GIS ASSESSMENT OF MUNICH'S URBAN FOREST STRUCTURE FOR URBAN PLANNING

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Abstract. A geographic information system (GIS) was developed and applied to assess the spatial pattern and environmental functions of the urban forest in the city of Munich. Urban land cover types were delineated as the underlying spatial units, characterized by physical and land-use attributes such as the percentage cover of built-on land and vegetation. The urban forest was described as the cover of trees and shrubs and the maximum age of trees. The survey was coupled with statistical databases and environmental data such as a habitat survey and thermal infrared photography. Trees and shrubs covered approximately 5,400 ha (13,300 ac) of land, or 18% of Munich's surface area. The spatial pattern of the urban forest was closely linked with the general zoning of different land use and building density. The relationship between cover, size, and age of woody vegetation and the incidence of woodland indicator birds was used to assess the role of the urban forest for urban nature conservation, and potential habitat links of closely neighboring woodlands were identified by means of the GIS. Furthermore, it was shown that the urban forest can effectively reduce air temperatures during hot summer days. Specific urban forestry programs and quantitative targets were proposed for urban zones. These would increase the forest cover to 22% of the city's surface area. An estimate for the overall costs for the establishment of the additional forest areas is given.

Key Words. Geographical information system; urban forestry; land cover.

Comprehensive knowledge is needed on the status and performance of the urban forest in order to preserve and enhance it. In particular, information is required on the trees' spatial distribution within the city (i.e., the species composition, age classes, and health status). Finally, the specific functions of the urban forest for recreation, aesthetic quality, environmental protection, and nature conservation need to be assessed.

Presently, only limited information exists about the structure and functions of the urban forest. Dorney et al. (1984), Nilon (1991), and McPherson and Rowntree (1989) studied the species composition and structural characteristics of urban forests in U.S. cities. Nowak et al. (1996) compared the canopy tree covers of 58 North American cities. McPherson et al. (1994) and American Forests (1996) investigated and modeled the potential environmental impacts of woody vegetation on reducing thermal loads on residential houses as a means of saving energy for air conditioning. Also, Nowak (1994) estimated the capacity of urban woody vegetation for the fixation of carbon dioxide. In Europe, however, little research has been conducted on these topics.

For the city of Munich, an approach was tested to assess the environmental performance of urban land-cover types for urban planning. The following sections will demonstrate how this approach can be used as an information base to assess the urban forest resource, both spatially and functionally, and to quantify targets for urban forestry planning.

MATERIAL AND METHODS

Munich is the center of a prospering urban agglomeration, based on modern industries and services. The city covers some 311 km^2 (120 mi^2), and its population is approaching 1.3 million. Urban land-cover units were mapped by means of aerial photographs (monochromatic, scale 1:5000) to delineate the different types of built-up and open spaces in the city, such as single-family housing, multi-story blocks, industrial areas, parks, agricultural lands, and woodlands. The predominant types of land cover and land use are considered to be the key ecological factors in urban systems. Thus, land units will have characteristic ecological properties and environmental conditions (Richter 1984). A first mapping scheme was carried out in 1981–1982 for the whole city, together with a separate habitat survey. While the habitat survey identified some 300 sites of 12 habitat types of specific ecological interest, the land-cover survey helped characterize the ecological properties of typical urban land uses. Over 3,000 land units were distinguished and grouped into 18 land-cover types. The survey was updated in a test area of some 50 km^2 (19 mi^2) in 1991 and included a representative cross section of all

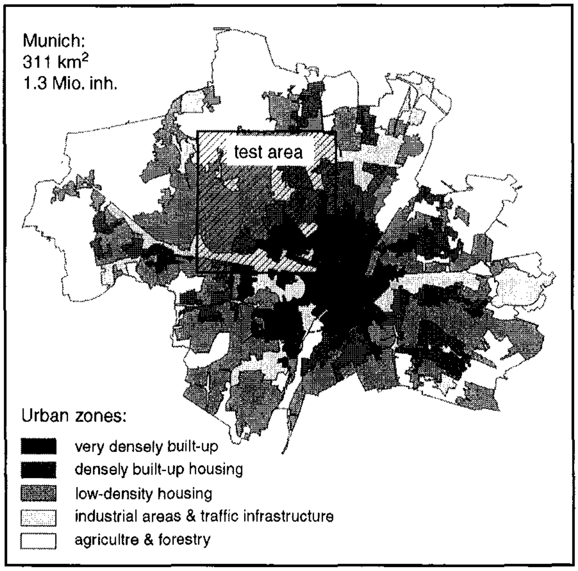

Figure 1. Urban zoning for Munich and the test area.

urban zones and land uses (Figure 1). While 4.6 ha (11.4 ac) was the average size, more than 25% of the units were smaller than 1 ha (2.5 ac), thus reproducing the fine-grained pattern of the various land covers.

