The data integration capabilities of Geographic Information Systems (GIS) are providing new opportunities for urban analysis. This article describes the work of a multidisciplinary team who used spatial data from NASA's Landsat earth observation satellite to analyze the net vegetation change between 1975 and 1992 in Detroit, Michigan. Furthermore, by integrating the satellite-derived change data with census data from 1970, 1980, and 1990, this research shows how the extensive demographic changes that occurred in Detroit over the past quarter century have resulted in physical landscape changes detectable from space. Strong correlations were found between the patterns of social, economic, and demographic data and the pattern of vegetation change seen in the satellite imagery, both for certain points in time and changes over time. These correlations suggest that the imagery reflects processes of urban growth, inner-city decline, population shifts, and change in urban form.

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Using Remotely Sensed Imagery to Detect Urban Change

Viewing Detroit from Space

Rhonda M. Ryznar and Thomas W. Wagner

The growing use of Geographic Information Systems (GIS) in urban planning has led to new research opportunities in the application of satellite imagery to urban analysis. Integrating digital data from satellites in a GIS allows researchers to compare the patterns of large metropolitan areas observed from space with georeferenced socioeconomic data available from the U.S. Census Bureau and other sources. Combining these two types of data may help improve our understanding of the forces that continually shape and reshape our urban environments.

The U.S. National Research Council (NRC) recently published a report pointing out that, although satellite images “have been employed for a variety of purposes … there are relatively few examples of those data being used in social science research” (National Research Council, 1998, p. 3). The report gives a number of examples of promising applications that integrate socioeconomic and satellite data. The examples are drawn from such fields as sustainable development, environmental assessment, the drivers of climate change, and human/environment interactions. However, past efforts to integrate these types of data in cross-disciplinary studies have been hampered by the fact that (1) the data of most interest to social scientists are not readily measured in satellite images; (2) not many outside the field of geography value the spatial explicitness of image data; (3) remote sensing and social science spring from different traditions with different theories, experimental methods, and spatial nomenclature; and (4) bridging the gap between social science and remote sensing involves the usual risks related to interdisciplinary research (National Research Council, 1998).

Perhaps more than social scientists, planners recognize the value of spatially explicit information and have more widely embraced GIS technolo-
gies as a means to understand the relationships between people and locations. A recent survey of local governments in cities with populations greater than 25,000 and counties with populations greater than 50,000 reports that in 1996, 77% of the respondents used GIS (Kollin et al., 1998). Improved satellite sensor technology; improved spatial data handling and analysis techniques; the increasing capabilities of GIS software; the widespread availability of training in GIS and image processing; and the increasing speed, memory, and storage capacity of personal computers have all made previously difficult image processing and data integration possible for everyday users and analysts.

This article explores and illustrates an approach to looking at urban landscapes in a way that shows how satellite-derived change data may be used to help visualize shifting metropolitan demographics. By integrating spatial data from satellites with selected indicators from the decennial census in Wayne County and the City of Detroit, Michigan, we found associations between changes in the natural environment and changes in social, economic, and demographic conditions.

Remote Sensing of Urban Environments

There is a long history of using remote sensing as a data source for urban management information. In 1858, Gaspard Félix Tournachon (later known as “Nadar”) took the world’s first aerial photographs (of Paris and surrounding countryside) from a hot air balloon (Newhall, 1964). Since then planners, among others, have come to recognize the value of this “bird’s eye view” for discovering the distinctive spatial patterns and forms that characterize urban spaces. There is a rich illustrated literature of cityscapes and urban patterns using aerial photos (e.g., Rotkin, 1962) and, more recently, images from other airborne sensors such as radars, scanners, and even video cameras. However, applications of data obtained from satellite platforms at 300 to 600 miles above the earth have remained limited for urban areas for a variety of reasons, including the low resolution of the images, the complexity of ground features in urban areas, and the technological differences from conventional photography (Kivel, 1993).

Until recently, the low resolution of satellite images has inhibited their use for urban analysis. Planners are used to seeing roads, buildings, and other small structures in aerial photos, and many urban analyses require mapped data to be at that level of detail, say scales of 1:500 to 1:10,000. The world’s first civilian Earth Resources Technology Satellite (ERTS-1), launched in the early 1970s, produced pictures too coarse to show these details of the built environment (Welsh, 1982). With pixels’ 80 meters on a side, the pictures from ERTS-1 (later renamed “Landsat”) could not be used to locate houses, streets, or individual plots. However, as the space sensor technology improved, pixel sizes decreased. The latest Landsat (#7), launched in April 1999, produces images with pixel sizes of 15 meters square in the panchromatic (black and white) band, 30 meters square in the six visible and near-infrared bands, and 60 meters square in a single heat-sensitive thermal band (United States Geological Survey, 1999).

