Urban Ecosystems, 4: 105–124, 2000

Urban forest cover of the Chicago region and its relation to household density and income

LOUIS R. IVERSON liverson/ne_de@fs.fed.us
USDA Forest Service, 359 Main Road, Delaware, OH 43015

ELIZABETH A. COOK
Center of Excellence for GIS and Wildlife Management, USDA-NRCS at Lincoln University, 306 Founders Hall Jefferson City, MO 65102

Abstract. Urban forests and herbaceous open space play a vital role in the environmental and aesthetic "health" of cities, yet they are rarely identified in land-use inventories of urban areas. To provide information on urban forests and other vegetative land cover in Illinois cities, Landsat Thematic Mapper (TM) data from June 27, 1988, were classified for the Chicago metropolitan region (9,717 km^2). Ten land-cover classes were identified, including two types of forestland (occupying 5.8% of the total area), residential land with trees (14.6%) or without trees (7.8%), cropland (37.5%), two types of grassland (7.7%), urban with impervious surfaces (23.1%), water (1.6%), and miscellaneous vegetation (2.1%). Correlation analyses indicated that household income and household density are strongly related to land covers in the region, particularly those with tree cover and urbanized land. Population changes for 1980–1985 and 1985–2010 (projected) show a pattern of increasing density in the urbanized zone concurrent with continued urban sprawl, primarily into current cropland.

Keywords: Chicago, Illinois, urban ecosystems, landscape ecology, socioeconomic, household density, household income, Landsat Thematic Mapper

Introduction

Forests provide many benefits, including habitat for a variety of plants and animals, recreation, protection of watersheds from erosion, and timber products (Iverson *et al.*, 1989; Iverson, 1994). Urban forests provide additional benefits less commonly associated with rural forests, for example, temperature modification and energy conservation, abatement of air and noise pollution, masking of unpleasant urban views, and corridors into urban habitat islands (Adams, 1994; Nowak, 1994, Schoeneman and Ries, 1994; Zalewski, 1994; Blair, 1996; Zipperer *et al.*, 1997). Yet data on urban forest resources are limited. Inventories of land use in urban areas typically have focused on classifying man-made features to the exclusion of data on the vegetation within these complex landscapes. For example, undeveloped land in urban settings often is labeled as "vacant land" and housing areas as "residential" without mention of the tree and herbaceous cover in these areas. As a result, many municipal governments lack the necessary data to manage and/or protect their urban forests against the pressures of continued development. In 1986, the Illinois Commission on Forestry Development issued a report that emphasized the need for additional information on the quantity, quality, and functionality of forests in the state's urban and urbanizing areas (Illinois Comm. on Dev., 1986). These areas are especially important because urban

dwellers account for 83% of Illinois' population, and because urban tree plantings, e.g., residential landscaping and street trees, represent significant increases in tree cover in a state that has only 12% of its land as forest cover (Iverson *et al.*, 1989; Cook and Iverson, 1991).

The use of satellite imagery to map urban landscapes has met with varying degrees of success (Quattrochi, 1983; Toll, 1984; Duggin *et al.*, 1986; Haack *et al.*, 1987; Sadowski *et al.*, 1987; Foresman *et al.*, 1997). Although most studies have reported high accuracies in identifying urban vegetation, Buchan and Hubbard (1986) reported that even the 20-m multispectral resolution of the SPOT (Systeme pour L'Observation de la Terre) satellite is insufficient for mapping the heterogeneity of some inner city areas because of the heterogeneous nature of the vegetation within a land-use category.

Sociological considerations are an integral part of ecosystem management, particularly as it relates to urbanizing regions (Whitney and Adams, 1980; Jones *et al.*, 1995). New and innovative methods for merging ecology and socioeconomics are central to studies of urban to rural transects (McDonnell and Picket, 1990; Grove and Burch, 1997; McDonnell *et al.*, 1997; Zipperer *et al.*, 1997). Satellite imagery can be used effectively with sociological measures to determine the relationship between population density and forest fragmentation (Vogelmann, 1995) or to categorize urban regions by degrees of population "crowding" (Weber and Hirsch, 1992).

Chicago has long been an important area for studies of forest–human interactions (Cronon, 1991) and for assessing the role of urban tree cover (Nowak *et al.*, 1996). McPherson *et al.* (1993, 1994, 1997) and Nowak (1994) inventoried Chicago's urban forests and estimated their value with respect to air pollutant cleansing, carbon sequestration, and energy savings for buildings. The benefits and costs of tree planting and care were evaluated; the long-term benefits of trees outweighed their costs 2 : 1. Our study differs in that they used extensive ground survey plots (652 vegetation plots) over two counties, while we analyzed six counties using Landsat TM imagery. The objective of this study was to inventory land cover, particularly urban vegetation, for the greater Chicago metropolitan region, and to correlate the derived land cover estimate to population density, household income, numbers of households, and changes in household numbers over time.

Materials and methods

Study areas

In addition to the City of Chicago and nearly 300 suburbs about the city core, the Chicago metropolitan area (9,557 km^2) comprises Cook (2,449 km^2), DuPage (866 km^2), Kane (1,348 km^2), Lake (1,159 km^2), McHenry (1,564 km^2), and Will (2,168 km^2) Counties. With more than 7.5 million residents, the Chicago metropolitan area is the third largest in the United States (U.S. Bur. Census, 1996). Projections of past population estimates indicate that rapid population growth in this region will continue in this century (Table 1).

Historically, the early population and business growth of these six counties was linked in part to the development of the Illinois and Michigan Canal, which since its completion in 1848 essentially connects the Great Lakes and the Gulf of Mexico via the Illinois and

Table 1. Human population (thousands) by county for 1980, 1990, and 1996.

Year	Cook	DuPage	Kane	Lake	McHenry	Will	Total
1980	5254	659	278	440	148	324	7104
1990	5105	782	317	516	183	357	7260
1996	5137	853	360	572	225	413	7561

Source: U.S. Bureau of the Census, 1996.

Mississippi Rivers (Bolin, 1990; Cronon, 1991). The population growth at that time is still reflected in the current population distribution.

Prior to European settlement, forest cover in the six counties ranged from 12% in Will County to 63% in Lake County (Iverson *et al.*, 1989). Early designations of forest preserve districts in all but McHenry County have placed significant forested tracts in public ownership. Today, these areas comprise substantial amounts of green space within the urban environment (McPherson *et al.*, 1993).

Within the six-county Chicago metropolitan area, we also compared the land cover for a subset of 29 out of the nearly 300 municipalities in this region. Criteria for selection included obtaining a wide range in municipal land cover, population density, household incomes, city finances, and the attitudes of local governments toward urban forestry. The 29 cities that were selected include the City of Chicago, Barrington Hills, Park Forest, and West Haven (Cook County); Carol Stream, Elmhurst, Naperville, Warrenville, and West Chicago (DuPage County); Aurora, Batavia, Hampshire, Montgomery, North Aurora, and St. Charles (Kane County); Antioch, Lake Forest, Libertyville, Long Grove, and North Barrington (Lake County); Algonquin, Cary, Crystal Lake, Lake-in-the-Hills, McHenry, and Woodstock (McHenry County); and Bolingbrook, Homer Township, and Crete (Will County) (figure 1).