Physical attributes and land-use features were recorded for every unit by interpreting monochromatic aerial photographs, scale 1:5,000 and sometimes 1:1,000. These attributes included the type of land use, intensity of land use, percentage cover of buildings, asphalt, vegetation (cover of trees, shrubs, lawn, herbs, and grasses), and maximum age of buildings and trees. Comparing the estimated cover of built-up land with corresponding data from a municipal file showed that estimation error lay mostly in the range of +/-10%. The survey was repeated for land units with larger estimation errors. The land units were further processed by means of a geographical information system (GIS: ARC/Info) as the baseline geography and the data set.

The survey of 1991 was coupled with statistical standard databases (i.e., socio-demographic data and detailed information for each building, such as use of floor space, total area of floor space, number of floors, rooms) available through the planning department. Environmental data were available from several sources, such as thermal imagery from a previous climatic research study (Bründl et al. 1987).

Thermal infrared (IR) imagery was used to measure surface temperatures in the test area. Air temperatures cannot be derived quantitatively from surface temperatures, but a close qualitative relationship exists between these parameters. Thus, surface temperatures provided a means for assessment of thermal conditions with complete spatial coverage of the urban area.

For the test area, data were analyzed for hot summer days at noon (8 July 1982, 12:05 P.M. to 2:30 P.M.) and at night (14 July 1982, 9:00 P.M. to 11:15 P.M.) when thermal conditions differentiate particularly well between built-up or sealed surfaces and vegetated surfaces. Because more actual data were not available, 15% of the test area's surface had to be excluded from the analysis due to significant land-cover changes. The data should still reflect accurately the relative temperature differences between all other units for which only minor land cover-changes had occurred in the meantime.

The resolution per pixel on the ground is approximately 6 × 6 m (19.7 × 19.7 ft) from IR images. This resolution allows the single crowns of bigger trees to be detected on the photographs. The percentage of pixels belonging to different temperature classes had to be estimated for every land-cover unit from paper prints. Because the scale of the prints was rather small (1:39,000), the pixel cover could only be roughly estimated. Mean surface temperatures were then computed for each land unit.

Data analysis (SPSS software, Nie et al. 1975) particularly explored the relationship between physical and land-use features of the land-cover types and their environmental performance. Results in the following sections refer to the whole city area of Munich, except the climate case study, which was carried out in the test area.

RESULTS

Spatial Pattern of the Urban Forest in Munich and Its Relationship to Urban Land Cover

Munich is a densely built up, monocentric city. More than 10,000 ha (24,700 ac) are either built on or covered with asphalt and pavement. Three zones can be distinguished:

- inner city and industrial areas; surface sealing 70% to 100%
- city fringe with low-density residential areas; surface sealing 20% to 60%
- farmland and forests; surface sealing <5%

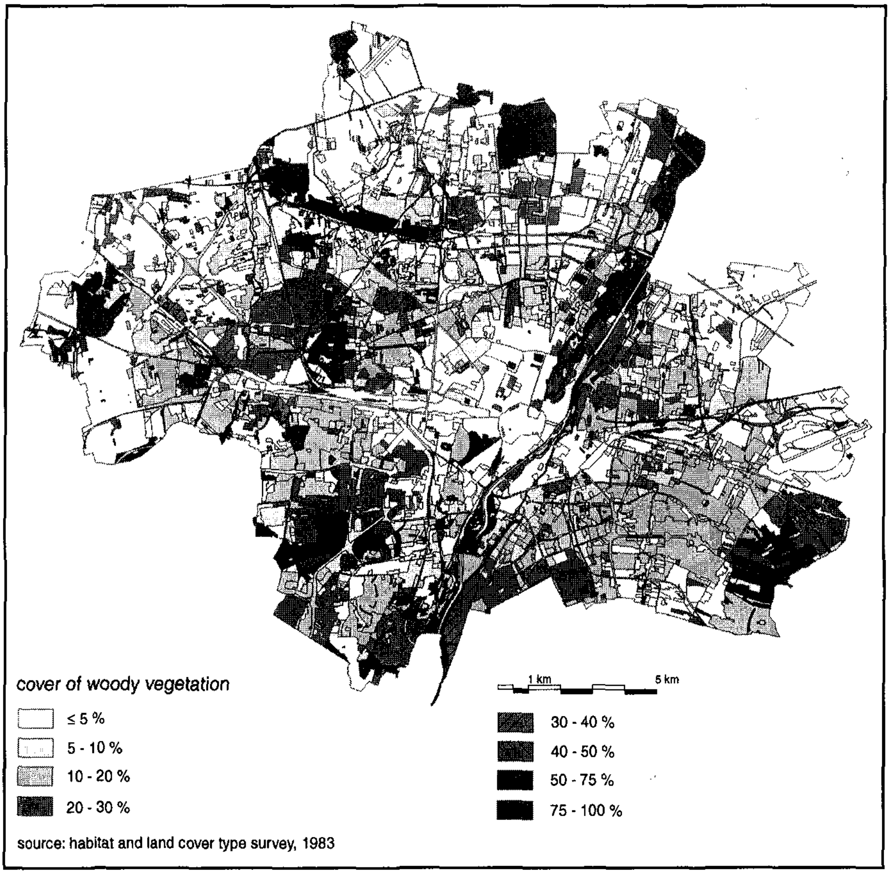

Figure 2. Spatial pattern of the urban forest in Munich.

