USING REMOTELY SENSED DATA IN URBAN SPRAWL AND GREEN SPACE ANALYSES

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ABSTRACT

Using two cities in southeast Idaho we developed a simple and widely applicable methodology for incorporating remotely sensed data into urban sprawl and green space analyses. We used land cover change data and Normalized Difference Vegetation Index (NDVI) data to assess: 1) location, amount, and direction of urban growth, 2) concentration and distribution of green space, and 3) fragmentation of green space areas. Our results document distinct patterns of growth for Pocatello, Idaho, compared to Idaho Falls, Idaho, over the past 15 years. Pocatello grew primarily to the north, while Idaho Falls grew more quickly and in a radial pattern from its urban center. These different growth patterns were influenced by topographic and land-ownership patterns of the region, as well as different zoning regulations. The simplicity of our methods and the minimal investment of time and money make incorporation of remotely sensed data into urban growth and green space analyses a potentially powerful tool for the urban planner/manager.

Key words: urban sprawl, GIS, green space, urban growth, urban planning

INTRODUCTION

Urban sprawl can be described as low-density development occurring on the edge or outside of a municipal area that does not follow a specific growth pattern (Tallinn 2002). Environmental impacts of urban sprawl include: 1) decreased watershed permeability resulting in an increased risk of flooding and groundwater contamination, 2) elevated air and noise pollution, and 3) loss of arable land to development (Knight et al. 1995, Auld 2001). Urban sprawl also can have substantial economic impacts on communities through increased cost of services such as emergency response, infrastructure, or public works and utilities (Chen 2000, Speir and Stephenson 2002).

Green space is an important feature of an urban environment that provides opportunities for outdoor recreation, wildlife habitat, groundwater recharge, pollutant filtering, urban beautification, and improved environmental health (Stephenson 1999, Stoel 1999). Urban sprawl leads to loss and increased fragmentation of green space areas, thereby diminishing the positive functions of green space (Wang and Moskovits 2001). Fragmentation has a particularly negative impact on wildlife in and around the urban area (Marzluff and Ewing 2001). Determining degree of fragmentation may prove useful to evaluation of urban green space.

Various methods exist for tracking urban sprawl such as recording the location and number of building permits or simple visual assessments. However, these data are often difficult to incorporate, e.g., compiling paper building permits into useful statistics, are frequently subjective, e.g., visual assessments, and may not accurately capture temporal patterns of urban growth and changes in green space. The use of remotely-sensed data to analyze urban growth and green space distribution allows land use planners to perform large-scale temporal analyses with minimal investment of time and money. Additionally, remotely-sensed data are easily incorporated into a geographic information system (GIS) along with other data such as zoning regions, topography, hydrography, geology, and political boundaries, allowing for urban managers to consider the effect these factors may have on observed growth patterns. This ancillary information is invaluable in determining the intrinsic suitability of regions (McHarg 1969) and aids in development of holistic land-use/ urban planning.

We used the cities of Pocatello and Idaho Falls, Idaho, as case studies of how remotely sensed data can be used to quantify urban growth, the concentration and distribution of green space, and fragmentation of green space areas. These cities have experienced markedly different growth patterns over the past 15 years, with a high proportion of the new growth occurring in the past five years. Additionally, due to topographic and land ownership characteristics, the type and direction of growth in these two cities also are quite different. Although specific growth patterns of Pocatello and Idaho Falls are important to planners in the region, in this paper we seek to address the potential for applications of remotely sensed data for urban planning.

MATERIALS AND METHODS

For our analyses we used phenologically synchronized LANDSAT Thematic Mapper 5 (TM5) multispectral satellite imagery (path 39, row 30) from 1987, 1997, and 2000. Phenologic synchronization is a process by which calculations of growing degree day and accumulated precipitation are used to select imagery dates to ensure that detected changes are not due to phenological differences (Weber 2001). TM5 imagery, which has a 30 x 30 m pixel size, provides adequate spatial resolution to analyze trends within the urban environment without excessive processing time that data of finer spatial resolution would require. TM5 imagery also is widely available and can be obtained free of charge or at relatively low cost.