Data acquisition

Ground-based variables

Data obtained from the Northeastern Illinois Planning Commission (NIPC) provided information, at a quarter section (0.25×0.25 mile or 0.42×0.42 km) level of detail, on the following socioeconomic factors: 1980 land use, 1980 and 1985 number of households (used as an index for population density), 1980 and 1985 income per household, and projected (2010) household numbers and income. Land-use (19 classes) data were reported in units of number of acres of each land-use class per quarter section. There were 15 "urban" land uses (residential, manufacturing, transportation, railroad, airport, street, private services, institutional services, military, entertainment, public buildings, warehousing, hotels, parking lots, and public open space) and four "rural" land uses (cemetery, mining, vacant land/agriculture/forests, and water).

A total of 81 topographic maps (7.5 minute) were used to rectify the Landsat images. These as well as aerial photographs (9×9 inch color infrared) dating from 1983 were used as sources for conducting the classification and ground validation.

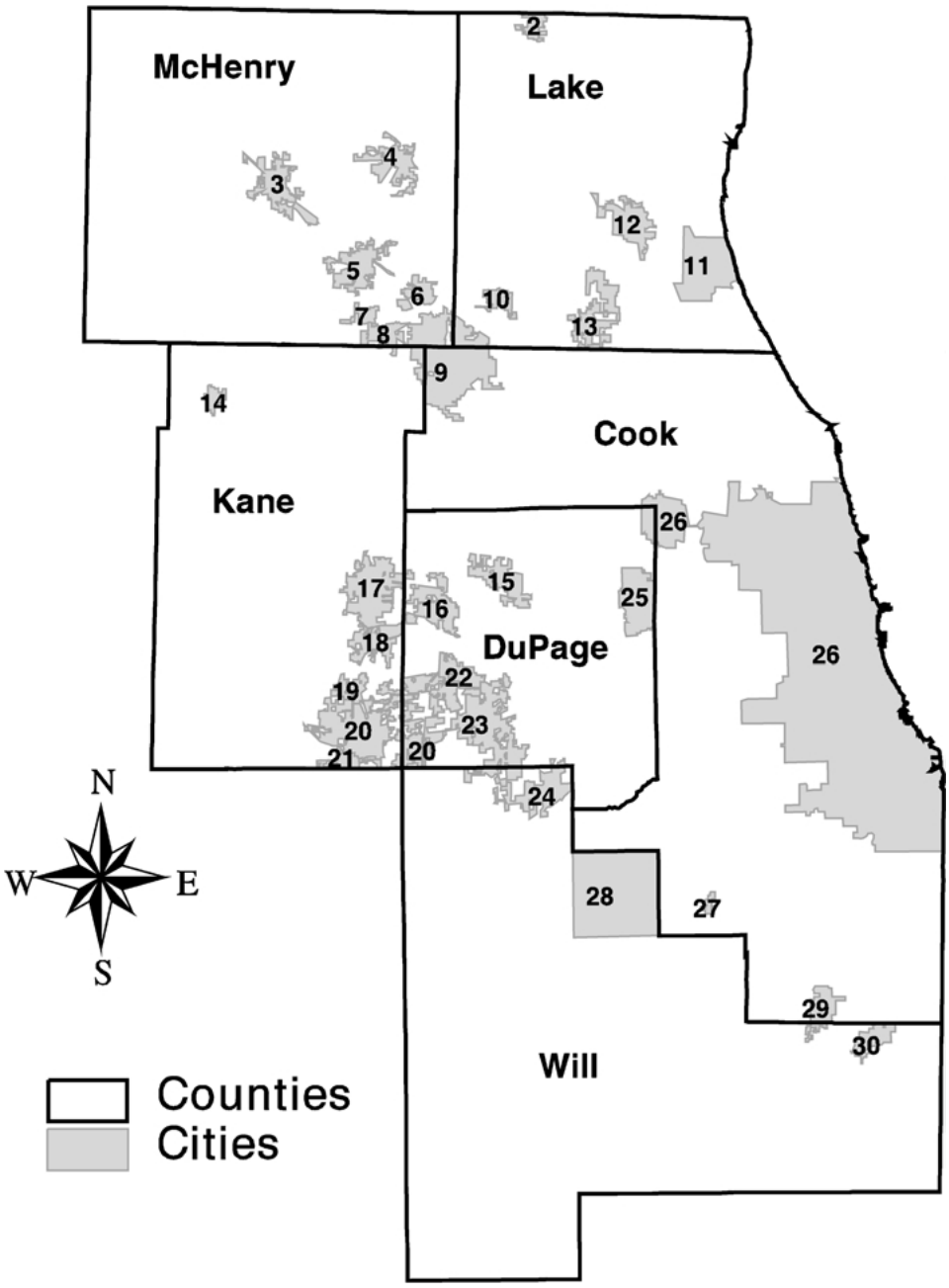

Figure 1. The six-county Chicago metropolitan area and the 29 municipalities that were assessed (numbers correspond to city number in Table 3).

Quarter section lines were digitized into an existing coverage of sections for the six counties. This coverage was used to link the NIPC quarter section tabular data to geographic coordinates, which allowed analysis of the NIPC data in association with the land-cover data. The percentage of each quarter section in "urban" uses is shown in figure 2. Selected municipal and forest preserve boundaries were also digitized for the Chicago region.

Remotely sensed data

A Landsat TM scene (path 23 row 31) from a clear day early in the growing season (June 27, 1988) was used for land-cover evaluation. Cost prohibited purchase of additional scenes, which would have been preferable to maximize potential spectral differences among land-cover classes. However, at this phenological time in Illinois, corn and bean row crops were not yet at 100% canopy cover, making them more spectrally distinct from forest and grassland. Previous experience told us that leaf-on imagery was essential, and that it was also critical to acquire data before the corn was at 100% canopy cover or it would appear spectrally similar to fully leafed trees. The TM scene was rectified with 60 small landscape features (often small ponds) located in the image data and on 7.5-minute quadrangle maps. Subpixel registration accuracy was achieved.

Classification of the area was achieved via a modified approach to unsupervised classification, described below. With the unsupervised approach, the computer statistically groups pixels into a set of clusters, which are later identified via comparison to aerial photographs or field checks. We wished to quantify the amount of tree and herbaceous cover within land-use types typically identified in urban land-use inventories. We included the term "residential" for those areas that are largely inhabited but with varying amounts of vegetative cover (in contrast to "forest" or "cropland" with few or no human inhabitants). The following 10 categories were used in the study:

1. Forestland—tree canopy closures greater than 50%.
2. Scattered trees with herbaceous ground cover—tree canopy closures 25 to 50%.
3. Residential areas—trees and herbaceous cover dominate the signature, but with significant amounts of impervious surfaces.
4. Residential and other urban land—impervious surfaces dominate the signature, but there are significant amounts of vegetation. Also may include bare ground, e.g., former cropland undergoing new development.
5. Manicured grassland (mowed closely).
6. Nonmanicured grassland—roadsides, abandoned land without trees, and pastures. Remnant prairies would also fall into this class.
7. Cropland.
8. Highly developed urban land that is dominated by impervious surfaces and buildings. Little or no vegetation present.
9. Water and wetland.
10. Miscellaneous vegetation not otherwise classified (e.g., sod farms).