Single-family housing is the largest category covering some 21% of the city area, followed by cultivated land on the urban fringe. Built-up land and infrastructures cover some 60% of the city area. When farmland is excluded, open spaces accessible to the public make up approximately 20% of the city area. While half of these belong to formal categories such as parks, cemeteries, or allotments, the other half can be characterized as informal open space (wasteland, extensively managed range land, etc.).

The spatial pattern of the urban forest is closely linked with the general zoning of land uses (Figure 2). Trees and shrubs cover some 5,400 ha (13,300 ac) of land, including forests. Remnants of natural woodlands cover only 4% of Munich but contain 18% of the woody vegetation. These are split up into 153 woodlots in Munich, 79% of which are smaller than 5 ha (12.4 ac). Woody vegetation is abundant in the broad ring of low-density housing areas around the inner city, in parks, and along the Isar floodplain. Stands of old trees are a particularly common feature of low-density housing from the turn of the century. Public open spaces (parks, cemeteries, etc.) and single-family housing contain over 30% of Munich's woody vegetation cover. In the very densely built-up inner city, trees and shrubs are rare with the exception of a few small parks and open spaces. Tree cover is also low in the farmland areas on the urban fringe.

The cover of woody vegetation is high, as one might expect, for forests and public greenspaces such as parks and cemeteries (Figure 3). In built-up areas, the cover drops from more than 20% in single-family housing to 6% in dense block buildings, industrial, and commercial areas. There is a sharp decrease of woody vegetation with increasing building density (Table 1). The decline is greatest when moving from a coverage of built-up land from below 20% to higher building densities.

Large land units with a significant cover of trees and shrubs attain the greatest absolute proportion of the wooded area. In built-up areas, land units having more than 5 ha (12.4 ac) of woody vegetation are found to the greatest extent in single-family housing areas. In old, low-density residential areas, well-developed woody vegetation can form an almost continuous cover, but in densely built-up parts of the city and in commercial and industrial areas, trees and shrubs are scattered mostly in small groups or single trees.

The maximum age of trees also differs greatly among the land-cover types. Again, old stands of trees (>80 years old) are found in forests and public greenspaces and also in the remnant cores of old villages and inner-city block buildings (Figure 4). In

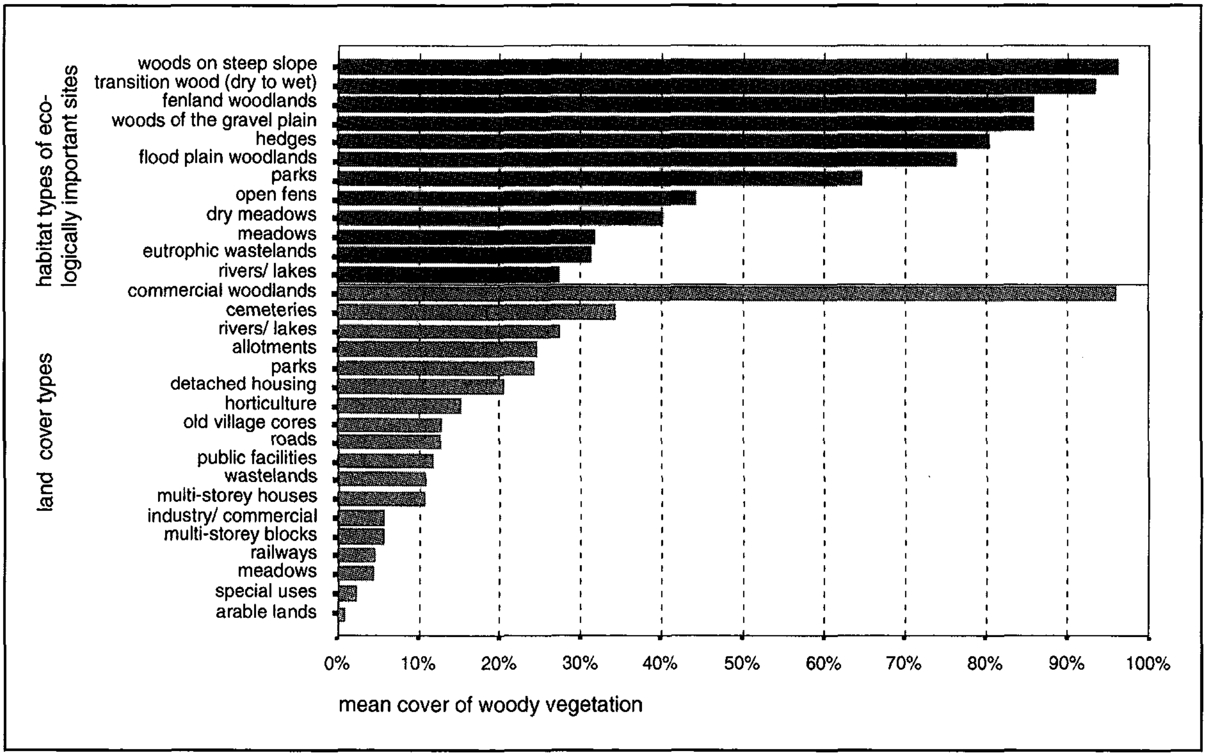

Figure 3. Percentage cover of woody vegetation in sites of specific ecological interest and land-cover types.

single-family housing areas built at the beginning of the 1920s, but mostly from 1950 on, really old stands of trees are rare, but there are extensive stands of medium-aged trees there. It is, however, young trees that predominate in multi-story housing and industrial areas.