To compare changes within the city versus sprawl development, we partitioned the cities of Pocatello and Idaho Falls into two zones. The urban zone (UZ) consisted of the urban extent of each city (as defined by the 2000 U.S. Census). The sprawl zone (SZ) was an area equal in size to the UZ and immediately surrounding the UZ (Figs. 1a and 1b). We compared measures of urban sprawl and green spaces distribution/fragmentation between the zones and between cities.

Land Cover Change Data and Urban Sprawl Analysis

We used a principle components analysis (PCA) to determine correlation between bands of the TM5 image to create a weighted composite image that would best represent unique data contained within multiple bands. Using the covariance matrix of the PCA we created a composite image using bands 5, 3, and 4 (with weightings of 89, 8, and 4%, respectively) that described >95 percent of the unique data in the imagery for each year (1987, 1997, 2000). We used the 5:3:4 composites to generate land-cover change (LCC) data for two time periods (1987-1997, 1997-2000) by performing image differencing change detection with LUCCAS software (Lunetta and Elvidge 1998, Pacific Meridian 1996). To exclude detected LCC that was non-anthropogenic, only those changes occurring ≤ 50 m from a road were included in the analyses. To delineate these areas, we created a 50-m buffer around all roads, and intersected this buffer with the LCC data. We determined buffer size based on the pixel size of the imagery. The 50-m buffer allowed at least one, but no greater than two pixels to be included on each side of each road.

NDVI Green Space Analysis

We quantified the abundance of vegetation by creating Normalized Difference Vegetation Index (NDVI) images