Classification was conducted using the ISODATA algorithm of ERDAS (ERDAS 1990), with single TM bands 1, 3, 4, 5, and 7 as inputs. Traditional unsupervised classification of the entire six-county area was not satisfactory because spectral confusion existed between

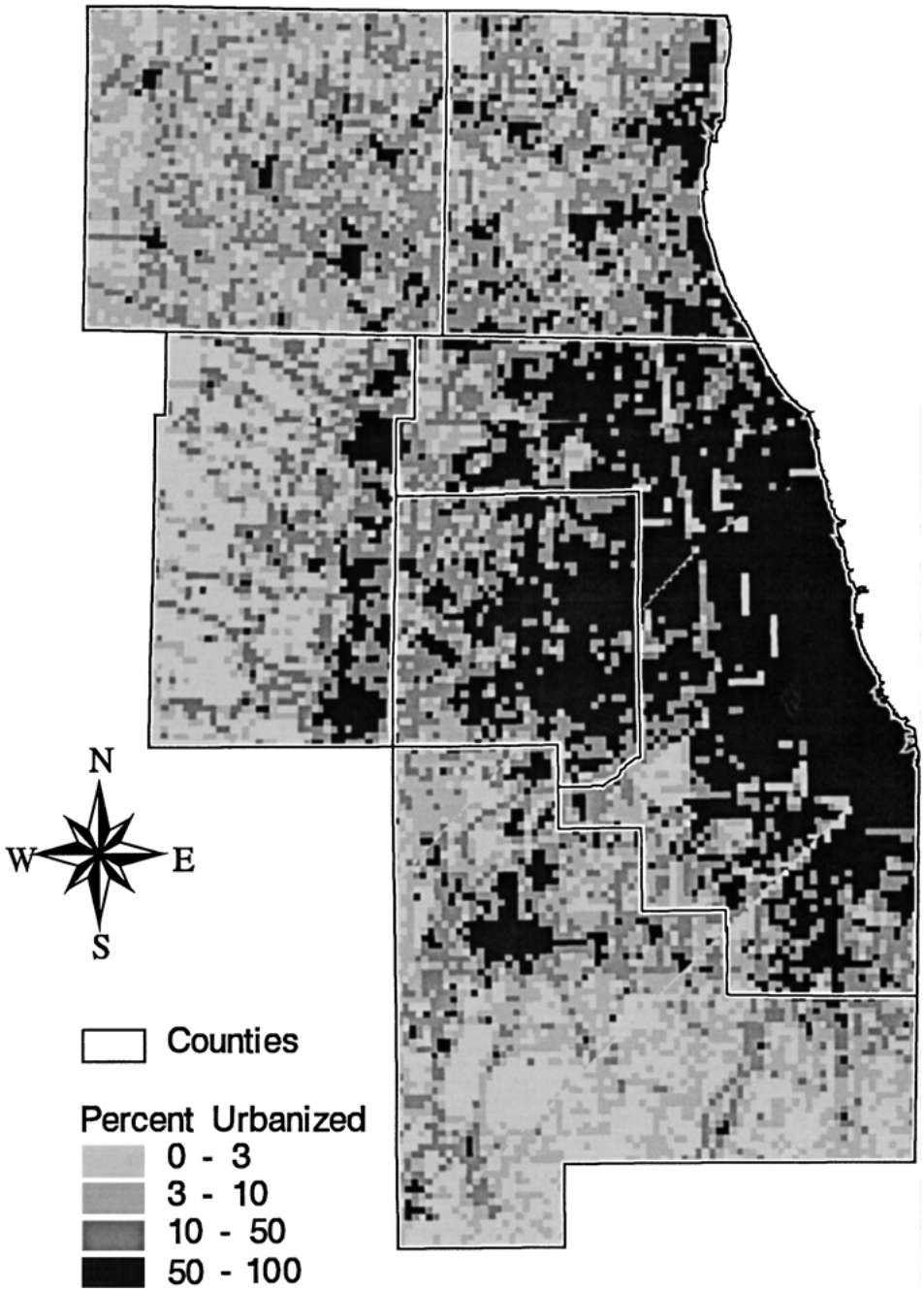

Figure 2. Percentage of each quarter section in urban uses for the Chicago metropolitan area (data from Northeastern Illinois Planning Commission).

several urban and rural classes. For example, a cover type such as a pasture in a rural area could be classified the same as a cemetery or golf course in an urban area because the underlying vegetation was similar. Over this large and diverse area, the sampling procedure for generating even 200 clusters did not adequately represent the heterogeneity of the data. As a result, the quarter section NIPC classification of 19 classes (15 urban and 4 rural) was used to stratify the TM data into "mostly rural" or "mostly urban" prior to unsupervised image classification. The resulting "rural" subset of TM data contained little spectral confusion and was classified using ISODATA without further processing.

The "urban" stratum was also classified with ISODATA, similar to the rural stratum. However, this subset of TM data required additional stratification for adequate clustering among urban classes. Within these urban areas, the major difficulty was separating residential areas having significant tree cover from public land areas with tree cover, e.g., forest preserves and parks. To make this separation, the urban subset was again stratified with NIPC data, this time after the ISODATA clustering algorithm had been run, to identify strata of (1) mostly residential areas, (2) mostly urban land uses devoid of vegetation, and (3) mostly public land. Finally, the resulting four subsets of clusters (rural, urban-residential, urban devoid of vegetation, and urban public land) were rejoined for a total 195 spectral clusters to be classified.

From these 195 clusters, the 10 land-cover classes were identified, as described above. Cluster identification was achieved by on-site visits to 131 locations in the field and by assessment using aerial photographs and topographic maps. The final clustering resulted in little spectral confusion, so that we were confident in the resulting land-cover map. Vector files of county, municipal, and quarter section boundaries were converted to raster format and used to summarize the land-cover data by these subdivisions.

Analysis of household number and income in relation to land cover

Simple product-moment correlation was used to relate the amount of each of the ten 1988 land-cover classes by quarter section to household income (1985), numbers of households (1985), and changes in household numbers (1980–1985, 1985–2010), as reported by NIPC. While the discrepancy of three years is not of consequence, we believe the trends would be very similar had the data been synchronized. The distribution of households by number and income is shown in figures 3 and 4, respectively.

Results and discussion

Land cover for the Chicago metropolitan area

Land-cover results for the Chicago metropolitan area are presented in Table 2. The qualitative accuracy assessment found no major spectral confusions or misclassifications, largely because the small percentage of spectral confusions was confined to the "miscellaneous" class; classes 1 and 2 were merged for the "forest" data and classes 5 and 6 for the "grass" data. Total tree cover is calculated here as the sum of the forest and residential with trees classes. Because the residential areas also include houses, lawns, and driveways, the total tree cover will be slightly overestimated. Also indicated in Table 2 are the percentages of