Assessing the Performance of the Urban Forest for Nature Conservation And Urban Climate Planning

Relative cover, absolute size, and the age of woody vegetation were chosen as the attributes for assessing the character of the different land-cover types. The relationship among these parameters and the incidence of three bird species with different demands to woodland habitats can be seen in Figure 5. This implies that more common species such as the chiffchaff (*Phylloscopus collybita*) might make use of built-up areas with a certain critical density of trees and shrubs. The short-toed tree creeper (*Certhia brachydactyla*) specifically needs old trees for foraging. Woodland birds such as the wood warbler (*Phylloscopus sibilatrix*), which are confined to old growth forests only, breed in a few single-family housing districts with large gardens that date from the turn of the century. These have dense stands of big trees and undisturbed edge zones.

Table 1. Relationship between building density in housing areas and cover of woody vegetation.

Cover of built-up land[z]	Number of cases[y]	Surface sealing[x] (%)	Total vegetation cover (%)	Woody vegetation (%)
0%–10%	31	20.4	75.5	28.7
11%–20%	346	38.8	55.9	20.3
20%–30%	265	53.7	44.6	14.0
30%–40%	120	64.8	33.8	10.9
40%–50%	44	78.1	21.2	7.5
50%–60%	35	90.6	9.4	3.7
60%–70%	3	94.0	6.0	2.2
70%–80%	3	99.0	1.0	1.0
Sum/mean	**847**	**51.1**	**45.9**	**15.8**

[z]The following land-cover types were included in the analysis: multi-story blocks and housing, single-family houses, old village cores.
[y]The analysis was performed in the study area of the 1991 survey of some 50 km^2 (19 mi^2).
[x]Built-up, asphalt, and paved surfaces. Sealed and vegetated surfaces do not total up to 100%. The remaining areas are covered by bare soils.

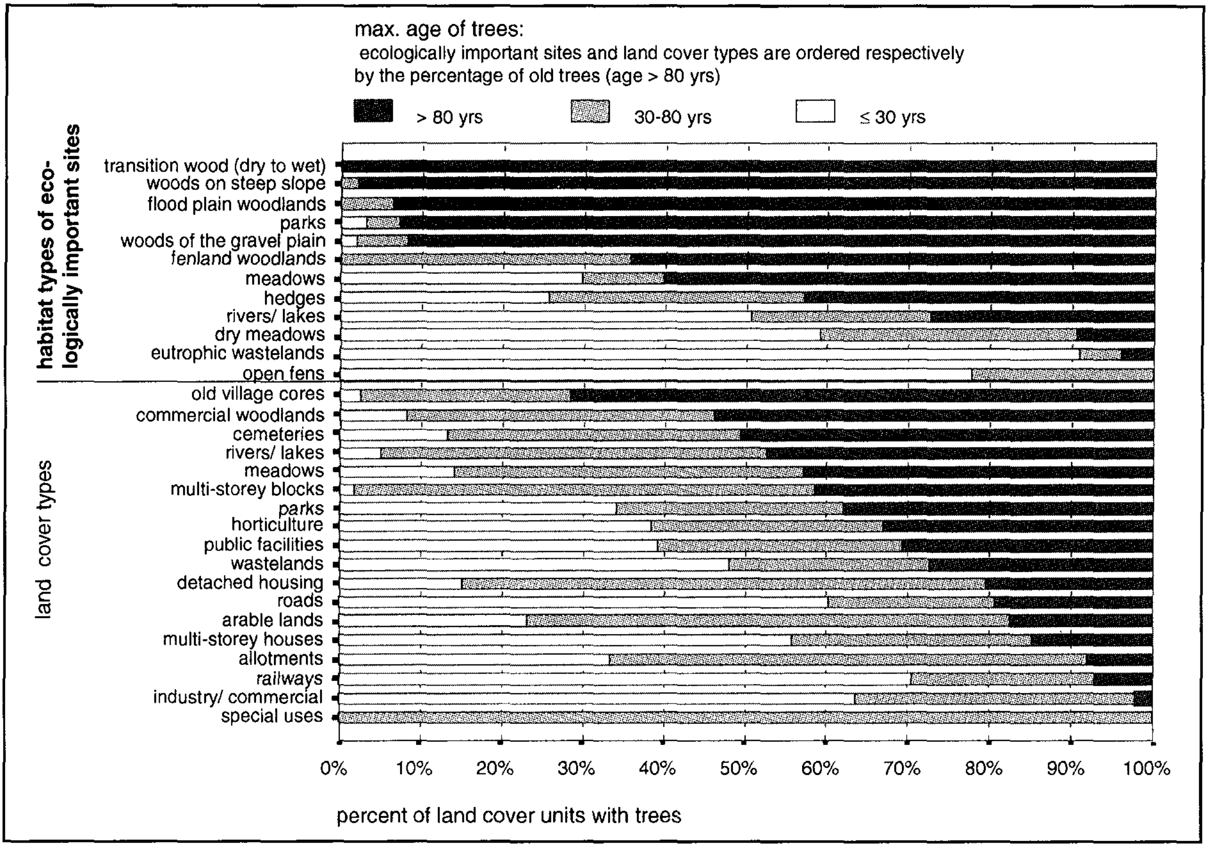

Figure 4. Maximum age of trees in sites of specific ecological interest and land-cover types.

