwardly into the NVC (National Vegetation Classification) system. For example, relict ancient woodlands in towns tend to have a depauperate ground flora compared with their rural analogues; they are often relatively small in areas and are not infrequently isolated, with implications for the dispersal of some plant and less motile animal species; and they have a greater amount of ‘edge habitat’ (with implications for disturbance) and less ‘core habitat’ than outside the built-up area. Another problem is that there exist a number of habitats that are essentially only ever found, or are only really important, in towns and cities, for example garden lawns, street trees, playing fields, waste lots and railway marshalling yards. And plant communities often reflect what has been called recombinant ecology, where species have ‘recombined’ into assemblages unique to particular urban locations or environments (Barker, 2000).

At the very least it is important to have descriptive information on what is present, whether land-use, habitat type, landscape characteristics or species distributions. A number of exercises, however, have also usefully attempted to place some level of ‘value’ on what is there. Quantification of value, however this is defined and whether for wildlife or for people, for conservation or amenity, is potentially valuable in its own right, but it also allows the planner to introduce ‘what if’ scenarios, and to quantify the environmental gains or losses associated with one set of changes compared to another: the consequences of creating or destroying a habitat corridor on wildlife, for example, or the effects of the addition or subtraction of an access route to a green area’s amenity value.

Mapping species and species associations

Species distributions and, consequently, spatial representations of biodiversity can only be assessed by field survey which is time-consuming and labour-intensive, and often requires a high level of taxonomic expertise. Results are generally presented as presence-absence maps on grids of 1 km X 1 km or 2 km X 2 km. Such maps become particularly valuable if there are opportunities to relate species distributions to key environmental variables, using GIS systems, thus giving some degree of explanation. Many species are valuable as biological indicators, identifying particular environmental conditions, favourable or otherwise. Appropriate monitoring can allow the identification of environmental improvement or deterioration, as has been shown for tracing improvements in air quality using lichens as biological indicators (seminally, in the UK: Ferry, Baddeley and Hawksworth, 1973, and Hawksworth and Rose, 1976; also, see references provided by the British Lichen Society at www.thebls.org.uk/refren.htm).

Distributional data collected using the same sampling procedures over a number of years and presented as a series of maps can be an important tool for monitoring environmental changes. Information presented as dot maps may be useful in identifying and explaining population as well as distributional changes (Harris and Rayner, 1986), or indeed potential disease threat, as with modelling the possible spread of rabies in urban foxes (Saunders, White and Harris, 1997).

Single maps, however, often represent data collected over a number of years, and might not be able to distinguish between, on the one hand, a single sighting some years previously of a species in practice no longer present and, on the other hand, multiple sightings of a common, regularly-occurring species. This, together with a lack of systematic survey, is a major criticism of such ventures as the Provisional Atlas of Mammals in the West Midlands (UK) (Wyatt, 2004), for example, though for plants in the same region a six-year survey of vascular plants makes botanical data more convincing. Fig 1, for example, shows the distribution of common poppy as produced by EcoRecord using the Recorder package from survey data covering the period 1982-2004, though with emphasis on the last six years. Despite such caveats it is clear that cartographic representations of distribution data are an important tool in urban conservation and planning, and have been since at least Bunny Teagle’s snapshot of the Birmingham, Sandwell, Dudley, Walsall and Wolverhampton conurbation in *The Endless Village* (Teagle, 1978), possibly the earliest cogent example of a survey-based argument for urban nature conservation in a particular region.

More interestingly, and also using a floristic database created with the Recorder package, presence/absence data for 829 vascular plant species in Plymouth, UK, have been analysed using two-way indicator species analysis (TWINSPAN) and canonical correspondence analysis to establish major species assemblages and to examine their spatial distribution across the city (Kent, Stevens and Zhang, 1999). TWINSPAN groups lying close to the first axis of variation correlated variation in plant species assemblages with the process of urban development and historical changes in urban structure. The second axis seemed to be related to a set of remnant semi-natural habitats within Plymouth that can be considered as ‘hotspots’ for survival. The idea of species hotspots, however, needs to be viewed in the context of the surrounding habitats and landscapes (see also below, ‘Value-added urban landscapes’). There are various ways of tackling this. One such is the relative approach adopted by Ricotta et al. (2001) who adjusted raw data on plant species richness, quantified for 190 cells covering the city of Rome, so that ‘biodiversity hotspots’ could still emerge even with a low degree of species richness where the surrounding cells were identified as having even lower values.

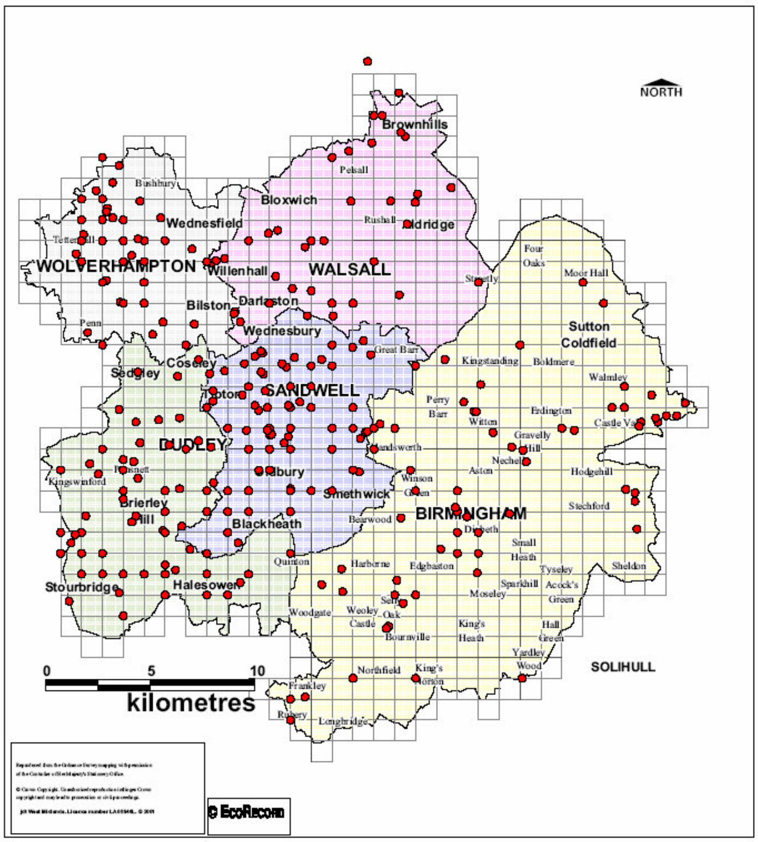


Fig 1 Common poppy *Papaver rhoeas*: distribution in the Birmingham and Black Country region

In another example of the application of mapping to both urban planning and nature conservation, Nakamura and Short (2001) examined the relationships between the distribution patterns of 165 endangered species (99 plant species and 66 animal species) and land-use planning in Chiba City, southeast of Tokyo, Japan. Distribution maps using 1.1 km X 0.9 km rectangular cells were analysed in terms of green cover and zoning categories, and suggested that regional diversity depended heavily on areas in which traditional landscapes remain relatively intact.