These Landsat data are available in image and digital formats from U.S. government and commercial sources at modest prices. Additionally, several private companies operate their own satellites and sell images with resolutions of 1 to 10 meters (e.g., SPOT Image Corporation, OrbImage, Space Imaging Corporation). Their prices are higher than for Landsat images, but still less than the cost of commissioning new aerial photography.

Satellite imagery technology is very different from conventional photography. The Landsat’s sensors record wavelengths of reflected light ranging from 0.45 mm to 12.5 mm—the visible, near-infrared, short-wave infrared, and thermal infrared portions of the spectrum. The number of spectral bands in civilian imaging satellites has increased from four in the first Landsats to hundreds in today’s hyperspectral satellite sensors. These different bands are recorded synchronously so that their pixels may be precisely matched up and compared with their counterpart pixels in other bands. This means that we can use spectral (“color”) differences to identify urban features to the extent that colors are diagnostic—sort of a coarse spectroscopy from space.

The spectral sensor technology, however, coupled with the complexity of ground features in urban areas, can make visual interpretations of satellite imagery both labor intensive and uncertain. To implement image interpretation, commercial or free software can be used to “train” computers to recognize the spectral signatures from sample locations. The software program will then read through an entire satellite dataset to tag other pixels that have similar characteristics (Gong & Howarth, 1990). This procedure works well with images of agricultural crops or forests in rural areas, but computers have had trouble distinguishing between different urban features. For example, building roofs are small compared to satellite pixels and have many colors and shadings due to their different materials and orientations to sunlight. As a result, this approach has had limited success in dealing with data for urban environments (Gao & Skillcorn, 1998; Harris & Ventura, 1995; Ridd, 1995). High-resolution images are being used to update urban information (Ehlers et al., 1990; Martin, 1989; Møller-Jensen, 1990;
Stow et al., 1990), but optimal results still usually need human visual interpretation of the computer-enhanced images (Kivel, 1993). More to the point, even today satellite imagery is seldom employed for making population estimates or for supporting housing surveys, at least not without accuracy checks using aerial photography (Paulsson, 1992).

For these reasons, much of the research in satellite data interpretation has focused on agricultural and forested areas, where the spectral responses from large fields with homogeneous types of vegetation provide relatively uncomplicated landscapes. In these simpler scenes, researchers assign unique “spectral signatures” to particular crops or vegetation types and can map their distributions. Fortunately, the research conducted with satellite imagery in rural settings has resulted in well defined computer classification maps for vegetation. Our research shows that this well established ability to identify vegetation may be a key to interpreting urban settlement patterns.

Detecting Vegetation

Vegetation of all types is highly distinctive in satellite images because of the way in which chlorophyll in leaves absorbs and reflects sunlight. Green leaves strongly absorb light in the blue and red wavelengths and reflect relatively greater amounts in the green and near-infrared wavelengths. Nothing else looks quite like green vegetation in a satellite image, and even the relative amount of vegetation within a pixel can be estimated by the strength of its spectral signature. Extensive research with various spectrally-based vegetation indices have demonstrated the utility of this approach (Goward & Dye, 1987; Huete, 1988; Pitney & Verstraete, 1992).

Vegetation is an important component of the urban landscape, and different types and amounts of vegetation have long been associated with urban environmental quality. Well tended expansive lawns and ornamental gardens communicate planned interactions of humans with the environment. Small weed- and shrub-covered lots or wild tree growth indicate where nature has filled spaces left vacant by humans (see Ford, 2000). This association, along with the ability to use satellite images to map vegetation, has led to studies exploring the relationship between patterns of social and physical spaces.

Forster (1983) used Landsat data to create a neighborhood quality index through a comparison of housing values, vegetation cover, and distance to the Sydney, Australia, central business district. More recent studies have developed quality-of-life indices from census data and vegetation patterns (Lo & Faber, 1997). Weber and Hirsch (1992) used SPOT imagery and population census data for Strasbourg, France, to develop landscape categories related to housing type and density, population density, number of home owners, density of middle-income residents, and urban vegetation. The categories were then used to create an “attractivity index” for the Strasbourg environment. Lo (1995, 1997) analyzed vegetation patterns from Landsat data along with census tract population density, per capita income, median home value, and percent college graduates in Athens–Clarke County, Georgia. Both Lo (1995, 1997) and Weber and Hirsch (1992) found that indices of high quality of life are spatially associated with high vegetation densities.