Dense, old stands of trees in parks and cemeteries and in old, single-family housing areas therefore can be important additional habitats for woodland species. From studies of the role of small woodlands in the distribution of woodland birds (e.g., van Dorp and Opdam 1987), conclusions may cautiously be drawn that well-developed stands of woody vegetation in housing areas may promote species dispersal between the fragmented remnants of woodlands.

The direct relationship between the cover of woody vegetation and surface temperatures at noon can be clearly seen in Figure 6 and Table 2. The cool area at the lower left side of Figure 6 is the park of Nymphenburg Castle, which is predominantly covered by mature woodlands (the warmer parts within the park are meadows). Densely built-up parts of the inner city are particularly warm areas. The absolute difference between the hottest and coolest units of the test area comes close to 20°C (68°F).

Thus, the vegetation in general and trees, in particular, during the daytime can effectively reduce air temperature. This is achieved by shading and transpiration cooling (Oke 1989).

Quantifying Targets for Urban Forestry Planning

On the basis of the land-cover-type survey and the complementary habitat mapping scheme, a nature conservation program was developed for Munich. The program covers a habitat linkage program and sets habitat development targets for city zones, including programs for woodlands and natural grasslands.

Potential habitat links between the remnants of natural woodlands were identified by means of the geographic information system. A maximum distance of 250 m (820 ft) was set as a threshold for existing habitat links. While many "core" species of woodlands will be able to disperse in continuous woodlands only over long periods of time, these corridors will promote habitat connectivity for species with better dispersal capability (e.g., winged insects, birds, small

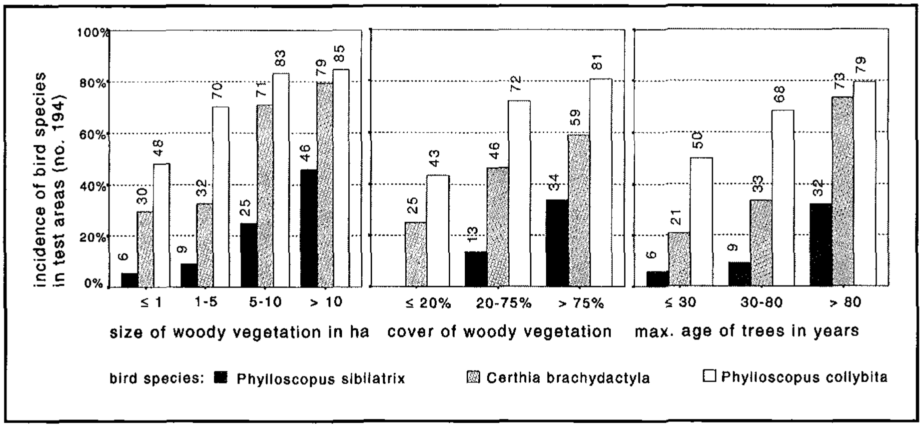

Figure 5. Relationship between characteristics of woody vegetation and incidence of woodland bird indicator species.

should be at least 80 to 100 ha (197.6 to 247 ac) in size to provide habitat potential for larger vertebrates.

The woodland programs and targets are summarized in Table 3. A total of 899 ha (2,220.5 ac) of woody vegetation will need to be created in the built-up city to meet these standards, with an additional 536 ha (1,324 ac) of woodlands established on the urban fringe. Overall, this would lead to a 5% increase in the woody vegetation of Munich from the current coverage of 18% to 2%. At some DM185 million (approximately US$100 million), the cost of creating new woody vegetation seems to be fairly high. However, extended over a period of ten years, the costs would be only minor compared with the overall city budget of some 7 billion deutsche marks (approximately $US3.8 million) per year.

Finally, the population density of both very young children and elderly people was chosen as an indicator for health risk groups (Figure 6). This helped to identify those areas for which measures for improving environmental conditions were needed most urgently.

mammals). The establishment of woody vegetation was proposed for creating habitat corridors between woodlands within a maximum distance of 2.5 km (1.6 mi). Following from the previous analysis, dense stands of woody vegetation with a coverage of more than 20% per unit and/or an age of more than 80 years were regarded as possible corridors or "stepping stones" in proximity to ecologically important sites.