Where comparable data are available for a number of time periods, of course, it is possible to analyse floristic or faunistic changes in a variety of ways. Godefroid (2001), for example, has taken advantage of 1 km X 1 km grid floristic data for Brussels, Belgium, from 1943 onwards to demonstrate an increasingly nitrophilous and shade-tolerant flora, and a flora also increasingly dominated by introduced species.

Land-use and land-cover mapping in towns

Land use generally refers to the different uses to which land is put, from a predominantly human perspective, and if they have no direct human use categories tend to be fairly general. Examples are forestry, lowland agriculture and residential land. *Land cover maps* represent the dominant landscape cover in a particular area, and while often similar to land use does not adopt a particularly human or natural perspective. Examples are coniferous trees, arable fields, built-up areas. *Habitat maps* detail the distribution of particular species (usually plant) assemblages, but as a rule have lacked detail in urban areas because assemblages are often small in scale, complex and reflective of often unique ecological outcomes.

During the 1930s the Land Utilisation Survey of Britain, conceived and directed by the geographer L. Dudley Stamp, created a detailed record of all major land-uses in England, Wales and southern Scotland. Data were surveyed on 1:10 560 (6 inches to a mile) Ordnance Survey maps. Information, which included urban areas, was then published on a set of 169 map sheets using OS 1:63 360 (1 inch to a mile) maps, displaying the information according to a set of colour codes. With emphasis on rural areas, discrimination of urban land-uses was inevitably weak, but different kinds of open space were distinguishable, for example grassland, woodland (coniferous, deciduous, mixed), orchards and wetlands. As part of the war effort, written reports on the land-use maps were published in 1941.

A similar methodology was used in the 1960s under the directorship of Alice Coleman, allowing comparison with the survey undertaken thirty years earlier, and therefore providing an opportunity to categorise and quantify change. This timeline of historical data has continued with ecological surveys undertaken by the Institute of Terrestrial Ecology in 1978 and the Countryside Surveys of 1984, 1990 and 1998 using air photo and satellite imagery and ground-truthing. Data are now digitised, and GIS is generally used to store and handle data (see, for example, www.defra.gov.uk/wildlife-countryside.resprog/findings/landusemaps/n.georef.pdf) In 1996 the Geographical Association initiated a further land-use survey of the UK, carried out on 1 km^2 sample squares. Some of these squares incorporate built-up areas, such as those for Brighton and Hove (Fig. 2). Focus, however, remains on rural Britain, and information on urban land-use and habitats are incidental (Walford, 1997; Cassettari, 2003).

Fig 2 Land-use survey of Brighton, and example of an urban area in the 1996 LUS initiated by the Geographical Association (www.sussex.ac.uk/geography/1-2-4-1-2.htm)

However, there has been a respectable post-war history of aerial photographs having been used to acquire information on the land use of towns (Pounall, 1950), for example in Leeds (Collins and El-Beik, 1971). GIS has been instrumental in the production of environmental atlases, for example in the Randstad region of The Netherlands (Canters et al., 1991) and in St Petersburg, Russia (Chertov, Kuznetsov and Kuznetsov, 1996). In his review of GIS in Italian town planning, Craglia (1992) argues that, while such information provides an important tool for local authority planning departments, the implementation and use of GIS depends not only on the nature and attitude of the authority and its organisational structure but also on the needs, wishes and cultural values of the town's residents. This was certainly evident in the work of Sung et al. (2001) who linked objective estimations of likely landscape changes (using a geo-spatial information system) with subjective community-based landscape preferences (using a model based on an artificial neural network) in planning for a proposed large-scale housing complex developed on a mountainous area bordering the South Korean city of Kwang Ju.

As well as looking to the future, description, explanation and evaluation of the dynamics of historical land-use change using GIS and remote sensing can give a sense of how often and how much the green open spaces of a city are under pressure, not only in the diminution of area but in the reduction of land parcel size and increased fragmentation (see the later section on 'Patches, edges, connectivity and corridors').

Phase 1 and cognate habitat surveys

Phase 1 surveys provide 'a standardised system for classifying and mapping wildlife habitats in all parts of Great Britain, including urban areas. . . . The aim of Phase 1 survey is to provide, relatively rapidly, a record of the semi-natural vegetation and wildlife habitat over large areas. . . .' (Nature Conservancy Council, 1990: 7). The habitat classification is based on vegetation, with topographic and substrate features included where appropriate, and augmented by as full a species list as was possible in and at the time of survey. For sites perceived to be of importance for ecological or other reasons, a follow-up Phase 2 survey describes the plant communities in greater detail, wherever possible in terms of the National Vegetation Classification – something that is not always realistic in an urban setting, and there may also be some information on fauna.

In a Phase 1 survey, each parcel of land is generally visited and the vegetation mapped onto Ordnance Survey maps, usually at a scale of 1:10,000. Certainly this scale has been practicable for this kind of survey in Greater London and the West Midlands, but in places a scale of 1:2500 has been useful. The smaller 1:10,000 scale is often more readily able to suggest spatial relationships, including habitat corridors and barriers, that might be significant in the context of planning for a green environment.

Nationally there are around ninety specified habitat types, which are plotted using a prescribed colour and pattern code. In urban areas many of these habitats are irrelevant, and on the basis of early Phase 1 survey work, particularly in parts of Greater London and in the St Helens and Knowsley region of Merseyside, the definitions of some habitats were expanded and made more rigorous, in particular the 'tall ruderal' and 'ephemeral/short perennial' habitat classes which are essential to record as early successional communities on derelict land. Furthermore, two new categories were added on the basis of the urban experience – 'amenity grassland' and 'introduced scrub'.

In urban areas some selectivity in choice of site will almost certainly be appropriate. It is common, for example, only to consider parcels of land or water with an area at or above 0.5 ha. Data can then be digitised, providing a statistical as well as cartographic record.

Phase 1 surveys have been undertaken for many urban areas, an early example being such work during the early 1980s in Birmingham, Solihull, Coventry, Sandwell, Dudley, Walsall and Wolverhampton as a prelude to the production of the West Midlands Nature Conservation Strategy of 1984. Four surveyors covered an area of approximately 880 km^2, taking a year to complete the exercise on the basis of two days of fieldwork each week (Nature Conservancy Council, 1990). Subsequent strategies (following the demise of the West Midlands County Council in 1986) such as the Black Country Nature Conservation Strategy (1994) and the Nature Conservation Strategy for Birmingham (1997) also used the 1980s data, together with varying levels of re-survey, as their basis (Jarvis, 1996). Some of the information is held in digitised cartographic form, for example by EcoRecord on behalf (among others) of the local authorities. Phase 1 surveys provide a basis for most management plans (e.g. Fig. 3). And throughout the UK, habitat surveys have also provided information for the many local and regional biodiversity action plans that were produced in the latter part of the 1990s and the first few years of the twenty-first century.

Maps resulting from Phase 1 surveys are akin to the spatially-incomplete (selective) mapping described later in this paper.