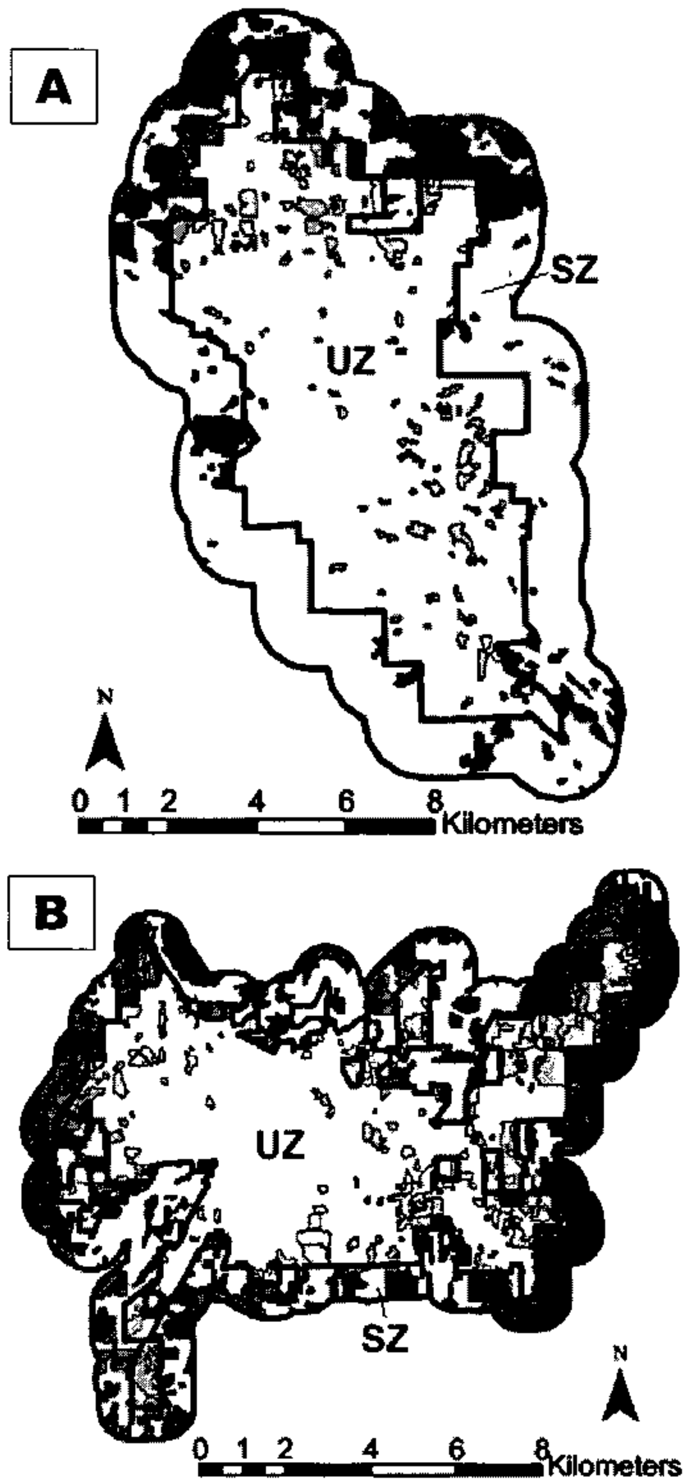

Figure 1. The total growth (UZ + SZ) in pocatello, Idaho (A) was ap[proximately 1/2 that of Idaho Falls, Idaho (B). Land Cover Change areas are shown in light gray (UZ) and dark gray (SZ).

(Lillesand and Kiefer 2000) for each year of our analysis (1987, 1997, and 2000). Resulting values ranged between -1 and 1, where non-vegetative areas, e.g., bare rock, water, etc., have a negative value, and areas of green vegetation have a positive value. To better correlate NDVI values to green space areas, we overlaid the NDVI image onto digital orthophotographs to identify the NDVI values for known or visually apparent green space areas, e.g., city parks, green ways, golf courses, etc. We also correlated the image values to known non-green space areas, e.g., parking lots, light industry, etc. Using these NDVI values, we reclassified the NDVI images into more useful categories representing non-vegetative, moderate quality green space, and high quality green space (Table 1). Using the classified NDVI images and UZ/SZ perimeters, we determined the amount of highly vegetative green space present in each zone for both cities. When expressed as a percent of the total area of each zone, these calculations allowed us to perform various comparative analyses between zones and between cities.

We analyzed the contiguity of green space using two methods. First, we created a standardized city block dataset (200 x 200m polygons) to determine the amount of highly vegetative green space/city block for the UZ and SZ. We used these data to better visualize the concentration and distribution of green space. Second, we used FRAGSTATS landscape metrics software (McGarigal 1995) to calculate core area of green space, i.e., the area of green space $\geq$ 30m from an edge, within each zone (UZ and SZ) and within the total area (UZ + SZ) of each city.

Results

Urban sprawl analysis using land cover change data for 1987-1997 showed total growth (UZ+SZ) in Idaho Falls to be approximately twice that of Pocatello. From 1997 to 2000, growth in Idaho Falls was approximately three times that of Pocatello. Additional visual analysis of the detected change areas revealed that Idaho Falls grew radially from its urban center, whereas growth in Pocatello was predominantly north of the urban center (Fig. 1). Within the two cities, growth in the SZ was approximately twice (2:1) that of the UZ for all intervals (1987-1997, 1997-2000) except for Idaho Falls (1997-2000) where SZ growth was slightly less than UZ growth (0.8:1) (Fig. 2).

Green space analysis using classified NDVI images revealed that the area of highly vegetative green space was approximately 2x greater in Idaho Falls than in Pocatello, even though the area of Idaho Falls is smaller than that of Pocatello (113.8 and 133.6 km^2, respectively). The area of highly vegetative green space in Pocatello averaged 1.3x greater in the SZ than in the UZ. In Idaho Falls, the area of highly vegetative green space averaged 1.7x greater in the SZ than in the UZ. (Figs.3a, 3b).