Quantitative targets for the development of woody vegetation in city zones were based on the identification of "best" reference units for each urban zone. Thus, the inner-city complexes of closely adjacent small parks and squares containing old stands of trees were identified as optimal for this zone. The habitat creation program in densely built-up and industrial areas thus aims to develop a basic recruitment of woody vegetation with a minimum density and size of 1ha/10 ha (2.5 ac/24.7 ac) area and at a maximum distance of 250 m (820 ft) between single stands of trees. A 20% cover of woody vegetation was proposed for low-density residential areas. To revitalize the now intensively used farmland areas of the northern parts of Munich, not only for wildlife but also for recreational activities, a network of forests was proposed (minimum density and size 10 ha/100 ha [24.7 ac/247 ac] and maximum distance of 2.5 km [1.6 mi] between forests). Single woodlands

CONCLUSIONS

The preservation and enhancement of the urban forest is feasible only when concepts and targets are effectively incorporated into the urban development

Table 2. Relationship among building density, vegetation cover, and surface temperatures in the test area.

Single-family housing, row houses	Number of of cases[z]	Surface sealing (%)	Vegetation cover (%)	Cover of woody vegetation (%)	Surface temperatures Midday (°C)	Night (°C)
0%–10%	25	13.6	81.5	26.4	31.5	15.8
11%–20%	59	35.6	62.3	24.2	33.1	18.4
20%–30%	18	46.9	52.3	25.4	34.4	19.0
30%–40%	7	65.0	48.6	20.9	33.6	19.2
40%–50%	1	65.0	30.0	12.0	34.2	20.2
60%–70%	1	95.0	5.0	2.0	39.4	23.1
Mean	**111**	**34.2**	**63.4**	**24.4**	**33.1**	**18.0**

[z]The analysis was performed in the study area of the 1991 survey of some 50 km^2 (19 mi^2).

Table 3. Habitat development programs.

City zones	Woodland programs	Existing vegetation (ha)	New woody vegetation Ha	New woody vegetation %	Estimated establishment costs
Densely built-up areas	Stands of woody vegetation, density 1 ha/10 ha, maximum distance 250 m	847	227	+27	DM45,400,000[z] (US$24,516,000)[y]
General housing	Stands of woody vegetation, coverage 20%	2,060	451	+22	DM90,100,000 (US$48,654,000)
Industrial areas and traffic infrastructure	Stands of woody vegetation, density 1 ha/10 ha, maximum distance 250 m	280	221	+79	DM44,200,000 (US$23,868,000)
Farmland and forests	Afforestation, density 10 ha/100 ha, maximum distance 2.5 km	2,330	536	+23	DM5,360,000 (US$2,894,400)
Total		5,517	1,435	+26	**DM185,000,000 (US$99,900,000)**

[z]DM200,000 (US$108,000) per ha woody vegetation in the built-up area; DM1,000 (US$540) per tree, 200 trees per ha; DM10,000 (US$5,400) per ha forest.

[y]Based on August 1999 exchange rate of DM1.00 approximately equivalent to US$0.54.