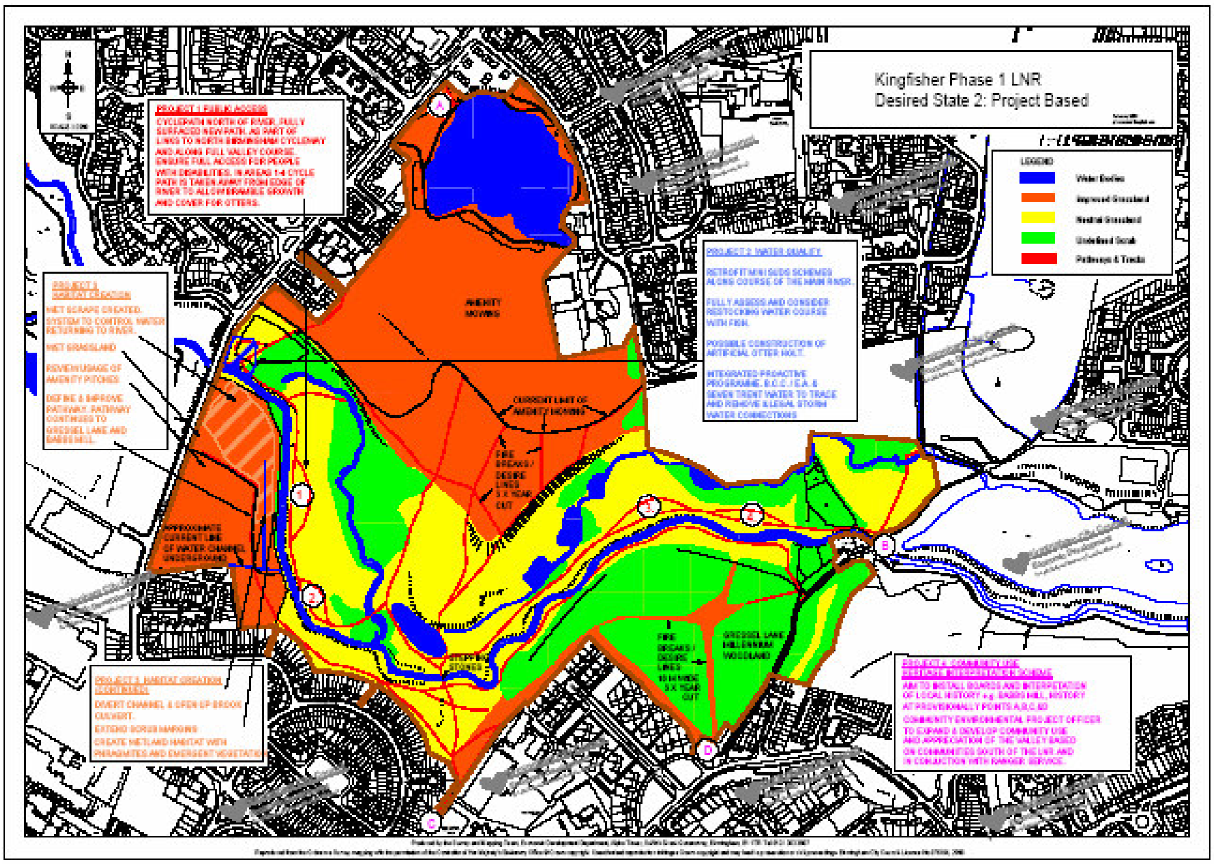


Fig 3 Project Kingfisher, Birmingham

Mapping tree cover and street trees

It is also often useful for planning purposes to survey just one particular kind of habitat (or land use), an obvious one in the context of planning for a green environment being that of woodland. Measurements of tree cover using remote sensing are also valuable in providing data used in urban forest management (Nowak, 1993), in modelling urban forest functions such as air pollution mitigation and carbon dioxide sequestration (Rowntree and Nowak, 1991) and in identifying opportunities for public recreation and other kinds of social benefit (Dwyer, et al., 1992). Certainly tree-cover data when combined with ground-sampling of species composition, tree height, trunk diameter and tree health enhances the opportunities for planning and the management of this green resource in towns.

There are four methods used in determining urban tree cover (Nowak et al., 1996):

- **Crown cover scale**, which involves placing a set of fixed transparent polygons (usually squares, for example on graph paper) over an aerial photograph. The percentage of polygons covering the particular land use or habitat can then be estimated, and converted into area.

- The **transect method** involves randomly located and orientated individual or parallel lines of random or fixed length which are made on acetate on overlain on the air photo. The length of line crossing tree crowns divided by the total length of the line gives a value for percent tree cover.

- The **dot method** is an alternative to the crown cover scale: instead of counting the area under each polygon, the land use or habitat under each polygon intersect (e.g. the intersections of a pattern of squares) is noted and added together. The number of dots (intersections) falling on tree crown divided by the total number of possible sample dots provides a generally good estimation of percentage tree cover, which once again can be readily converted to real area.

- However, with digitised imagery, **scanning** is these days the most precise, detailed and accurate method of analyzing urban tree cover, and is an integral part of most GIS.

As well as information concerning woodland cover it is often also useful for planners and urban landscape designers to know something about the distribution of street trees – species, location, condition, etc. Techniques used in street tree inventories have been reviewed by McBridge and Nowak (1989). Sanders (1981, 1984), for example, has looked at both urban forest structure and diversity in the street trees of Syracuse, New York, identifying a methodology for selecting appropriate strategies for future tree replacements. A similar exercise was undertaken in Ithaca, New York, in 1987 when the Shade Tree Advisory Committee conducted a complete street tree survey (Sun and Bassuk, 1991).

Using the rapid tree-sampling methodology proposed by Jaenson et al. (1992), Maco and McPherson (2003) used Davis, California, as a model for producing four kinds of information concerning public and private street trees, set into a context of costs and benefits:

- **Resource structure** (species composition, species diversity, age distribution, condition, etc.)

- **Resource function** (quantification of environmental and aesthetic benefits)

- **Resource value** (monetary value of benefits)

- **Resource management needs** (arboricultural care, etc)

Results showed that Davis maintained nearly 24 000 public street trees that contributed net annual environmental and property value benefits of around $1.2 million.

Jim (1986, 1987, 1989, 1993) has also examined in great detail the status, canopy characteristics and landscape implications of street trees in Hong Kong using questionnaires and field surveys. Such data strengthened his conclusion that land could be zoned specifically for tree planting, and that this could be more generous and spatially more evenly distributed to allow penetration of greenery into wider parts of the city.

Where there are long-term projects involving local authority and/or community-based tree planting schemes it is important to maintain a record of what has been planted, and where - evident in the UK at a regional level, for example schemes undertaken under the aegis of the National Urban Forestry Unit (www.nufu.org.uk) or London's Million Trees Campaign, launched in June 2002 (www.treesforlondon.org.uk/researchreports/milliontreescam), and at a more local level, for example the 10 000 street trees and over 15 000 park trees which are the responsibility of Lambeth Borough Council (www.lambeth.gov.uk/services/environment/parks-green-spaces/trees.shtml) or the 13 000 street trees which are the responsibility of Wolverhampton City Council (www.cartoplus. co.uk/wolverhampton/text_1/07natcon.htm).