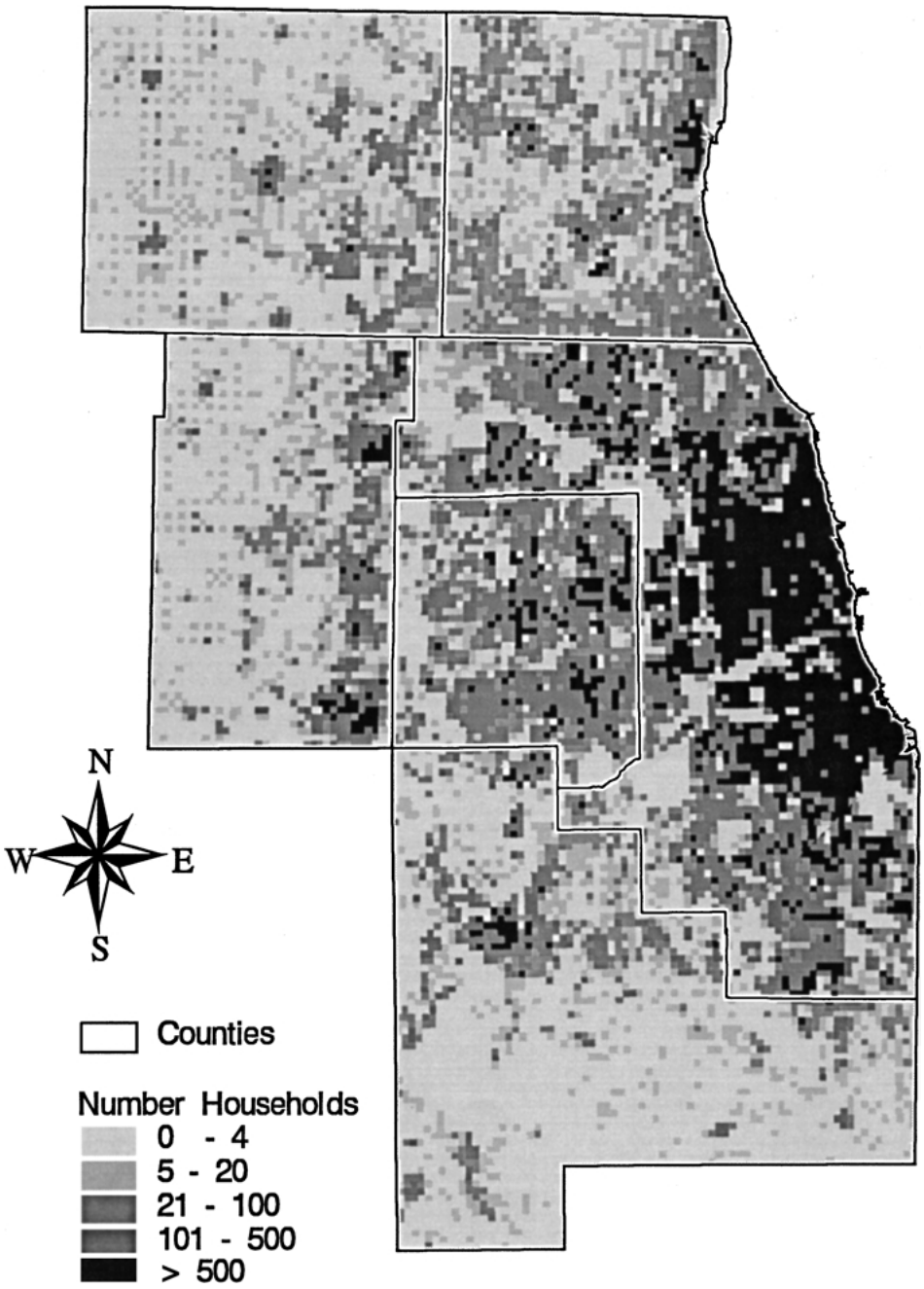

Figure 3. Number of households in 1985 in each quarter section for the Chicago metropolitan area (data from Northeastern Illinois Planning Commission).

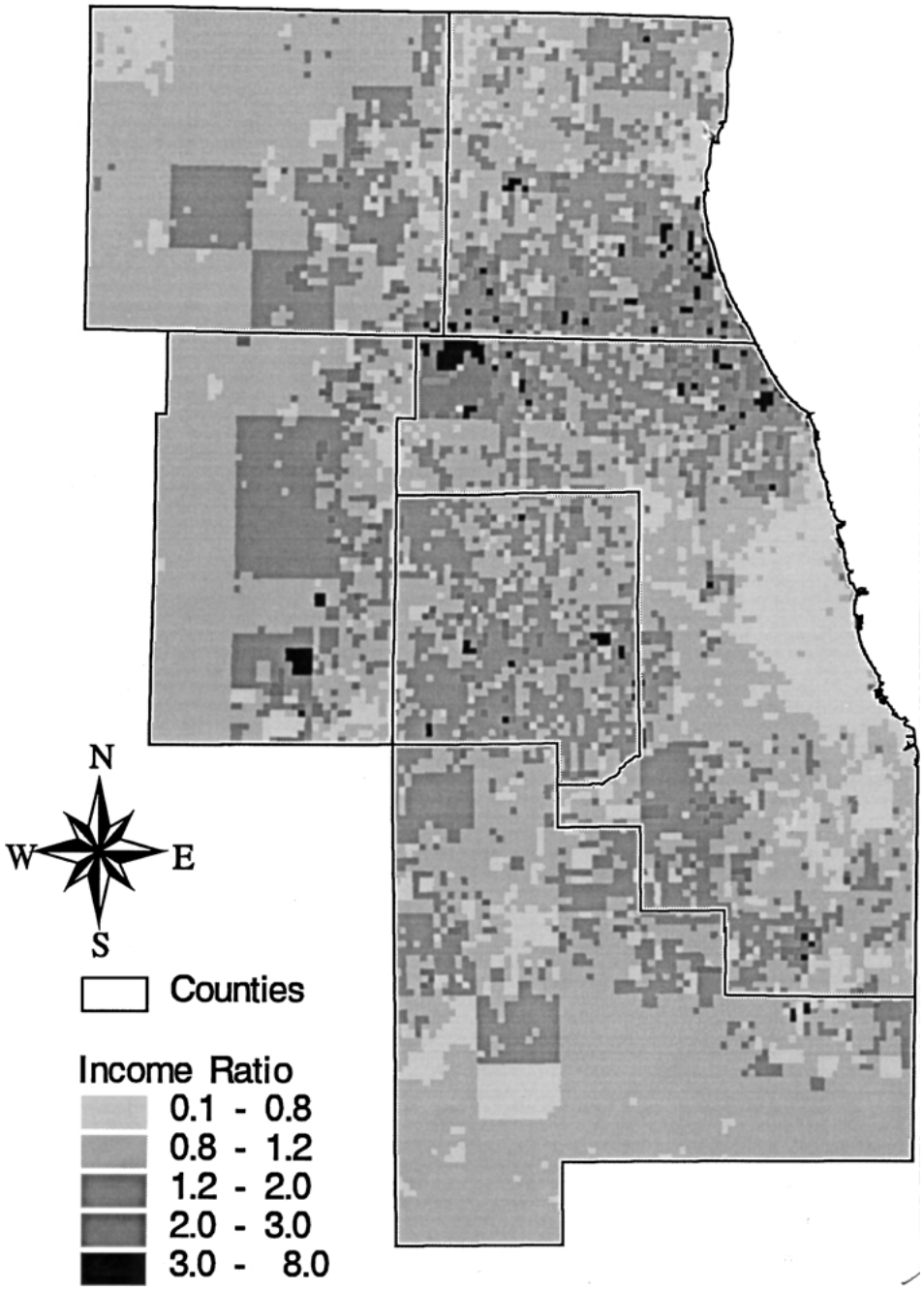

Figure 4. Household income in 1985 (as a ratio to the regional average) in each quarter section for the Chicago metropolitan area (data from the Northeastern Illinois Planning Commission).

Table 2. Area and population (1980, 1990, 1996) data and land-cover percentages (1988) for the six-county Chicago metropolitan area. Presettlement forest cover and land-use forest data from the 1970s are also presented. The forest class includes class 2 (scattered trees), while classes 5 and 6 were merged into a "grass" class.