The results of the standardized city block analysis illustrated the distribution of green space in Pocatello by identifying regions with a large number of contiguous city blocks consisting primarily of highly vegetative green space (Fig. 4). Our analysis using landscape metrics revealed that only 53 percent of highly vegetative green space in Pocatello (UZ+SZ) was classified as core area, while 65 percent of

Table 1. Reclassification of NDVI Values for Green Space Analysis

Classification	NDVI Value	Example
"Non-Vegetative"	-1.0 – 0.0	Parking Lots, Light Industry
"Moderately Vegetative"	0.01 – 0.29	Sagebrush, Fallow Agricultural Fields
"Highly Vegetative"	0.3 – 1.0	Forested Areas, City Parks

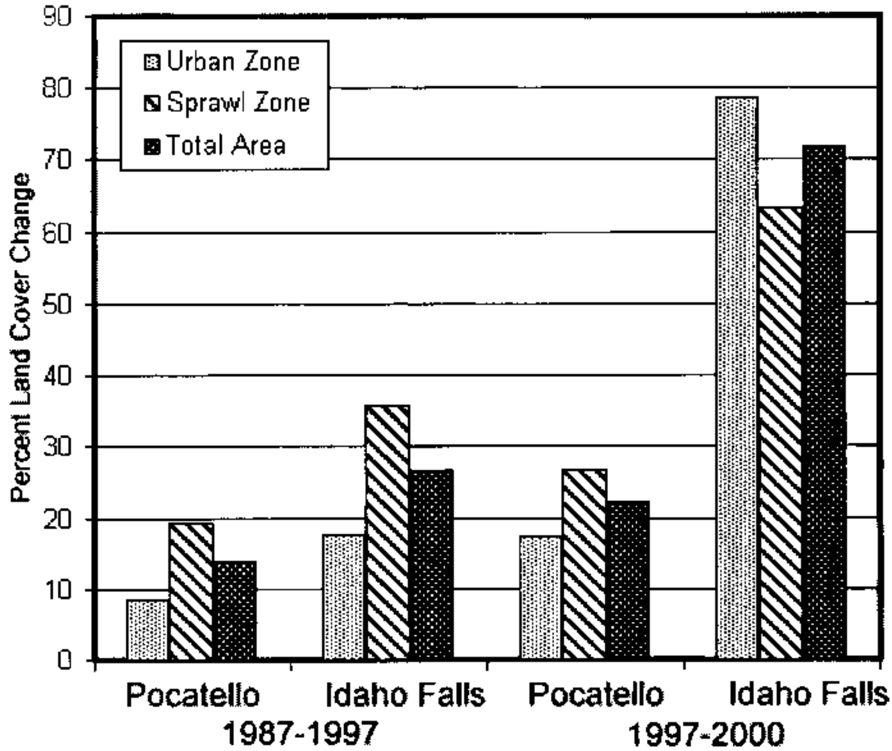

Figure 2: Land Cover Change (1987-1997 and 1997-2000) for Pocatello and Idaho Falls, Idaho.

highly vegetative green space in Idaho Falls was classified as core area. Additionally, for both cities and for each year of the analysis more core green space areas were present in the SZ when compared to the UZ (Figs. 3a, 3b).

Discussion

Monitoring patterns of urban growth and green space change is an important part of holistic land use management. Common economic, ecological, and social consequences of urban sprawl and green space loss include: 1) increased cost of providing infrastructure and services, e.g., schools, roads, emergency services, and other utilities, to a sprawling population, 2) increases in traffic congestion, noise pollution, and air pollution as distances driven by daily commuters and general automobile dependence increases, 3) failing public transportation systems as it becomes economically infeasible for cities to provide adequate services for commuters, 4) conversion of green space and arable agricultural land to urban and residential developments, and 5) degradation and fragmentation of existing urban green space areas. The methods described in this paper provide a means to quantify urban changes and their effects on the aforementioned issues.

Our results also provide useful information describing the location and direction of growth, including an assessment of some of the factors that influence growth and development. The rugged topography surrounding Pocatello, much of which is publicly owned, provides limited opportunity for urban development. Conversely, much of the area surrounding Idaho Falls is private agricultural land that is more readily available for development. Geographic factors restricting growth of Pocatello have led to the rapid development observed north of Pocatello, whereas developments around Idaho Falls have occurred more radially from city center.