Biotope and habitat mapping

Most ecological mapping of use to the urban planner and environmental manager is of habitats or biotopes. Habitats and biotopes are not infrequently used synonymously, though the latter is more accurately limited to describing an area with boundaries within which plants and animals can live (Dahl, 1908). Forman (1995) similarly refers to a discrete environmental areas characterised by certain conditions and populated by a characteristic biota. Large biotopes, however, can be considered as a ‘landscape’: the concept is scale-dependent and partly species-specific. The word habitat itself often has at least a resonance of implying how the various components of the biotope interact and function.

While the importance of green open space, especially green public open space, had long been recognised beforehand, it has been especially since the late 1970s that the value of more natural urban habitats to people, plants and wildlife has become a generally accepted part of planning philosophy. In their assessment of how urban biotopes represent a valuable tool in natural conservation, Starfinger and Sukopp (1994) stress how the green open spaces of towns represent modifications of older biotopes.

Selective mapping

The earliest biotope mapping programmes of the 1970s restricted themselves to the habitats of endangered plant and animal species in natural and semi-natural ecosystems in rural areas, with the aim of prioritising areas worthy of protection. Mapping was therefore selective. An example of selective mapping was the ‘Mapping of habitats worthy of protection in the city’, undertaken in Munich in 1978 (Brunner et al., 1979; Duhme et al., 1983). Mapping identified areas with at least some of the following characteristics: species-rich areas and the occurrence of at least some rare species; areas with high structural diversity; and areas of importance for informal recreation and with opportunities for urban dwellers to have contact with nature. Criteria for assessing the importance of these sites to people and wildlife were: degree of naturalness; rarity of the biotope (or individual components of the biotope); reproducibility of the site; intensity of land use; age of the site; size; location in the city; degree of disturbance or pollution; and the structural and species variety.

The biotope mapping of Brunner et al. (1979) in Munich was based on its flora but their interpretation incorporated planning and education issues as well as those of natural history. And in Augsburg (Bichlmeier et al., 1980; Müller and Waldert, 1981) biotope mapping incorporated information on flora, birds, herpetofauna and certain Orders of insect (beetles, butterflies and dragonflies).

A major problem of early survey work was that it was costly in terms of labour and money. What was needed was an approach to mapping which was quick and inexpensive while retaining its ability to indicate ‘value’, however value were to be defined. One attempt at this compromise approach was undertaken in Düsseldorf by Wittig and Shreiber (1983), who used a point-scoring system associated with four criteria – period of development (i.e. age and continuity of the biotope), area, rarity, and function as habitat. A major advantage of this methodology is that it requires no botanical or zoological survey, simply the recording of vegetation structure, and therefore information can be recorded by non-specialists taking a relatively short period of time.

Period of development (D) (how long the same community would take to establish itself elsewhere)

Scale: D0 = 1-2 years
D1 = 2-5 years
D2 = 5-10 years
D3 = 10-20 years

D4 = 20-50 years
D5 = 50-100 years

Area (A) (the larger the area the greater the probability of a species-diverse community, so age can be used as a measure of the biotope's value)

Scale: A0 = 0.1 ha
A1 = 0.1-<1 ha
A2 = 1-<5 ha
A3 = 5-<10 ha
A4 = 10-<25 ha
A5 = 25-<50 ha
A6 = 50-<100 ha
A7 = 100-<200 ha
A8 = 200+ ha

Rarity (R)

Scale: R0 = many similar biotopes occurring in the built-up area, the nearest equivalent being < 500m away
R1 = several similar biotopes, the nearest equivalent being 500-1000 m away
R2 = several similar biotopes, the nearest being 1-2 km away
R3 = nearest equivalent biotope > 2 km away, or only 5-10 corresponding biotopes in the whole built-up area
R4 = only 1-4 equivalent biotopes
R5 = no equivalent biotopes in the built-up area but existing in remaining urban area or within adjoining communities up to 5 km from the city boundary
R6 = no equivalent biotope in the whole urban area and local surroundings but > 5 in the total administrative area
R7 = no more than 5 equivalent biotopes in the whole metropolitan county area

Habitat (H) (only vegetation structure was considered)

Scale: H0 = almost exclusively grass or trampled ground
H1 = almost exclusively a uniform vegetation structure other than grass or trampled ground
H2 = two different vegetatioin structures
H3, H4 etc correspondingly increasing number of vegetation structures by one each time

The following were considered as different vegetation structures: wood; rows of trees; groups of trees; single trees; hedges and shrubbery; tall herbs; hay meadow; pasture; park grass/ornamental lawn; trampled areas; therophyte areas; ruderal xerothermic grassland; wall communities; reed communities, floating-leaved plant communities.

Because the four sets of criteria were not cardinal numbers and the separate scales were not of equal length it was felt that formulaic addition of the individual scores would be inappropriate, so the four assessment results were considered in parallel. The scores given to each location or to a particular biotope could not be used in any absolute manner: they could provide relative rankings of sites within an urban area but their significance had to be context-dependent. In this way, in a highly built-up town with little green space even a small green area would probably be valuable to nature and/or people, while a similarly-sized green space in a 'green' town (such as Düsseldorf) would probably have relatively less significance. However, in turn this would also depend on the type, typicality and rarity of the particular biotope. Wittig and Shreiber identified 124 biotopes which they rated as being especially valuable in Düsseldorf, including those such as woodland which required more than fifty years to develop, those which were larger than 25 ha, and those which were unique to the city. Although the presence of rare or endangered species, valuable communities or biodiversity richness were not explicitly considered, subsequent comparison with detailed biological recording showed that all nesting species of owl and birds of prey, all reptiles and amphibian habitat, all woodpecker biotopes and all locations of characteristic urban vegetation were contained in the 124 biotopes rated as being particularly valuable.

Such pre-judgement as to what to map followed by selective mapping generally has major limitations, though where a specific planning goal does not demand complete spatial cover it becomes a strength. This is evident, for instance, in the survey methodology behind the land-use decision-making model for use on urban sites with naturally-regenerating habitats in Leeds, UK, undertaken by Freeman (1997) or in work in the same city on the relationship of indigenous and spontaneous vegetation to urban development by Millard (2004).

Evaluating areas solely on the basis of selective mapping, however, is inadequate since biotopes, especially in urban areas, need to be evaluated in the context of their surroundings.

Comprehensive (spatially-complete) mapping

Since value (for people, plants and wildlife), however defined, is context-dependent, most recent work has focused on comprehensive, spatially-complete habitat or biotope mapping. The initial map is purely descriptive and non-evaluative. In the context of their work on biotope mapping in West Berlin, Sukopp et al. (1979, 1980) similarly describe the need not only to categorise the biotopes appropriately and to map their distribution, but also to indicate the structure and uses of each area, the flora (at least the woody element) and vegetation, and characteristics of a selected group of animals (for example density of breeding birds). The basis for the habitat inventory of Berlin, however, remained the mapping of land use, with subsequent sampling of each land-use type (Sukopp and Weiler, 1988).