These urban vegetation/quality-of-life studies captured the association between vegetation and quality-of-life indicators at a single point in time. Myers (1987) suggests, however, that focusing on local trends, or changes, can be important to assessing quality of life and a community's livability over time. The ability to detect vegetation may be important to applying satellite remote sensing in urban areas, and the use of satellite-derived spatial data on changes in vegetation provides opportunities to quantitatively assess long-term environmental effects of urban social processes.

A significant aspect of satellite data and one of its distinct advantages as an urban data source is its repetitive coverage. Landsat data have been collected in computer-compatible form for most parts of the world since 1972. This means we can go back in time, not only to observe earlier local conditions, but we can also see how the landscape has evolved. We can observe the same areas at different times and ask precisely and measure quantitatively “what has changed.” The growing archive of digital satellite data, including the newer high-resolution images, even record those parts of the world where aircraft flights are difficult or restricted.

Our questions began to focus on how changes in vegetation patterns could contribute to urban analysis and whether these changes provide information about human processes. Because of the link between vegetation and quality of life in the urban environment, our thesis was that the differences in vegetation patterns over time would provide us with diagnostic information about urban social transitions.

The Detroit Study

Researchers from the Department of Urban and Regional Planning at the University of Michigan and the Environmental Research Institute of Michigan (ERIM) joined to investigate this thesis. Landsat data from two dates (May 10, 1975 and May 16, 1992) were used to identify the changes in green vegetation for the 640-square-mile area of Wayne County, Michigan, over this
cent to the City of Detroit, such as those in the northeast corner of the county, did not change.

The pattern of vegetation change suggests the concentric zones of the area's growth: the historic inner-city core area (black) surrounded by a Detroit residential area (gray), which in turn is surrounded by a ring of suburban communities (some gray in a predominantly white area). Beyond this zone of suburban residential communities lies a rural area of rapid sprawl and active development with both black and gray areas.

The pattern of vegetation increases in Figure 1 can be compared with the areas in Figure 2, a map that shows suburban growth in Wayne County between 1965 and 1995 and areas of projected development to 2020 in the outer reaches of the county (Liu & Rogers, 1999). The vegetation increase seen in the satellite images in these suburban areas may be the result of farmland being converted to low-density urban uses. Active agricultural fields (normally plowed or newly planted in May) are being replaced by permanent lawns, parks, and roadside landscaping, resulting in an increase in greenness between the two dates. Some areas may be returning to natural shrub or woodland as a result of agricultural land being taken out of production by land speculators.

**Vegetation Change in Detroit**

Closer inspection of the change pattern within the boundary of the City of Detroit, (see Figure 1), shows vegetation increase in the central part of the city while the outlying areas are losing vegetation, as if the city were turning “inside out.” White areas, indicating little or no change, are interspersed within the black and gray areas. Some unchanged areas of the city were stable, older commercial and industrial areas with little or no vegetation. No known cartographic features correspond to these patterns. However, ground truth observations showed significantly different environmental conditions in each of the areas (Nystuen et al., 1996).

The large, almost contiguous areas of increased vegetation in the City of Detroit are characterized today by scattered houses and boarded-up businesses, and by open green spaces with few trees or buildings. Situated near the city center, these neighborhoods have old, poorly maintained or abandoned houses interspersed with vacant lots and overgrown alleys. This is a zone with severe economic and social decline and depopulation. Census data for the City of Detroit show that between 1970 and 1990, more than 80% of the city's census tracts lost population, some by as much as 75%. The loss amounted to almost half a million people. Approximately 117,000 houses were demolished during the same period, and few were replaced (Neill, 1995).
The gray areas, indicating decreased vegetation, are largely intact middle-income residential neighborhoods. Many of the streets are lined with recent tree plantings that led us to speculate that the vegetation decrease was due in part to the loss of American elm trees to Dutch elm disease. In 1970, Detroit had some 310,000 elms, but was reported to be losing them at a rate of 3.2% per year (Detwiler, 1972). At that rate, by the time of the Landsat image taken in 1992, less than half of the elm trees would have been left. The City of Detroit replaced many of these trees on public land with other species, but few as yet have grown very large. The effects of tree loss have not been included in this analysis because there is little detailed information on the locations of the losses. However, it may be safe to assume that the losses were widespread throughout the region and would not have created the pattern of clusters of increasing and decreasing vegetation seen in the satellite images.