Class	All	Cook	Du Page	Kane	Lake	McHenry	Will
Area, sq km	971.7	248.3	85.7	134.7	122.8	159.3	220.9
Population, (× 1000) 1980	7104	5254	659	278	440	148	324
1990	7260	5105	782	317	516	183	357
1996	7561	5137	853	360	572	225	413
Forest	5.8	8.3	5.6	3.9	8.5	4.3	3.8
		(13.6)[a]	(13.5)	(35.0)	(63.2)	(42.7)	(12.5)
		[7.8][b]	[6.5]	[3.6]	[7.1]	[7.4]	[5.4]
Residential with trees	14.7	24.2	31.3	8.5	20.0	3.8	5.7
Total tree cover	20.5	32.5	36.9	12.4	28.5	8.1	9.5
Residential without trees	7.8	21.3	9.4	2.2	4.1	0.7	2.4
Grass	7.7	6.6	12.1	9.2	10.4	5.0	6.7
Crop	37.2	5.1	9.9	53.9	27.7	62.0	62.5
Urban	23.1	33.0	29.4	19.6	21.4	18.7	15.6
Water	1.6	1.0	0.6	0.6	4.4	1.5	1.8
Miscellaneous vegetation	2.1	0.6	1.7	2.2	3.5	4.2	1.6

[a]Percentages in parentheses are presettlement forest cover for county. (From Iverson *et al.*, 1989).
[b]Percentages in brackets are 1970's land use forest cover for county. (From Iverson *et al.*, 1989.)

forest cover by county at the time of European colonization (Iverson *et al.*, 1989). At this time, Lake County was primarily forested (63.2%), while McHenry and Kane counties also were over one-third forested. The remaining counties were largely prairie prior to European colonization. This prairie was almost entirely removed, with only small remnants and restorations providing that important habitat today (Iverson, 1988).

As one would expect, highly urbanized Cook County has the most urban land cover (impervious surfaces), but only slightly more than rapidly urbanizing DuPage County (33 versus 29.4%). Kane, McHenry, and Will Counties have correspondingly lower amounts of urban land, because more than half their respective land use is agricultural.

Forest cover in the six counties ranges from 3.8% in Will County to 8.5% in Lake County. Total forest cover for the six-county area is 5.8%. Cook County, the most urbanized of the six counties, has only slightly less forest land than Lake County (8.3 vs. 8.5%) and has a higher proportion of total tree cover than Lake County when forested residential areas and forestland are combined (32.5 versus 28.5%). DuPage County has the most combined tree cover (36.9% forests plus forested residential); the total for all counties together is 20.5%.

The data from Cook and DuPage Counties relate to two points about forests in the Chicago area. First, through preservation of forested tracts as county forest preserves and other public land, these counties have maintained significant proportions of their original forest cover (41 and 61% compared to only 10 and 11% for McHenry and for Kane County, respectively).

Cook County's forest preserve system includes more than 67,000 acres (McPherson *et al.*, 1993). Second, residential landscaping and street-tree plantings have increased tree cover over time in urbanized areas (McPherson *et al.*, 1994). Trees cover about one-third each of Cook, DuPage, and Lake Counties, the three most urbanized counties in the Chicago metropolitan area.

Considering the rapid urban growth and small amounts of forest cover in Kane, McHenry, and Will Counties (Table 2), there are more overall negative consequences from conversion of prime farmland to urban land uses than the loss of forestland in these areas. The amount of cropland that was being subdivided for development during this study, especially in Will County, was very high.

Land cover for municipalities

Land-cover statistics for the 29 municipalities of the Chicago metropolitan area are listed in Table 3. Cook County hosts the municipalities with both the most and the least forest cover (Barrington Hills and West Haven). As with the county-level data, this finding reflects the key role of forest preservation in determining the current land cover of Cook County. Lake Forest (Lake County) has the highest percentage of tree cover (67.1), while West Haven has the lowest (6.2%). Forest cover in the 29 municipalities averaged 5.3%, while total land with trees averaged 31.6%.

The percentage of urban (impervious) cover ranged from 8.6 in North Barrington (Lake County) to 54.2 in Carol Stream (DuPage County). Carol Stream has a higher percentage of urban land than even Chicago, largely because that city is undergoing a great deal of development on former cropland, i.e., land that is bare or with little mature vegetation. Urban land in the 29 municipalities averaged 32%.

Analysis of household number and income in relation to land cover

Correlations between the 10 land-cover categories (1988) and the household data (1985) for the six-county region reveal mostly obvious and expected trends, with some exceptions. Nonetheless, it is informative to observe and confirm the trends statistically uncovered with merged land cover and household data. For example, overall and for each county individually, the amount of forestland is strongly and inversely related to the number of households (Table 4). Cropland and other vegetation also are negatively related to household density. However, as one would expect, there is a strong positive relationship between numbers of households and residential areas without significant tree cover, and between household density and urbanized areas (Table 4).

The more populated quarter sections (>100 households) are almost exclusively urban, residential without trees, or residential with trees (figure 5). However, as the number of households continues to increase, the percentage of land in residential with trees drops dramatically (Sanders, 1984). With low population density, cropland covers more than 60% of the area; obviously, large numbers of households are not compatible with cropland, and the proportion in cropland diminishes rapidly when the number of households increases. The proportion of forest cover is highest where household density ranges from 10 to 50

Table 3. Land-cover percentages (1988) for selected categories in the Chicago metropolitan area municipalities. The forest class includes initial class 2 (scattered trees and herbaceous).

Location	City number	Forest	Residential with trees	Total tree cover	Residential without trees	Urban
Cook County						
Chicago	26	1.5	13.7	15.2	32.8	49.3
Barrington Hills	9	22.1	18.7	40.8	0.9	12.2
Park Forest	29	4.0	56.0	60.0	14.7	18.2
West Haven	27	0.2	6.0	6.2	21.9	41.8
Du Page County						
Carol Stream	15	0.4	12.9	13.3	16.7	54.2
Elmhurst	25	0.8	52.4	53.2	16.5	28.3
Naperville	23	2.4	29.7	32.1	14.7	38.5
Warrenville	22	4.5	35.4	40.0	6.2	27.1
West Chicago	16	7.1	25.9	33.0	6.8	29.1
Kane County						
Aurora	20	1.8	21.6	23.4	14.3	41.0
Batavia	18	1.6	36.6	38.1	5.8	35.1
Hampshire	14	3.2	9.2	12.3	5.1	31.5
North Aurora	19	0.9	19.2	20.1	10.4	47.6
Montgomery	21	2.0	19.7	21.7	11.6	49.5
St. Charles	17	6.4	34.6	41.0	9.4	33.6
Lake County						
Antioch	2	2.7	13.3	16.0	10.8	35.0
Lake Forest	11	9.4	57.7	67.1	2.4	10.1
Libertyville	12	8.4	32.3	40.7	9.0	32.7
Long Grove	13	10.0	19.4	29.5	1.6	18.7
North Barrington	10	14.4	48.3	62.7	0.5	8.6
McHenry County						
Algonquin	8	9.1	32.3	41.4	7.1	38.0
Cary	6	3.6	22.1	25.7	7.9	44.2
Crystal Lake	5	3.8	22.5	26.3	10.6	41.1
Lake-in-the-Hills	7	2.2	33.9	36.1	5.8	18.2
McHenry	4	2.6	18.1	20.7	7.4	40.7
Woodstock	3	5.2	12.5	17.8	6.7	35.7
Will County						
Bollingbrook	24	2.8	18.0	20.9	25.1	34.8
Homer Township	28	7.1	7.1	14.2	2.3	15.4
Crete	30	12.1	34.2	46.3	4.2	18.1

Table 4. Correlation between 1988 land cover categories and number of households per quarter section area in 1985. Number in parenthesis refers to significance level.