Seventeen biotope mapping projects had been undertaken in West German cities by 1980; by the mid-1990s this number had risen to over 160 (Schulte et al, 1993; Starfinger and Sukopp, 1994). A fairly coherent and consistent approach was adopted thanks to the 1978 guidelines concerning methodology produced by the Working Group on Biotope Mapping in Urban Areas, consisting of planners and academics. The methodology was reinforced by a further working group on Methods for Biotope Mapping in Built-up Areas, set up in 1986. A new working group was created in 1993 (Schulte et al, 1993) involving the Federal Nature Conservancy and the State Offices for Nature Conservation and Landscape Management, producing a revised programme which among other things made a recommendation to include information on small-scale features, such as hedgerows, that play an important role in urban nature conservation. From the earlier attempts of selective mapping there was now encouragement to have a complete land-use/biotope survey, to view context, to include small-scale features, and to include people as well as nature in evaluation of the individual biotope and the pattern that all the biotopes provided.

The success of the German methodology has led to its application elsewhere, for example in Japan where a study began in 1996 in the urban agglomeration of Tokyo (Müller, 1998) and in Brazil (Weber and Bede, 1998).

A rather different approach to spatially-complete mapping had been evident in the urban wildlife programme developed in the USA by the Department of Environmental Conservation’s Division of Fish and Wildlife in 1974, and exemplified by work in New York State. In order to evaluate the suitability of the urban environment for wildlife and human enjoyment of that wildlife, an inventory was made of existing vegetation and land use using pre-existing census tracts, the data being transformed to map overlays at a scale of 1:9600. Ground-truthed air photo interpretation identified thirty-one cover types and twenty-one basic land-use categories. Some of the latter were further divided, for example waste disposal areas into dumping grounds, junk yards and landfill areas, and railway into active and disused. It is stressed that the resulting maps and computerised data provide baseline information to be used to identify and quantify landscape change, and for planning and management of the green resources of urban New York State (Matthews, O’Connor and Cole, 1988).

Spatially-complete habitat mapping has been essayed in New Zealand by Freeman and Buck who aimed ‘to produce a map that would accommodate the diverse highly modified habitats characteristic of Dunedin and that would incorporate all types of urban open space ranging from indigenous habitats, such as forest, to exotic habitats such as lawns, and residential gardens’ (Freeman and Buck, 2203: 161). The project developed a hierarchical classification that considered both land use and habitat, and the resulting map was the first to record all land uses in any New Zealand city at a large scale (1:3000).

Dunedin City Council wanted, and got, an ecological habitat map which displayed key habitat types and their relative qualities which would be a basis for developing an overall open space strategy for the city. However, it became clear that the map had many further capabilities with important potential in urban environmental planning, for example identification of areas deficient in natural vegetation, identification of potential corridor links, mapping possible scenarios, establishing the GIS database as an ‘ecological core data’ to which other ecological information could be added, and undertaking ecological habitat suitability analysis for particular animal species.

Patches, edges, connectivity and corridors: the language of landscape ecology

Habitat corridors are a component part of the geometry of landscape ecology. They provide links between spatially separate habitat patches – opportunities for movement for many plants and non-flying animals, and facilitating movement within a sympathetic habitat for many birds and flying insects. Much recent work has explicitly used landscape ecology as both a vocabulary and grammar in the analysis of spatially information-rich survey data and, indeed, as a paradigm (a particular way of looking at relationships and interactions) within which interpretation, planning and management can usefully take place.

In their study of Shanghai, China, for example, Zhang et al. (2004) demonstrated that as the city became more and more urbanised so there was a reduction in the average size of the habitat/biotope patches, with particularly sharp decreases in the number of large patches. This in turn led to an increase in patch density and the amount of habitat edge. The whole urban landscape became more complex in its pattern, and there was a pronounced decrease in landscape connectivity, whether measured as the extent of shared edge between adjacent patches or as corridor links between patches. As the landscape became geometrically more complex so, ecologically, it became increasingly fragmented.

More explicitly aimed at providing a management tool for nature conservation and the enhancement of biodiversity, work in Oslo, Norway, again used GIS to demonstrate how urbanisation has led to pronounced changes in habitat amount, type and distribution pattern (Pedersen et al., 2004). By classifying the green environment into fifty-six types, including ‘cultural landscapes’, the resulting species/habitat database has provided planners with important information. ‘Many cities have good quality data about biodiversity, but too little communication with the physical planning system . . . . The GIS-based tool for supporting local authorities in translating sustainable development goals on biodiversity into all physical planning and decision-making is one important step to avoid [this] trend’ (Pedersen et al., 2004: 437).

In Stockholm, Sweden, Löfvenhaft, Björn and Ihse (2002) used a biotope classification in their attempt to provide urban planners with context-sensitive planning tools which would be sufficiently flexible to allow individual responses to the environmental conditions of each individual area. Biotope patterns were inter-related at species levels, using the distribution of amphibians and of insects living on dead wood, indicator taxa representing mosaic organisms (dependent on several different biotopes) and specialists (requiring specific habitat conditions). Four types of planning category were identified, each with a different set of requirements for spatial planning and management. The concept of a ‘landscape ecological zone’ was used to mean a core area with a surrounding connectivity and/or buffer zone.

- **Core areas**: green areas with significant ecological values that need protection and management appropriate for maintaining both biodiversity and recreational and cultural values

- **Connectivity zones**: larger spatial units lying between core areas that also have ecologically valuable biotopes, where measures are needed to strengthen present biotope distribution and to limit further ecologically-adverse development

- **Buffer zones**: larger spatial units surrounding core areas and connectivity zones, where a compromise is necessary between urban development and ecological significance, so that biotopes and their biodiversity can still be supported

- **Green development areas**: areas within core areas and connectivity zones with a high ecological potential, and where restoration of existing biotopes and the establishment of new ones are priorities

'The value of this method lies in the depiction of those ecological features that need to be handled properly in planning and management from an ecological-geographical perspective and in order to maintain recreational and cultural values that are related to the biological diversity in the landscape' (Löfvenhaft, Björn and Ihse, 2002: 236)

Value-added urban landscapes

It is all very well identifying and mapping what is present in terms of habitat and its spatial configuration, but three key inter-related questions remain:

- In the planning and management of green space, how possible is it to compromise between the often conflicting demands on an area by plants and wildlife on the one hand, and people (for amenity, recreation and education) on the other?

- Is it possible to define different kinds of 'value' that green open spaces may have and to quantify these?