A survey of vacant land by Detroit's City Planning Commission in 1990 noted that in areas containing over 30% vacant land “the amount of vacant land is beginning to have an effect, there are numerous weed covered lots and the decline is spreading to the maintenance of the existing housing stock” (City of Detroit, 1990, p. 2). The areas reporting 71% to 100% vacant land are described as “simply vast areas of open space” and the similarity between the pattern of change in the City of Detroit shown in Figure 1 and Detroit’s maps of vacant property is striking.
Exploring Associations between the Social and Natural Environments

In seeking to better understand the relationship between the Landsat vegetation change image and the social-economic-demographic processes in Detroit, Ryznar (1998) created a 1-kilometer-square grid that covered the entire city and resampled the Landsat change data to this grid. Given the previous associations researchers had been able to make between vegetation and neighborhood status, indicators of quality of life were extracted from census data for 1970, 1980, and 1990 and fit to the grid. The choice of indicators was based on demographic measures of the physical quality of life (Morris, 1979) that are available in the census and have been shown to be significant quality-of-life indicators by Anson (1991). These indicators include population, median income, ratio of children to women, ratio of males to females, ratio of mid-age adults to young adults, and ratio of White residents to Black residents. Anson’s quality-of-life indicators were intended to capture neighborhood viability and economic vitality.

The census data from each time-period layer were assigned to the overlaying grid by means of an areal interpolation procedure described in Flowerdew et al. (1991). The data were stacked in such a way that each grid cell contained data for each census year and could be associated both spatially and temporally with the vegetation change data.

Table 1 shows the Pearson correlation coefficient, r, and its significance, P, between the census variables and the change in greenness for each grid cell. The most sig-
ificant correlations (shown with an asterisk) indicate that the increase in greenness (i.e., vegetation) between 1975 and 1992 in Detroit took place in neighborhoods where the population decrease was the greatest over those 17 years (signifying abandonment), the residents were poorest in all time periods, and the ratio of children to women highest. These associations between the quality-of-life indicators and physical change, or abandonment, can be supported by the literature on neighborhood succession (Ahlbardt & Brophy, 1975; Burgess, 1925; Grigsby et al., 1987; Leven et al., 1976; Temkin & Rohe, 1996; White, 1984).

Some researchers believe that geographic separation of households according to real income lies at the core of the neighborhood succession process and generally conclude that neighborhood succession leads to neighborhood decline (Galster, 1987; Grigsby et al., 1987). Lower-income residents may not be able to afford to maintain properties or may feel it is not worth the expense. As a neighborhood deteriorates and property values drop, a further influx of lower-income households may trigger out-migration of other residents.

Interestingly, a number of the demographic variables chosen from the census for this study appeared to have little relationship to the environmental change—particularly race (ratio of White to Black residents) and gender (ratio of males to females). These variables were not related to whether or not a neighborhood was abandoned. Grigsby et al. (1987) claim that although race can be a major factor in neighborhood succession, it is rapid change that is the most damaging, because social ties take time to build. Since Detroit's population loss was rapid in this short time period, this theory could explain why the race and gender of the residents had little effect.

Also importantly, these results contrast with previous studies. Earlier studies linking remote sensing data with quality of life in urban areas at one point in time showed that high amounts of vegetation are associated with a high quality of life. Change data for the City of Detroit, however, shows that over time vegetation increased the most where quality of life was the lowest.

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<thead>
<tr>
<th>TABLE 1. Pearson correlation coefficient, $r$, between change in amount of vegetation and selected census variables.</th>
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*highly significant correlation

Implications for Urban Planning and Research

In this exploration, multispectral Landsat satellite data were used to view vegetation changes in the Detroit metropolitan area between 1975 and 1992. These data showed distinct patterns associated with changes in population, which decreased in areas in the inner city with the lowest income and highest fertility (ratio of children to women). A general conclusion is that satellite data can provide information on the spatial effects of certain urban processes, and that these processes are interwoven with social, economic, and environmental factors.

The vegetation change image shown in Figure 1 suggests that two different processes have lead to the same result, net vegetation increase. One process occurred in the inner city and is associated with economic and social decline and an exodus of people. The other process appears to be occurring in a zone near the edge of the metropolitan area and could be associated with economic development and land conversion. We suspect that this is a much different process than in the center of Detroit, yet possibly linked through regional population shifts. (We are in the process of exploring the data beyond the boundaries of Detroit, as well as adding another point in time with additional satellite images and data from the 2000 census.)