Class	All	Cook	DuPage	Kane	Lake	McHenry	Will
Forest	−.67	−.66	−.70	−.47	−.80	−.36	−.50
	(.000)	(.000)	(.000)	(.033)	(.000)	(.118)	(.018)
Scattered trees	−.61	−.60	−.44	−.29	−.55	−.23	−.36
	(.001)	(.002)	(.045)	(.196)	(.012)	(.359)	(.114)
Residential with trees	.02	−.04	.54	.63	.66	.88	.53
	(.913)	(.836)	(.008)	(.001)	(.001)	(.000)	(.005)
Residential without trees	.72	.70	.99	.99	.99	.97	.99
	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
Manicured grass	−.40	−.49	−.49	−.13	−.18	−.48	−.09
	(.048)	(.013)	(.019)	(.560)	(.423)	(.031)	(.689)
Nonmanicured grass	−.66	−.70	−.79	−.63	−.81	−.18	−.47
	(.000)	(.000)	(.000)	(.001)	(.000)	(.442)	(.028)
Crop	−.49	−.46	−.57	−.55	−.66	−.71	−.67
	(.013)	(.019)	(.005)	(.009)	(.001)	(.001)	(.001)
Urban	.76	.56	.76	.36	.01	.52	.15
	(.000)	(.004)	(.001)	(.087)	(.973)	(.018)	(.498)
Water	−.51	−.35	−.48	−.40	−.68	−.32	−.62
	(.012)	(.095)	(.031)	(.082)	(.001)	(.190)	(.003)
Miscellaneous vegetation	−.71	−.65	−.60	−.79	−.79	−.88	−.72
	(.000)	(.000)	(.003)	(.000)	(.000)	(.000)	(.000)

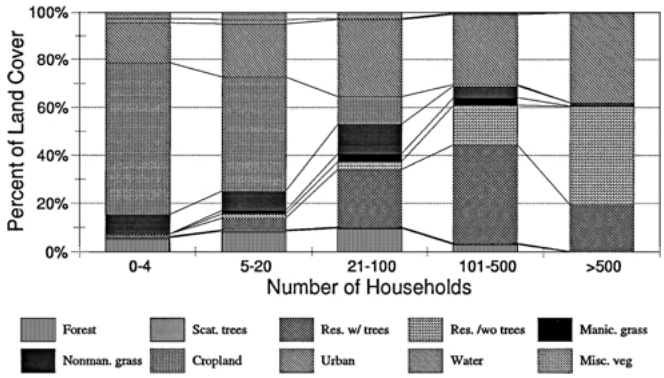

Figure 5. The relationship of land cover (1988) to the number of households per quarter section (1985) for the Chicago metropolitan area.

Table 5. Correlation between 1988 land cover categories and income of households in 1985 as a ratio to regional average. Number in parenthesis refers to significance level.

Class	All	Cook	Du Page	Kane	Lake	McHenry	Will
Forest	.62	.56	.11	−.14	.55	.43	.62
	(.003)	(.009)	(.644)	(.617)	(.010)	(.095)	(0.10)
Scattered trees	.60	.38	−.18	−.41	−.05	.76	.04
	(.004)	(.087)	(.498)	(.188)	(.836)	(.005)	(.877)
Residential with trees	.87	.80	.56	.07	.74	.14	.44
	(.000)	(.000)	(.009)	(.810)	(.000)	(.606)	(.087)
Residential without trees	−.72	−.74	−.40	−.55	−.73	−.31	−.14
	(.000)	(.000)	(.074)	(.052)	(.000)	(.359)	(.582)
Manicured grass	.65	.31	.37	−.32	.29	−.08	.30
	(.001)	(.168)	(.109)	(.224)	(.209)	(.760)	(.254)
Nonmanicured grass	.40	.29	−.35	.22	−.58	.75	.36
	(.071)	(.202)	(.118)	(.403)	(.006)	(.001)	(.161)
Crop	−.19	.40	.22	−.15	−.21	−.33	−.69
	(.397)	(.088)	(.409)	(.558)	(.392)	(.233)	(.003)
Urban	−.79	−.87	−.79	−.25	−.78	.24	−.35
	(.000)	(.000)	(.000)	(.343)	(.000)	(.380)	(.170)
Water	−.42	.36	−.20	.30	−.59	−.33	.17
	(.056)	(.100)	(.430)	(.304)	(.006)	(.256)	(.541)
Miscellaneous vegetation	.44	.57	−.09	.53	−.23	−.16	.57
	(.045)	(.007)	(.725)	(.037)	(.318)	(.546)	(.020)

households per quarter section, while the residential with trees class is most prominent in quarter sections with 200 to 600 households. The landscapes with the highest proportion of tree cover (48.5% in residential with trees, 0.7% in forest) are found in quarter sections of relatively high population density (400 to 600 households per quarter section, figure 5).

A similar analysis comparing land cover to household income levels is shown in Table 5 and figure 6. Although the one-quarter section scale is limiting, certain trends are apparent. Forests, areas with scattered trees, residential areas with trees, and manicured grass are strongly and positively correlated with household income in the six-county area. Conversely, increases in urban land are linked with lower household incomes.

Tree cover is greatest in quarter sections with three or four times the average income for the region (figure 6). However, some of the wealthiest quarter sections, where household income exceeds four times the regional average, have proportionately more manicured grassland compared to tree cover. The poorest quarter sections (<0.4 times the regional average) are strongly correlated with urban land and are probably housing projects in the city center. Many individuals living in these areas may be suffering economic hardships; the lack of trees may also contribute to increased environmental hardships for these individuals (Iverson *et al.*, 1989; Iverson, 1991). For quarter sections with average income levels, about

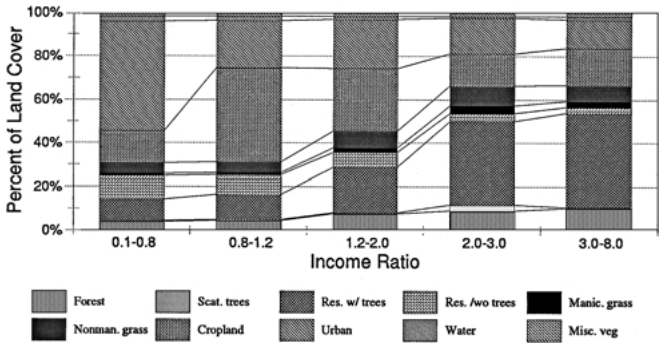

Figure 6. The relationship of land cover (1988) to the household income (as a ratio to the regional average) per quarter section (1985) for the Chicago metropolitan area.

16.2% of the area is tree covered (forest + scattered trees + residential with trees); 48.3% is cropland or unmanicured grass, and 30.7% is urban or residential without trees. These data show that wealthy areas of a city, such as the "Gold Coast" along Lake Michigan north of Chicago (figure 4), are among the most heavily vegetated.

Changes in household density were also investigated for 1980–1985 and 1985–2010. For 1980–1985, there was a positive correlation between the changes in number of households per quarter section and the proportion of the land in residences without trees, and a negative correlation with percentage nonmanicured and manicured grass (Table 6). Figure 7 also shows the largest population increases occurring almost exclusively in three land classes: residential without trees, residential with trees, and urban. For the residential without trees, this result is attributed to the massive migration into former cropland, such that new development occurs in regions with little or no tree cover (i.e., bare ground). The negative correlation (and relatively higher proportion of land showing population decreases) between manicured grass and population changes can be attributed partly to inner city emigration and subsequent increases in vacant, nonmanicured grass. There also may be less mowing in parks and other land as a cost-saving measure.