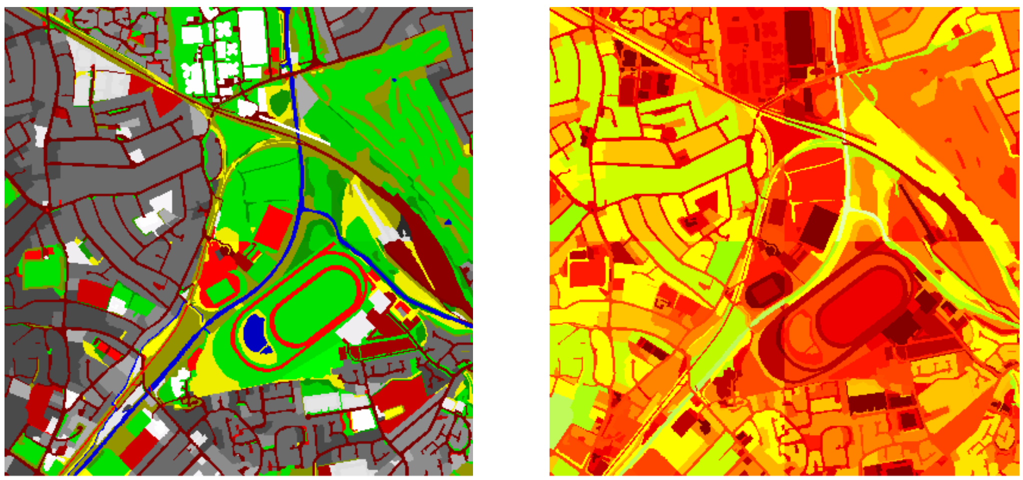
- Can we use any such quantification in measuring enhanced or reduced 'value' following land-use change and reconfiguration of the geometry of landscape compartments or biotopes?

An attempt to quantify 'value', measure habitat change and integrate ecological importance and amenity/recreation importance in an urban landscape made by Young and Jarvis (2002) used a 'Habitat Value Index' (HVI) which evaluated each habitat patch individually then viewed this patch within the context of its immediate site, neighbourhood (within a 1 km X 1 km grid) (Fig. 4) and indeed regional landscape (a 10 km X 10 km grid). Initially using aerial photographs each patch was digitally mapped on a base map, visited in the field and given a numerical score on the basis of two 'assessment' criteria (structural elements and indicator species) and three 'weighting' criteria (general habitat structure, habitat size and 'attractiveness' or aesthetics). The assessment criteria were used to provide a measure of the internal variety of a patch, incorporating both natural and anthropogenic constituents, while the weighting criteria were used to moderate or accentuate the scores, emphasising (with a higher score) those patches which were more favourable for wildlife and more attractive to people (Young and Jarvis, 2001a). A structural element was defined as an anthropogenic or semi-natural landscape feature that in some way added to the vertical or horizontal structural heterogeneity within a more obviously-defined patch: an example would be the enhancement of 'value' to an otherwise featureless improved amenity grassland by a single tree.

Although the resulting patchwork map was detailed – more so that the traditional biotope map – each patch took on average less than five minutes to survey. Each one square kilometre took eight working days to survey, with an additional one or two days to digitise and input data. Re-survey two years after the original work, to examine short-term changes in land use and therefore in patch value, took less than two days per square kilometre. Predicted future changes in HVI could be computed for each habitat patch or group of patches. The survey method did not require specialist knowledge. That the information was stored in a GIS (in this case, IDRISI) allowed further quantitative analysis of habitat fragmentation and the structural heterogeneity of the area (Young and Jarvis, 2001b, 2001c).

Maps of the noise and thermal environments in towns

A wide set of interconnecting environmental factors becomes relevant in describing, understanding and planning the promotion of nature in towns and cities, and these may be mapped in their own right. Noise, for instance, is an important part of the quality of life for people, but can also impact animals – for example in reducing breeding effort in birds nesting close to roads. Noise maps represent acoustic information in a cartographic form, generally using isolines (lines of equal noise levels). Noise maps in towns usually emphasise levels of vehicular use, so can also be used as surrogate qualitative measures of vehicular pollution.



(a) (b)

Fig. 4 (a) Land-use mosaic within the main 2km X 2 km study area in NW Wolverhampton, England
(b) Habitat Value Index (HVI) map: from dark red to dark green = low to high score (value)

An early attempt at a national survey of noise levels in the United Kingdom was made in 1990 under the direction of the Building Research Establishment for the Department of the Environment, but the scale and therefore spatial resolution were inappropriate for any cogent conclusions to be drawn. More useful maps, at city level or even larger scales, have recently been generated using a variety of modelling techniques (Hinton, 2002).

As a response to the European Commission Green Paper on Future Noise Policy published in 1996, for example, a noise map of Birmingham was undertaken in 1998 by the city council, looking at major industrial noise sources as well as those generated by road, rail and air transport (www. defra.gov.uk/environment/noise/mapping/birmingham). Similar maps are available for other British cities, for example (inevitably) London (www.noisemapping.org/frames/Map.asp) and for a number of European cities, for example for Prague in 1997 (www.ceroi.net/reports/prague/charts/a5-10.gif).

The thermal environment of built-up areas is useful to understand in terms of sustainability, since areas of controllable heat loss can be identified, but such information can be linked with more general aspects of environmental quality. Nichol and Wong (2004), for example, have demonstrated the use of an objective, satellite-based method for three-dimensional visualisation of urban environmental quality achieved by combining image fusion for increased spatial detail of Landsat ETM+ thermal images with 3D virtual reality models. Application to Hong Kong allowed, among other things, the identification of small pockets of neglected green space, small parks and street trees as sites or spots of high environmental quality.

Reflectance also indicates the nature and condition of vegetation, and thermal mapping can be a useful adjunct to air photo and satellite imagery interpretation. Early application of this technology involved satellite imagery, first using multispectral scanner and subsequently the much higher resolution of the US Landsat Thematic Mapper. In a characterisation of urban forest, for example, Wang (1988) showed how twenty-three spectral classes corresponded to eight distinct tree communities of remnant natural forest, and fifteen planted residential forest communities in Mobile, Alabama. The woodlands were distinguishable on the basis of species composition, age, density, crown closure and vertical structure.

Green public open space

Where particular planning goals can be identified, the mapping of green open spaces can also provide important tools. Ahern (1991), for example, used what he called an extensive open space system as a strategy for planning and management in a rural Massachusetts landscape, but his ideas would readily translate into an urban landscape. The method explicitly recognises the importance of spatial configuration. While it is geared towards the human use of public open space, implications for the ecological components of the landscape can readily be seen.

The provision of urban green space, its accessibility and its attractiveness have all been studied in four urban areas in Flanders, northern Belgium – Antwerp, Ghent, Aalst and Kortrijk (Van Herzele and Wiedemann, 2003). Green spaces should, if possible, have multiple uses: people use such landscapes – parklands, playing fields, urban forests, etc. – often without regard to their original purpose.

A practical guide to mapping and assessing the resource and implementing local standards for the provision of accessible natural greenspace in towns and cities is provided by the Centre of Urban and Regional Ecology (Handley et al, n.d.) on behalf of English Nature in an attempt to provide a means of establishing urban areas within or outside English Nature-recommended availability of public open space. Emphasising the promotion of the provision of multifunctional spaces (i.e. providing a number of functions for people and wildlife), and using GIS as a means to apply network analysis, a sequential procedure identified candidate sites, natural versus non-natural greenspaces, level of accessibility, greenspace size and proximity to residential areas, site catchment zones, and options for actions. The need to consider site quality is recognised, a small high-quality greenspace having greater value than a large one of poorer quality. Considerations of quality need to take on board the perception of visitors as to the 'natural experience' offered, the facilities regarding visitor access and perception of safety, and the performance of the site in ecological terms. An example of such mapping for a real area is shown for Sheffield at www.map21ltd.com/COST11/sheff-gr1.htm.