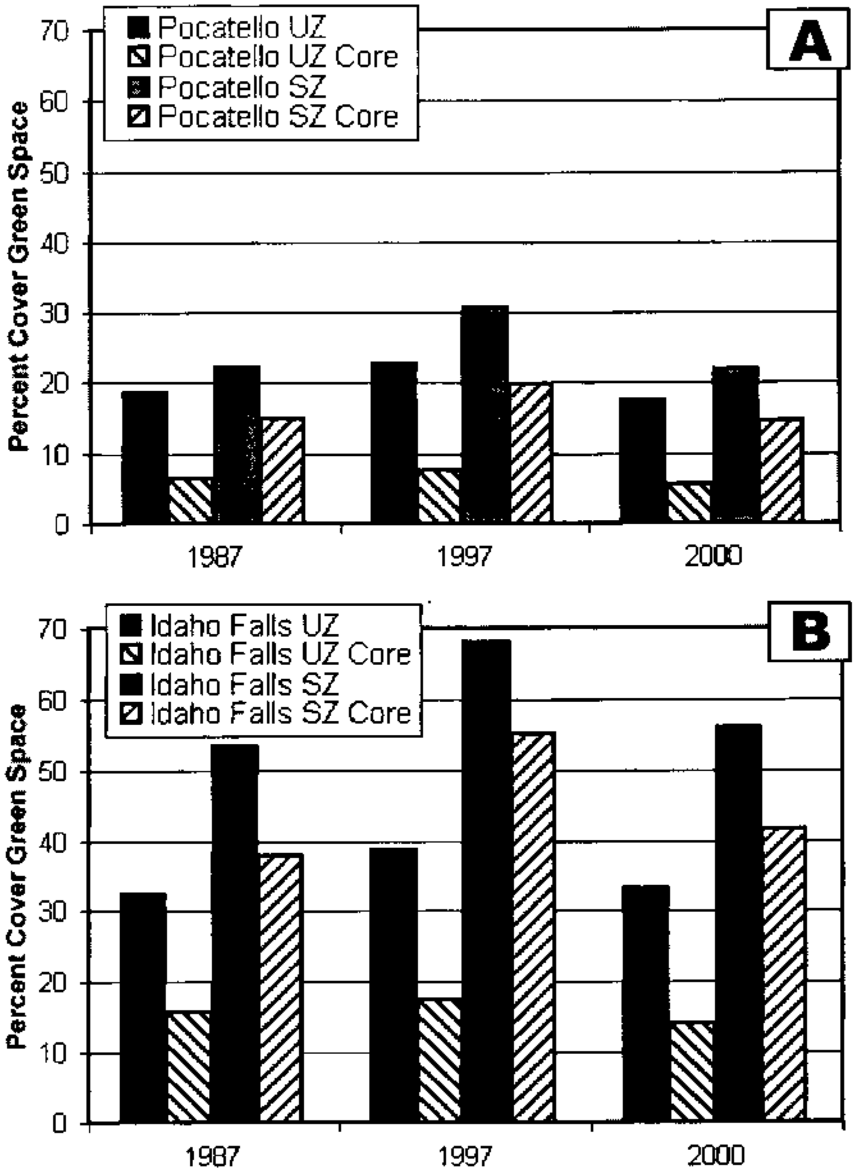

Fig. 3. Percent cover of total green space vs. core green space categorized by zone type for Pocatello (A) and Idaho Falls (B).

Additionally, much of the growth in both cities occurred in the SZ, which illustrates a common trend of sprawling developments taking precedence over renewal within existing urban areas. These are important factors to consider in developing a growth management plan that is suitable for a region, especially the roles that physical and political geographies of the region may have in shaping growth patterns.