The Landsat change image may give us a picture of some of the spatial aspects of the population shift of both processes. The satellite data show areas of Wayne
County that are most rapidly increasing and most rapidly decreasing in population. However, it is likely that the suburban areas in between are also affected. The actual process of population shift may involve many small steps that add up to a significant change over time. Many families moving into previously undeveloped areas might have come from adjacent suburbs. People leaving areas closer to the metropolitan core take their place. This implies a time lag, as well as a spatial lag, in these data.

In Detroit, population movement and changes in land values may link the process in the inner city with that of the suburbs—the latter perhaps being an economic expression of the former. The population loss in the inner city is partially compensated for by increases in the fringe areas. There was little population change between 1965 and 1995 in the metropolitan area as a whole (SEMCOG, 1999), but developed land grew by 76% in the same period (Liu & Rogers, 1999). However, the net result could be a population shift from the inner city to the urban fringe. While these results were for only one county, data for the entire seven-county metropolitan region could be used to provide a comprehensive view of regional change.

Two applications are suggested for the use of Landsat satellite data: (1) estimating the social correlates at times and locations where current data are not available, and (2) incorporating the vegetation change data in urban growth models so that regional environmental change can be included in modeling and analysis, especially as an expression of social processes or demographic shifts. While these models have been in use since the 1960s, only recently have GIS begun to play a role (Batty, 1992; Landis, 1993). As many of the world’s largest metropolitan areas approach stages of maturity with reduced population growth rates, there is an urgent need to understand how their populations are redistributing. Remote sensing data representing the physical impacts of population shifts can help model that process.

Satellite image data have many advantages for planning research. These data are readily available from public sources and are relatively inexpensive and faster to acquire than images from aerial photography. General cost comparisons are difficult because costs depend on the location and type of mapping being carried out. Aerial photography costs can vary according to map scale, area size, aircraft operating costs, staffing, field logistics, and climatic restrictions. Satellite data, however, consistently cost less than aerial photography, especially in data acquisition and map revisions, and save time (Paulsson, 1992). The time and cost savings, as well as the ease of access to systematic and up-to-date information, may be especially critical attributes for meeting the urban data needs in less-developed countries where resources are scarce, yet annual population growth can be up to 10% and urban area expansion can be 50% to 100% every 10 years (Paulsson, 1992).

Research with the Wayne County data is ongoing to determine if the processes and natural environmental effects in the inner city associated with quality-of-life indicators and population shifts are the same or different from those occurring at the outer edges of the county. Comparisons with other cities in similar and dissimilar climatic regions would also be helpful in determining if vegetation change data from satellite imagery are reliable indicators of social processes. Results from the City of Detroit, however, show promise for the use of satellite imagery in the analysis of urban change.

NOTES

1. Pixels or “picture elements” are square-shaped grid cells arranged in columns and rows in a digital image. Each pixel covers an area on the earth’s surface, and the size of the pixel defines the resolution of the image.

2. The following two Landsat data sets were selected from the ERIM archives for use in this research: (1) MSS data from May 10, 1975 (#4421-574), and (2) TM data from May 16, 1992 (#5-020/03070). The data were of good quality, with no cloud cover, and were from the same time of year.

3. The processing of the images included resampling to 25-meter pixels (see Chiesa & Tyler, 1994), a rasseled-capped transformation (TCT) procedure to create a “greenness” vector image (see Crist & Cicone, 1984; Cicone & Olsen-Holler, 1997), and a change vector analysis (CVA) to compute the total change magnitude per pixel in greenness between the two dates (see Michalek et al., 1993; Virag & Kolwell, 1987). The initial CVA image was a two-byte file where channel 1 indicated a change type and channel 2 contained the scaled vector magnitudes. The CVA data were further processed using the TCF#4 data as a binary filter. The above information and descriptions of the image processing performed by ERIM can be found in Wagner et al. (1994).

4. The grid was created in the GIS using the raster satellite image and resulted in 312 1-kilometer-square grid cells covering the City of Detroit. These grid cells were then the units of observation in subsequent processing and analysis.

5. Resampling is a process to transfer data from map units in one layer to map units in another layer that differ in orientation, size, or shape from the original units. Each grid cell was composed of 1600 25-meter-square pixels and assigned a value equal to the percentage of vegetation change calculated as the number of black pixels minus the number of gray pixels, divided by the total number of pixels.
REFERENCES


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