Green maps

Perhaps complementary to the kinds of mapping exercises discussed above, so-called 'green maps' provide another means of describing (and no more than describing) the location of green areas and 'green facilities' in towns and cities (www.greenmap.com). Using a series of icons, a range of features are simply located on the map - from bird-watching areas to recycling plants, from wildlife corridors to litter bins.

Mental maps

Mental maps are cartographic representations of the 'known space' of individuals, groups or communities. They are subjective visualisations which emphasise (and are generally more accurate in the representation of) the familiar and the valued. That such maps can clearly indicate the importance placed upon green (and blue) open space was demonstrated by Soini (2001) in her review of the potential use of mental maps in Finnish landscape planning.

Conclusions

There remain a number of limitations concerning the acquisition, storage, cartographic representation, analytical modelling, interpretation and use of spatial data appropriate to planning for a green urban environment. Nevertheless a great deal of progress has been made, particularly in the last twenty-five years or so. The rise of and access to technologies such as satellite imagery, aerial photographs and various geographic information systems means that it is becoming easier not only to gather data but also to analyse it, and model scenarios pertinent to the conservation and enhancement of urban nature. The increasing use of GIS, web sites and computerised databases also means that data can be updated, transferred and shared more readily, and a more informed and professional approach adopted.

References

AHERN, J. (1991) Planning for an extensive open space system: linking landscape structure and function. *Landscape and Urban Planning,* **21**: 131-145

BARKER, G. (ed) (2000) *Ecological recombination in urban areas: implications for nature conservation* (English Nature, Peterborough)

BICHLMEIER, F., BRUNNER, M., PATSCH, J., MÜCK, H. and WENISCH, E. (1980) Biotope mapping in the city of Augsburg. *Garten & Landschaft*, **7**/**80**: 551-559

BRUNNER, M., DUHME, F., MÜCK, H., PATSCH, I. and WENISCH, E. (1979) Kartierung erhaltenswerter Lebensräume in der Stadt (Mapping valuable preserved living space in the city) *Das Gartenamt, Sonderdruck*, **28**: 1-8

CANTERS, K.J., DEN HERDER, C.P., DE VEERS, A.A., VEELENTURF, P.W.M. and DE WAAL, R.W. (1991) Landscape-ecological mapping of the Netherlands. *Landscape Ecology*, **5:** 145-162

CASSETTARI, S. (2003) A new generation of land use mapping in the UK. *Cartographic Journal*, **40**: 121-130

CHERTOV, O.G., KUZNETSOV, V.I. and KUZNETSON, V.V. (1996) The Environmental Atlas of St Petersburg City area, Russia. *Ambio*, **25**: 533-535

COLLINS, W.G. and EL-BEIK, A.H.A. (1971) The acquisition of urban land use information from aerial photographs of the City of Leeds. *Photogrammetrica*, **27**: 71-92

CRAGLIA, M. (1992) GIS in Italian urban planning. *Computers, Environment and Urban Systems*, **16**: 543-556

DAHL, F. (1908) Grundsätze und Grundbegriffe der biozönotischen Forschung (Principles and theories of biozone research) *Zoologischer Anzeiger*, **33**: 349-353

DUHME, F. and 15 others (1983) *Kartierung schutzwürdiger Lebensräume in München* (Mapping living space worthy of protection in Munich) (TU München), 129 pp.

DWYER, J.F., McPHERSON, E.G., SCHROEDER, H.W. and ROWNTREE, R.A. (1992) Assessing the benefits and costs of the urban forest. *Journal of Arboriculture*, **18**: 227-234

FERRY, B.W., BADDELEY, M.S. and HAWKSWORTH, D.L. (eds) (1973) *Air pollution and lichens* (Athlone Press, London)

FORMAN, R.T.T. (1995) *Land mosaics: the ecology of landscapes and regions* (Cambridge University Press, Cambridge)

FREEMAN, C. (1997) *The development of a landuse decision-making model for use on sites with naturally regenerating habitat*. Unpublished PhD thesis, Leeds Metropolitan University

FREEMAN, C. and BUCK, O. (2003) Development of an ecological mapping methodology for urban areas in New Zealand. *Landscape and Urban Planning,* **63**: 161-173

GODEFROID, S. (2001) Temporal analysis of the Brussels flora as indicator for changing environmental quality. *Landscape and Urban Planning*, **52**: 203-224

HANDLEY J. et al. (n.d.) *Providing accessible natural greenspace in towns and cities. A practical guide to assessing the resource and implementing local standards for provision* (Centre for Urban and Regional Ecology, University of Manchester; on behalf of English Nature)

HARRIS, S. and RAYNER, J. (1986) Urban fox (*Vulpes vulpes*) population estimates and habitat requirements in several British cities. *Journal of Animal Ecology*, 55: 575-591

HAWKSWORTH, D.L. and ROSE, F. (1976) *Lichens as pollution monitors* (Arnold, London)

HINTON, J. (2002) How to map noise. *Noise and Health*, **4**: 1-5

JAENSON, R., BASSUK, N., SCHWAGER, S. and HEADLEY, D. (1992) A statistical method for the accurate and rapid sampling of urban street tree populations. *Journal of Arboriculture*, **28**: 171-183

JARVIS, P.J. (1996) Planning for a green environment in Birmingham. In: A.J. Gerrard & T.R. Slater (eds), *Managing a conurbation: Birmingham and its region* (Studley: Brewin Books): 90-100

JIM.C.Y. (1986) Street trees in high-density urban Hong Kong. *Journal of Arboriculture*, **12**: 257-263

JIM, C.Y. (1987) The status and prospects of urban trees in Hong Kong. *Landscape and Urban Planning*, **14**: 1-20

JIM, C.Y. (1989) Tree-canopy characteristics and urban development in Hong Kong. *Geographical Review*, **79**: 210-225

JIM, C.Y. (1993) Trees and landscape of a suburban residential neighbourhood in Hong Kong. *Landscape and Urban Planning*, **23**: 119-143

KENT, M., STEVENS, R.A. and ZHANG, L. (1999) Urban plant ecology patterns and processes: a case study of the flora of the City of Plymouth, Devon, UK. *Journal of Biogeography*, **26**: 1281-1298

LÖFVENHAFT, K., BJÖRN., C. and IHSE, M. (2002) Biotope patterns in urban areas: a conceptual model integrating biodiversity issues in spatial planning. *Landscape and Urban Planning,* **58**: 223-240

MACO, S.E. and McPHERSON, E.G. (2003) A practical approach to assessing structure, function, and value of street tree populations in small communities. *Journal of Arboriculture*, **29**: 84-97