Forest cover was highest in quarter sections that saw little or no change in households between 1980 and 1985. Many of these lands are locked in nature preserves or forest districts. However, for quarter sections losing 3 to 20 households or gaining 6 to 30 households, the highest percentages were typically in residential areas with trees (figure 7). This trend seems to indicate that some former forestland is being subdivided into large-lot housing, and that some residential areas with trees are losing population. Overall, the urban and residential without trees categories contain most of the land with rapid population increases.

With respect to projected changes in household numbers per quarter section from 1985 to 2010, forestland will apparently continue to experience little change, but residential areas with and without trees are projected to show a large increase in the proportion of quarter sections with reduced numbers of households, especially in Cook County (Table 7, figure 8). Nonmanicured grasslands and urban land are projected to increase in household density. A substantial portion of today's cropland will remain intact with little or no change in household density, though a significant portion of cropland also will be converted to

Table 6. Correlation between 1988 land cover categories and change in number of households per quarter section from 1980 to 1985. Number in parenthesis refers to significance level.

Class	All	Cook	Du Page	Kane	Lake	McHenry	Will
Forest	−.22	−.11	.08	−.85	.13	.30	.27
	(.321)	(.617)	(.772)	(.000)	(.581)	(.242)	(.269)
Scattered trees	−.23	−.14	.28	.24	.07	.24	.17
	(.289)	(.529)	(.301)	(.363)	(.784)	(.347)	(.496)
Residential with trees	−.07	−.06	.49	−.26	.40	.05	.07
	(.747)	(.792)	(.052)	(.320)	(.081)	(.841)	(.781)
Residential without trees	.56	.58	−.54	.28	.37	−.26	−.35
	(.005)	(.004)	(.031)	(.276)	(.112)	(.305)	(.141)
Manicured grass	−.52	−.47	−.34	−.42	−.02	.12	.06
	(.012)	(.023)	(.193)	(.092)	(.948)	(.649)	(.819)
Nonmanicured grass	−.55	−.46	−.27	−.02	−.64	.11	.25
	(.007)	(.027)	(.313)	(.942)	(.003)	(.686)	(.297)
Crop	−.39	−.67	.30	.36	−.47	.38	.23
	(.063)	(.000)	(.259)	(.156)	(.035)	(.128)	(.375)
Urban	.24	.27	−.56	−.44	−.22	−.76	−.16
	(.262)	(.221)	(.023)	(.079)	(.346)	(.000)	(.522)
Water	−.16	−.13	.26	.31	.02	.30	.18
	(.469)	(.542)	(.336)	(.224)	(.947)	(.241)	(.458)
Miscellaneous vegetation	−.26	−.38	.07	−.10	−.29	.40	.25
	(.228)	(.075)	(.798)	(.715)	(.221)	(.112)	(.295)

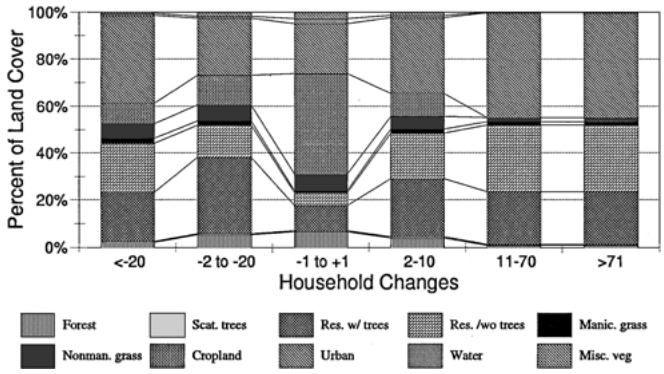

Figure 7. The relationship of land cover (1988) to the change in household numbers between 1980 and 1985 per quarter section for the Chicago metropolitan area.

Table 7. Correlation between 1988 land cover categories and projected changes in number of households per quarter section from 1985 to 2010. Data were not available for Lake and McHenry counties. Number in parenthesis refers to significance level.

Class	All	Cook	Du Page	Kane	Will
Forest	.00	−.33	−.20	.09	−.26
	(.984)	(.153)	(.470)	(.726)	(.301)
Scattered trees	.05	−.53	.31	−.24	−.15
	(.829)	(.015)	(.266)	(.353)	(.540)
Residential with trees	−.62	.−.90	−.75	−.35	−.25
	(003)	(.000)	(.001)	(.173)	(.323)
Residential without trees	−.50	−.78	−.40	−.45	−.22
	(.022)	(.000)	(.141)	(.073)	(.378)
Manicured grass	.77	.13	−.02	.07	−.06
	(.000)	(.594)	(.937)	(.790)	(.818)
Nonmanicured grass	.90	.16	.80	.42	.27
	(000)	(.494)	(.000)	(.097)	(.281)
Crop	.10	.45	.07	.14	.01
	(.651)	(.047)	(.797)	(.585)	(.971)
Urban	.82	.94	.69	.41	.18
	(.000)	(.000)	(.004)	(.099)	(.472)
Water	−.28	−.37	−.20	−.29	−.33
	(.215)	(.102)	(.474)	(.252)	(.175)
Miscellaneous vegetation	.18	.06	−.15	.57	.04
	(.428)	(.817)	(.603)	(.017)	(.874)

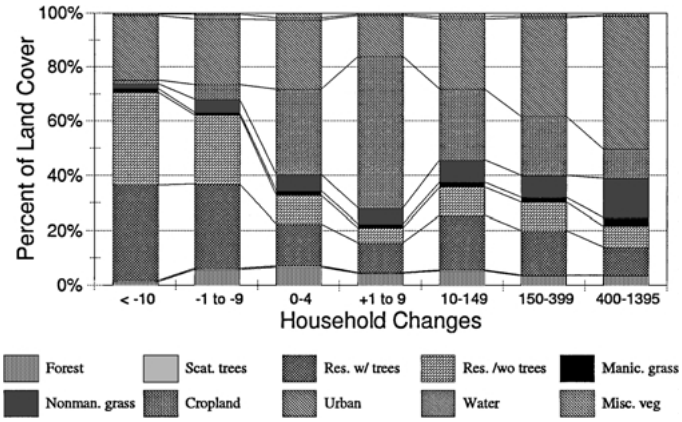

Figure 8. The relationship of land cover (1988) to the projected change in household numbers between 1985 and 2010 per quarter section for the Chicago metropolitan area. Data were not available for Lake and McHenry counties.

developments with 100 or more households (figure 8). Thus current urbanization patterns are projected to continue in this century for the six-county metropolitan area.

Conclusion

Urban forests and other urban green space serve vital functions in our cities and are increasingly important as the proportion of the urban-dwelling population grows. Landsat TM data provide inexpensive and reasonably accurate information on urban land cover. Stratification by pre- or postclustering, or both, improves classification accuracy by reducing heterogeneity within strata. Classification of TM data for the Chicago metropolitan area provided information on urban vegetation that may aid local officials in minimizing the impacts of continued growth.