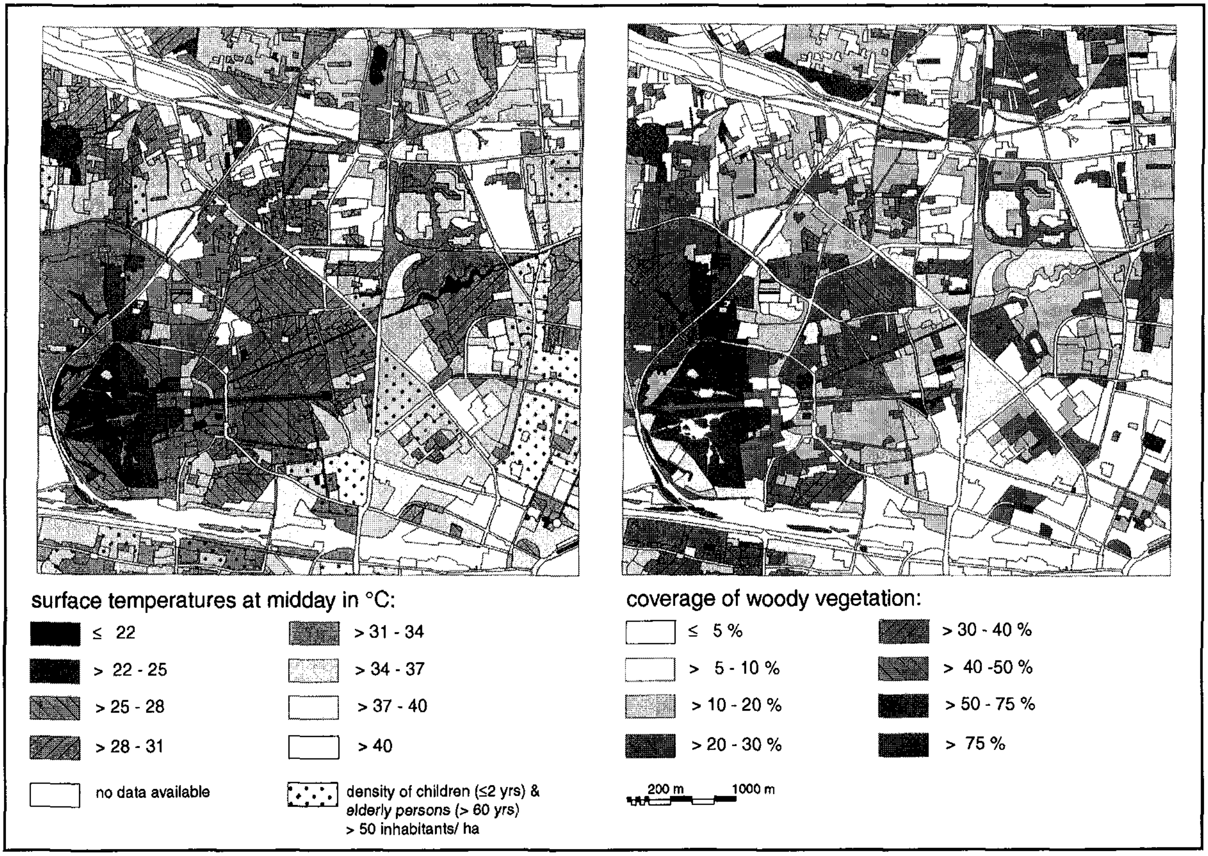

Figure 6. Spatial pattern of surface temperatures and woody vegetation in the test area.

process. The survey of land-cover types provides geographical units for urban forestry planning and management. The typology was based on established categories of land-use plans, which were further modified for analysis of the urban ecosystem. The land units allow spatial analysis of environmental conditions to be determined at an intermediate level of accuracy (scale of aerial photographs 1:5,000) so that more detailed information can be interpreted in the context of the urban setting as a whole.

The citywide inventory of land-cover types provided baseline data for physical features of the cityscape (e.g., cover of built-up and vegetated surfaces) and the urban forest (e.g., the cover of trees and shrubs and the age classes of trees). To record more specific information on the species composition, structure, and health status of the urban forest, city quarters can be selected that are representative of the urban land-cover types.

The results show how the approach to land-cover type helps to assess the functions of the urban forest for protecting nature and natural resources. While the case studies demonstrated the application of the concept for nature conservation and urban climate planning, future knowledge is required concerning amenity functions of the urban forest (e.g., visual perception, aesthetic value, recreation, carbon sequestration).

Hydrological features, the energy use for space heating, and carbon dioxide emissions for the different land-cover types have been characterized in other case studies (Pauleit 1998). Thus, environmental profiles for the different land-cover types based on quantitative information show the strengths and weaknesses of each type as a basis for specific environmental plans and targets.

We believe, therefore, that land-cover types are a useful concept to link environmental planning and more specifically urban forestry with general land-use and structure planning. This is highly necessary to successfully implement urban forestry goals in future urban development.

LITERATURE CITED

American Forests. 1996. Urban Ecological Analysis for Milwaukee, Wisconsin. Report of American Forests. Washington, DC. 38 pp.

Bründl, W., H. Mayer, and E.-M. Noack. 1987. Untersuchung des Einflusses von Bebauung und Bewuchs auf das Klima und die lufthygienischen Verhältnisse in bayerischen Großstädten. Bay. Staatsministerium für Landesentwicklung und Umweltfragen (Ed.). Materialien 43. München. 346 pp.

Dorney, J.R., G.R. Guntenspergen, J.R. Keough, and F. Stearns. 1984. Composition and structure of an urban woody plant community. Urban Ecol. 8:69–90.

McPherson, E.G., D.J. Nowak, and R.A. Rowntree (Eds.). 1994. Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service, Northeastern Forest Experiment Station, General Technical Report NE-186. Radnor, PA. 201 pp.

McPherson, E.G., and R. Rowntree. 1989. Using structural measures to compare twenty-two U.S. street tree populations. Landscape J. 8:13–23.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. SPSS. Statistical Package for the Social Sciences, 2nd ed. McGraw-Hill, New York, NY.

Nilon, C.H. 1991. Classification of urban forests in three U.S. cities: A test of Moll's urban forest zone model. Arboric. J. 15:255–263.

Nowak, D.J., R.A. Rowntree, E.G. McPherson, S.M. Sisinni, E.R. Kerkmann, and J.C. Stevens. 1996. Measuring and analyzing urban tree cover. Landscape Urban Plann. 36:49–57.

Nowak, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's urban forest, pp 83–94. In McPherson, E.G., D.J. Nowak, and R.A. Rowntree (Eds.). Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service, Northeastern Forest Experiment Station, General Technical Report NE-186, Radnor, PA.

Oke, T.R. 1989. The micrometeorology of the urban forest. Philos. Trans. R. Soc. London, Series B, Biology Science 324 (1223):335–349.

Pauleit, S., 1998. Das Umweltwirkgefüge städtischer Siedlungsstrukturen. Darstellung des städtischen Ökosystems durch eine Strukturtypenkartierung zur Bestimmung von Umweltqualitätszielen für die Stadtplanung. Landschaftsökologie Weihenstephan, Vol. 12, 151 pp.

Richter, H. 1984. Structural problems of urban landscape ecology, pp. 29–41. In Brandt, J., and P. Aggers (Eds.). Proceedings of the First International Seminar of the International Association for Landscape Ecology (IALE), Vol. 1. Roskilde University Centre, Roskilde, Denmark, October 15–19, 1985.

van Dorp, D., and P.F.D. Opdam 1987. Effects of patch size, isolation and regional abundance on forest bird communities. Landscape Ecol. 1:59–73.