MATTHEWS, M.J., O'CONNOR, S. and COLE, R.S. (1988) Database for the New York State Urban Wildlife Habitat Inventory. *Landscape and Urban Planning,* **15**: 23-37

MILLARD, A. (2004) Indigenous and spontaneous vegetation: their relationship to urban development in the City of Leeds, UK. *Urban Forestry and Urban Greening*, **3**: 39-47

MÜLLER, N. (1998) Assessment of habitats for natural conservation in Japanese cities – procedure of a pilot study on biotope mapping in the urban agglomeration of Tokyo. In: J. Breuste, H. Feldmann & O. Ohlmann (eds), *Urban ecology* (Springer-Verlag, Berlin): 631-635

MÜLLER, N. and WALDERT, R. (1981) Erfassung erhaltenswerter Lebensräume für Pflanzen und Tiere in der Stadt Augsburg – Stadtbiotopkartierung (Recording preserved living space of value for plants and animals in the city of Augsburg – urban biotope mapping) *Natur und Landschaft*, **56**: 419-429

NAKAMURA, T. and SHORT, K. (2001) Land-use planning and distribution of threatened wildlife in a city of Japan. *Landscape and Urban Planning*, **53**: 1-15

NATURE CONSERVANCY COUNCIL (1990) Handbook for Phase 1 habitat survey. A technique for environmental audit. (UK Joint Nature Conservancy Council, Peterborough)

NICHOL, J. and WONG, M.S. (2004) Modeling urban environmental quality in a tropical city. *Landscape and Urban Planning* (in press)

NOWAK, D.J. (1993) Historical vegetation change in Oakland and its implications for urban forest management. *Journal of Arboriculture*, **19**: 313-319

NOWAK, D.J., ROWNTREE, R.A., MCPHERSON, E.G., SISINNI, S.M., KERKMANN, E.R. and STEVENS, J.C. (1996) Measuring and analyzing urban tree cover. *Landscape and Urban Planning*, **36**: 49-57

PEDERSEN, Å.Ø., NYHUUS, S., BLINDHEIM, T. and KROG, O.M.W. (2004) Implementation of a GIS-based management tool for conservation of biodiversity within the municipality of Oslo, Norway. *Landscape and Urban Planning,* **68**: 429-438

POUNALL, L.L. (1950) Photo interpretation of urban land use. *Photogrammetric Engineering and Remote Sensing*, **16**: 414-426

RICOTTA, C., CELESTI GRAPOW, L., AVENA G. and BLASI, C. (2001) Topological analysis of the spatial distribution of plant species richness across the city of Rome (Italy) with the echelon approach. *Landscape and Urban Planning*, **57**: 69-76

ROWNTREE, R.A. and NOWAK, D.J. (1991) Quantifying the role of urban forests in removing carbon dioxide. *Journal of Arboriculture*, **17**: 269-275#

SAUNDERS, G., WHITE, P.C.L. and HARRIS, S. (1997) Habitat utilization by urban foxes (*Vulpes vulpes*) and the implications for rabies control. *Mammalia*, **61**: 497-510

SOINI, K. (2001) Exploring human dimensions of multifunctional landscapes through mapping and map-making. *Landscape and Urban Planning*, **57**: 225-239

STARFINGER, W., SUKOPP, H. and WERNER, P. (eds) (1993) … (Comprehensive biotope mapping as a basis for nature conservation-orientated planning) *Natur und Landschaft*, **68**: 491-526

STARFINGER, H. and SUKOPP, H. (1994) Assessment of urban biotopes for nature conservation. In: E.A. Cook & H.N. Van Lier (eds), *Landscape planning and ecological networks* (Elsevier, Amsterdam): 89-115

SUKOPP, H., KUNWICK, W. and SCHNEIDER, C. (1979) Biotopkartierung in der Stadt (Biotope mapping in towns) *Natur und Landschaft*, **54**: 66-68

SUKOPP, H., KUNICK, W. and SCHNEIDER, C. (1980) Biotopkartierung im besiedelten Bereich von Berlin (West). Teil II. Zur Methodik von Geländearbeit und Auswertung (Biotope mapping in the built-up areas of West Berlin. II. Fieldwork methods and analysis) *Garten und Landschaft*, **90**: 560-564

SUKOPP, H. and WEILER, S. (1988) Biotope mapping and nature conservation strategies in urban areas of the Federal Republic of Germany. *Landscape and Urban Planning,* **15**: 39-58

SUN, W.-Q, and BASSUK, N.L. (1991) Approach to determine effective sampling size for urban street tree survey. *Landscape and Urban Planning*, **20**: 277-283

SUNG, D.-G., LIM, S.-H., KO, J.-W. and CHO, G.-S. (2001) Scenic evaluation of landscape for urban design purposes using GIS and ANN. *Landscape and Urban Planning*, **56**: 75-85

TEAGLE, W.G. (1978) *The endless village* (Nature Conservancy Council, Shrewsbury)

VAN HERTZELE, A. and WIEDEMANN, T. (2003) A monitoring tool for the provision of accessible and attractive urban green spaces. *Landscape and Urban Planning,* **63**: 109-126

WALFORD, R. (1997) *Land use – UK: a survey for the 21st century* (Geographical Association, Sheffield)

WANG, S.-C. (1988) An analysis of urban tree communities using Landsat Thematic Mapper data. *Landscape and Urban Planning,* **15**: 11-22

WEBER, M. and BEDÊ, L.C. (1998) Comprehensive approach to the urban environmental status in Brazil using the biotope mapping methodology. In: J. Breuste, H. Feldmann & O. Ohlmann (eds), *Urban ecology* (Springer-Verlag, Berlin): 636-640

WITTIG, R. and SCHREIBER, K.-F. (1983) A quick method for assessing the importance of open spaces in towns for urban nature conservation. *Biological Conservation*, **26**: 57-64

WYATT, N.M. (ed) (2003) *A provisional atlas of the mammals of Birmingham and the Black Country* (Wildlife Trust for Birmingham and the Black Country, Birmingham), 40 pp

YOUNG, C.H. and JARVIS, P.J. (2001a) A simple method for predicting the consequences of land management in urban habitats. *Environmental Management*, **28**: 375-387

YOUNG, C.H. and JARVIS, P.J. (2001b) Measuring urban habitat fragmentation: an example from the Black Country, UK. *Landscape Ecology*, **16**: 643-658

YOUNG, C.H. and JARVIS, P.J. (2001c) Assessing the structural heterogeneity of urban areas: an example from the Black Country (UK) *Urban Ecosystems*, **5**: 49-69

YOUNG, C.H. and JARVIS, P.J. (2003) A multicriteria approach to evaluating habitat change in urban areas: an example from the Black Country, West Midlands (UK) In: J. Brandt & H. Vejre (eds), *Multifunctional landscapes. Vol. II. Monitoring, diversity and management* (WITPress, Southampton): 59-74

ZHANG, L., WU, J., ZHEN, Y. and SHU, J. (2004) A GIS-based gradient analysis of urban landscape patterns of Shanghai metropolitan area, China. *Landscape and Urban Planning*, **69**: 1-16