Analysis of household and income patterns with 1988 land cover shows typical patterns associated with urbanization: (1) wealthy regions have higher tree cover while poor regions have lower; (2) household density is lowest in areas dominated by cropland, followed by forestland, residential with trees, residential without trees, and urban (impervious surfaces) with the highest household density; (3) from 1980 to 1985, maximum change in household density was seen in the residential without trees class, most of which can be accounted for by new housing developments on former cropland; and (4) evaluation of the projected number of households (1985–2010) indicate that urbanization patterns will continue in a similar fashion in this century, providing the current trends in land use, population growth, and economic conditions continue on a similar trajectory. It is up to the people, be they urban planners or lay people, to use the information and technology available to adopt a "smart growth" policy to sustain environmental services while providing humans with a reasonable quality of life.

Acknowledgments

Much of this study was conducted while the authors were employed by the Illinois Natural History Survey. We acknowledge the financial support provided by the Illinois Natural History Survey, the Illinois Council of Forestry Development, the University of Illinois Department of Forestry, the Illinois Department of Energy and Natural Resources, and the USDA Forest Service. The following helped formulate or provide data for the project: Gary Philo, Kristina Reichenbach, Charles Metalitz, Richard Newhard, William Faedtke, Larry Stipek, Richard Hilton, Suzanne Ehardt, Paul Gorte, Mark Brown, Mike Pasteris, and Mark Dunteman. Sharon Baum digitized the ancillary data. Wayne Zipperer, David Nowak, Charles Scott, and Marty Jones reviewed previous drafts of this paper, and Mary Boda prepared the final document.

References

Adams, L.W. (1994) In our own backyard: Conserving urban wildlife. *Journal of Forestry* **92**, 24–25.

Blair, R.B. (1996) Land use and avian species diversity along an urban gradient. *Ecological Applications* **6**, 506–519.

Bolin, J., ed. (1990) The I & M canal national heritage corridor: five years of progress. *The Nature of Illinois* **5**, 1–32.

Buchan, G.M. and Hubbard, N.K. (1986) Remote sensing in land-use planning: an application in west central Scotland using SPOT-simulation data. *International Journal of Remote Sensing* **7**, 767–777.

Cook, E.A. and Iverson, L.R. (1991) Inventory and change detection of urban land cover in Illinois using Landsat thematic mapper data. In *Proceedings of the 1991 ASPRS/ACSM Annual Convention, Volume 3, Remote Sensing*, pp. 83–92. American Congress on Surveying and Mapping and American Society for Photogrammetry and Remote Sensing, Bethesda, MD.

Cronon, W. (1991) *Nature's Metropolis: Chicago and the Great West*. Norton, New York.

Duggin, M.J., Rowntree, R., Emmons, M., Hubbard, N., Odell, A.W., Sakhavat, H. and Lindsay, J. (1986) The use of multidate multichannel radiance data in urban feature analysis. *Remote Sensing of the Environment* **20**, 95–105.

ERDAS (1990) *ERDAS Field Guide*. ERDAS, Atlanta, Georgia.

Foresman, T.W., Pickett, S.T.A. and Zipperer, W.C. (1997) Methods for spatial and temporal land use and land cover assessment for urban ecosystems and application in the greater Baltimore–Chesapeake region. *Urban Ecosystems* **1**, 201–216.

Grove, J.M. and Burch, W.R., Jr. (1997) A social ecology approach and applications of urban ecosystem and landscape analyses: a case study of Baltimore, Maryland. *Urban Ecosystems* **1**, 259–275.

Haack, B., Bryant, N. and Adams, S. (1987) An assessment of Landsat MSS and TM data for urban and near-urban land–cover digital classification. *Remote Sensing of the Environment* **20**, 201–213.

Illinois Commission on Forestry Development (1986) *Forestry in Illinois: Opportunities for Action*. Illinois Commission on Forestry Development, Springfield.

Iverson, L.R. (1988) Land-use changes in Illinois, USA: The influence of landscape attributes on current and historic use. *Landscape Ecology* **2**, 45–61.

Iverson, L.R. (1991) The forests of Illinois: What do we have and what are they doing for us? *Illinois Natural History Survey Bulletin* **34**, 361–374.

Iverson, L.R. (1994) Forest resource trends in Illinois. *Erigenia* **13**, 4–23.

Iverson, L.R., Oliver, R.L., Tucker, D.P., Risser, P.G., Burnett, C.D. and Rayburn, R.G. (1989) The forest resources of Illinois: an atlas and analysis of spatial and temporal trends. Illinois Natural History Special Publication 11.

Jones, J.R., Martin, R. and Bartlett, E.T. (1995) Ecosystem management: the U.S. Forest Service's response to social conflict. *Society and Natural Resources* **8**, 161–168.

McDonnell, M.J. and Pickett, S.T.A. (1990) Ecosystem structure and function along urban–rural gradients: an unexploited opportunity for ecology. *Ecology* **71**, 1232–1237.

McDonnell, M.J., Pickett, S.T.A., Pouyat, R.V., Zipperer, W.C., Parmelee, R.W., Carreiro, M.M. and Medley, K. (1997) Ecosystem processes along an urban-to-rural gradient. *Urban Ecosystems* **1**, 21–36.

McPherson, E.G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R. and Rowntree, R. (1997) Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project. *Urban Ecosystems* **1**, 49–61.

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

McPherson, E.G., Nowak, D.J., Sacamano, P.L., Prichard, S.E. and Makra, E.M. (1993) *Chicago's Evolving Urban Forest: Initial Report of the Chicago Urban Forest Climate Project*. General Technical Report NE-169. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Nowak, D.J. (1994) Understanding the structure. *Journal of Forestry* **92**, 42–46.

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.

Quattrochi, D.A. (1983) Analysis of Landsat-4 Thematic Mapper data for classification of the Mobile, Alabama metropolitan area. In *Proceedings of the Seventeenth International Symposium on Remote Sensing of Environment*. ERIM, Ann Arbor, MI, pp. 1393–1399.

Sadowski, F.G., Sturdevant, J.A. and Rowntree, R.A. (1987) Testing the consistency for mapping urban vegetation with high-altitude aerial photographs and Landsat MSS data. *Remote Sensing of the Environment* **21**, 129–141.

Sanders, R.A. (1984) Some determinants of urban forest structure. *Urban Ecology* **8**, 13–27.

Schoeneman, R.S. and Ries, P.D. (1994) Urban forestry: managing the forests where we live. *Journal of Forestry* **92**, 6–10.

Toll, D.L. (1984) An evaluation of simulated Thematic Mapper data and Landsat MSS data for discriminating suburban and regional land use and land cover. *Photogrammetric Engineering and Remote Sensing* **50**, 1713–1724.

U.S. Bureau of the Census. (1996) USA Counties 1996 on CD-ROM (machine-readable data files). U.S. Bureau of the Census, Washington, DC.

Vogelmann, J.E. (1995) Assessment of forest fragmentation in southern New England using remote sensing and geographic information systems technology. *Conservation Biology* **9**, 439–449.

Weber, C. and Hirsch, J. (1992) Some urban measurements from SPOT data: urban life quality indices. *International Journal of Remote Sensing* **13**, 3251–3262.

Whitney, G.G. and Adams, D. (1980) Man as a maker of new plant communities. *Journal of Applied Ecology* **17**, 431–448.

Zalewski, A. (1994) A comparative study of breeding bird populations and associated landscape character, Torun, Poland. *Landscape and Urban Planning* **29**, 31–41.

Zipperer, W.C., Sisinni, S.M., Pouyat, R.V. and Foresman, T.W. (1997) Urban tree cover: an ecological perspective. *Urban Ecosystems* **1**, 229–246.