The NDVI green space analysis focused on the amount of highly vegetative green space present in each city for the three years of our analysis. The total amount of highly vegetative green space remained relatively constant for both cities, whereas distribution of green space varied as influenced by active/fallow agricultural fields in the SZ of both cities. We attributed some of this variability to precipitation

Figure 4. A 200 x 200m grid was used to better examine the distribution and concentration of green space areas.

differences, the effect of crop rotation, and irrigation practices. Results within the UZ were less affected by these factors and may more accurately describe the distribution of green space within the city. The ability to quantify the location and concentration of green space areas is important, especially loss of green space over time. This would allow urban planners to identify existing green space areas to protect from urban development, or to target certain areas for conversion into new green space areas, e.g., vacant lots into city parks, or unused rail lines into greenways, etc.

The standardized city block analysis addressed some of the shortcomings of the general NDVI green space analysis, and provided insight into the concentration and fragmentation of quality green space within the UZ and SZ. Much of the highly vegetative green space in the two cities is fragmented, especially within the urban zones. Such fragmentation decreased the amount of usable green space and degraded the natural landscape.

Landscape metrics analysis provided even more specific information concerning the degree of green space fragmentation in Pocatello and Idaho Falls. Similar agricultural biases existed as mentioned above, whereas agricultural regions representing large areas of highly vegetative green space did not represent usable, quality green space. Therefore, calculation of fragmentation within the UZ was the most useful data that we generated in this analysis. Despite the relatively constant amount of high-quality green space within the UZ, the percent of highly vegetative green space that was core area (contiguous) decreased for both cities over the three years of analysis. This trend of green space fragmentation will have a greater impact on the overall landscape than simple loss of green space. This emphasized the importance of analyzing contiguity of green space in addition to the total amount of green space in an urban area.

Utilization of remotely-sensed imagery for monitoring urban sprawl and changes in the distribution and fragmentation of green space can aid in development of growth plans for communities. Remotely-sensed data, used in conjunction with other tools currently available to land-use planners, will permit a more comprehensive approach to managing urban growth and green space. These data also may serve to identify areas of intrinsic value to be reserved from development and establish management regimes such as development boundaries that limit the extent of urban sprawl and subsequent loss and fragmentation of green space.

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Literature Cited

Auld, J. W. 2001. Consumers, cars, and communities: the challenge of sustainability. International Journal of Consumer Studies 25:228-237.

Chen, D. D. T. 2000. The science of smart growth. Scientific American. December 2000.

Knight, R. L., G. N. Wallace, and W. E. Riebsame. 1995. Ranching the view, subdivisions versus agriculture. Conservation Biology 9:459-461.

Lillesand, T. M., and R. W. Kiefer. 2000. Remote sensing and image interpretation. Fourth Ed. John Wiley and Sons, New York, NY. 736 pp.

Lunetta, R. S., and C. D. Elvidge. 1998. Remote sensing change detection. Ann Arbor Press, Chelsea, MI. 350 pp.

Marzluff, J. M., and K. Ewing. 2001. Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. Restoration Ecology 9:280-292.

McGarigal, K., and B. J. Marks. 1995. FRAGSTATS. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

McHarg, I. L. 1969. Design with nature. Natural History Press, Garden City, NY. 198 pp.

Pacific Meridian. 1996. Land use and cover change analysis system (LUCCAS). Pacifica Meridian Resources, Emeryville, CA.

Speir, C., and K. Stephenson. 2002. Does sprawl cost us all? Isolating effects of housing patterns on public water and sewer costs. Journal of the American Planning Association 68:56-70.

Stephenson, R. B. 1999. A vision of green. Lewis Mumford s legacy in Portland, Oregon. Journal of the American Planning Association 65:259-269.

Stoel, T. B. 1999. Reining in Urban Sprawl. Environment 41:6-16.

Tallin, E. 2002. Suburban sprawl, GIS Helps evaluate living patterns. GeoWorld 15:38-39.

Wang, Y., and D. K. Moskovits. 2001. Tracking fragmentation of natural communities and changes in land cover: applications of landsat data for conservation in an urban landscape. Conservation Biology 15:835-843.

Weber, K. T. 2001. A method to incorporate phenology into land cover change analysis. Journal of Range Management 54:A1-A7.

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