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Résumé. Un système d'information géographique (SIG) a été développé et utilisé pour déterminer la forme et les fonctions environnementales de la forêt urbaine de la ville de Munich. Les types de couvert de territoire urbain ont été délimités et ont servi d'unités spatiales de fond de plan ; ils étaient caractérisés par des attributs physique et d'utilisation tels que le pourcentage d'occupation des bâtiments et de la végétation. La forêt urbaine a été décrite en regard de la couverture en arbres et arbustes et par l'âge maximum des arbres s'y trouvant. L'inventaire a été mis en relation avec des données statistiques de base et environnementales telles que l'inventaire des bâtiments et par des photos aériennes infrarouges. Les arbres et les arbustes recouvraient environ 5400 hectares de superficie ou 18% du territoire de la ville de Munich. Le schéma spatial de la forêt urbaine était relié intimement avec le zonage général d'utilisation des différents secteurs ainsi qu'avec la densité en bâtiments. Une relation entre la couverture, la dimension et l'âge de la végétation ligneuse avec l'incidence d'oiseaux de milieu boisé a été utilisée pour déterminer le rôle de la forêt urbaine sur la conservation de la nature ; de plus, les liens d'habitat potentiels avec des boisés voisins ont été identifiés au moyen de moyennes calculées avec le SIG. En plus, il a été démontré que la forêt urbaine allait effectivement réduire la température ambiante durant les jours chauds d'été. Des programmes spécifiques de foresterie urbaine et des objectifs quantitatifs ont été proposés pour les différentes zones urbaines. Ces derniers vont accroître le couvert forestier de la ville de 22%. Un estimé des coûts globaux pour ces nouveaux aménagments est donné.

Zusammenfassung. In der Stadt München wurde ein neu entwickeltes geographisches Informationssystem (GIG) angewendet, um die räumliche Verteilung und die ökologischen Funktionen der Stadtwälder zu untersuchen. Die unterschiedlichen städtischen Landbedeckungstypen wurden hierbei als räumliche Einheiten unterlegt und durch ihre physikalischen und Nutzungseigenschaften, wie Prozentsatz der Bedeckung und der Vegetationsanteil charakterisiert. Der Stadtwald wird beschrieben als die Bedeckung durch Bäume und Sträucher sowie das maximale Alter der Bäume. Die Studie wurde mit statistischen Datenbanken und ökologischen Daten, wie Lebensraumuntersuchung und Infrarotaufnahmen gekoppelt. Die Bäume und Sträucher bedecken schätzungsweise 5.400 Hektar bzw. 18 % der Fläche von München. Die räumliche Verteilung des Stadtwaldes ist stark verknüpft mit der allgemeinen Aufteilung der Landnutzung und der Bebauungsintensität. Die Beziehungen zwischen der Bedeckung, Größe und Alter der Vegetation und der Anwesenheit von Vögeln als Standortindikatoren wurde genutzt, um die Rolle der Stadtwälder im Naturschutz zu untersuchen. Es wurden auch die potentiellen Habitatvernetzungen benachbarter Waldstücke durch das GIS untersucht. Desweiteren konnte gezeigt werden, daß Stadtwälder die Temperatur während heißer Sommertage reduzieren. Für urbane Bereiche wurden nun spezielle Programme vorgeschlagen und quantitative Ziele gesetzt. Diese können die Waldbedeckung des Stadtgebietes auf 22 % heraufsetzen. Eine Schätzung für die entstehenden Kosten einer Erweiterung der waldbedeckten Fläche ist hier beigefügt.

Resumen. Se desarrolló y aplicó un sistema de información geográfica (GIS) con el fin de estimar el patrón espacial y las funciones ambientales del bosque urbano en la ciudad de Munich. Fueron delineados los tipos de cobertura del terreno como unidades espaciales sobrepuestas, caracterizadas por atributos físicos y de uso del suelo tales como el porcentaje de cobertura con vegetación y terreno construido. El bosque urbano fue descrito como la cobertura de árboles y arbustos y la edad máxima de los árboles. El estudio fue acoplado con bases de datos estadísticas y datos ambientales tales como un estudio de hábitat con fotografía termal infrarroja. Los árboles y arbustos cubrieron aproximadamente 5,400 hectáreas de terreno o el 18 por ciento del área superficial de Munich. El patrón espacial del bosque urbano estuvo estrechamente unido con la zonificación general de usos diferentes del suelo y la densidad de edificaciones. La relación entre cobertura, tamaño y edad de la vegetación maderable y la incidencia de pájaros indicadores del bosque fue usada para estimar el papel del bosque urbano en la conservación de la naturaleza. Los potenciales de hábitats unidos estrechamente a los bosques vecinos fueron identificados por medio de GIS. Por otra parte, se demostró que el bosque urbano efectivamente reduce las temperaturas del aire durante los días calientes de verano. Son propuestos programas forestales urbanos específicos con propósitos cuantitativos para las zonas urbanas. Esto incrementaría la cobertura forestal al 22 por ciento del área de la ciudad. Se presenta una estimación de los costos para el establecimiento del bosque adicional.