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Mapping land cover in urban residential landscapes using very high spatial resolution aerial photographs

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ABSTRACT

Accurate information on existing residential landscapes is essential for framing ordinances and monitoring residential water use in the Urban Greenspace Ecosystem. We classified residential landscapes of New Mexico's largest city, Albuquerque, to explore the spatial distribution of residential greenspace and its composition among zip codes and median incomes. Geographic Information System (GIS) vector files including parcels, city limits, zip codes and land-use maps, were integrated with ownership information. The database was stratified by Albuquerque's 16 zip codes. Four hundred eighty residential landscapes were selected randomly for study. Very high spatial resolution (0.15 m) 2008 true color aerial photographs and the object-oriented supervised classification module in ENVI EX were used to identify residential features. Spatial and textural variables, created by image segmentation, were classified using the *K*-Nearest Neighbor (*K*-NN) algorithm embedded in ENVI EX. Classification accuracy was 89%. Larger greenspace, tree, shrub, and grass areas were in larger parcels. Landscapes in lower income groups and older zip codes include larger greenspace and tree cover because of mature tree sizes, while grass dominated landscapes of higher income groups and newer zip codes. This knowledge of residential vegetation distribution could serve as a basis for policy makers, planners, and water conservation officers wishing to enact ordinances and regulations that govern the urban residential landscape.

Introduction

Knowledge of the spatial characteristics of urban residential landscapes have been used to improve urban ecosystems and enhance municipal landscape policies and zoning decisions (Zmyslony and Gagnon, 1998; Myeong et al., 2001). For example, in 2006, the City of Baltimore decided to double tree cover by 2026 after analysis of spatial vegetation patterns of the city revealed social and ecological concerns. Findings from vegetation analysis study revealed that reduced vegetation cover would impact city beautification, property values, air quality and ambient air temperature regulation (Boone et al., 2010). Thus, the study of urban land cover is crucially relevant to urban planners, decision makers and research institutes even though the subject is challenging (Zhou et al., 2008).

Urban ecosystem plant species distribution, complexity, and density studies provide a better understanding of the relationship between urban land cover biodiversity and composition and the surrounding natural environment (Smith et al., 2005). But mapping urban residential landscapes and private lot greenspace patterns continues to be a challenge because urban ecosystems are complex, dynamic, heterogeneous (Grimm et al., 2000; Zheng et al., 2011) and scale dependent (Pickett et al., 2005). Furthermore, people's landscape preferences, behaviors, interests (Zheng et al., 2011; St. Hilaire et al., 2010; Spinti et al., 2004), socioeconomic status, the time of area development (Martin et al., 2004), lifestyle behavior and median housing age (Grove et al., 2006b) all influence residential greenspace composition which further complicates mapping of urban land cover.

Because of its complexity, a robust scientific investigation of urban landscape vegetation requires the study of a large number of residential units to generate accurate data. Accuracy and spatial scale categorization of vegetation analysis data dictate the calculation of vegetative water and the utility of the water demand information (Al-Kofahi et al., 2012). Although urban vegetation cover is unevenly distributed in urban areas (Hofmann et al., 2011), the computation of landscape water use must account for that spatial variation at multiple scales to be useful to municipalities (Al-Kofahi et al., 2012). This is especially relevant for arid urban environments in the United States where landscape irrigation can account for 40–70% of the household water-use (Ferguson, 1987).

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While an ordinance crafted for water restrictions might target the residential unit (Larson et al., 2009), urban planners often require information about city-wide impact of that ordinance. Thus, an outcome of this research is to generate vegetation land cover analysis that will be robust enough to better understand water use at the residential unit while providing information that can be applied on a city-wide basis.

Site visits (Richards et al., 1984; Zmyslony and Gagnon, 1998), ground measurements (Richards et al., 1984; Smith et al., 2005), visual assessments such as estimating areas (Richards et al., 1984) and binary assessment, that is, the presence or absence of an object (Zmyslony and Gagnon, 1998) have been used to gather data on the vegetative composition of the residential landscape. Although these methods are accurate, the time, cost and effort involved in gathering data make them inefficient (Myeong et al., 2001).

Using remotely sensed images as an alternative to visiting the landscape is a well-established and efficient method of gathering urban ecosystem land cover information (Xie, 2009; Walker and Blaschke, 2008; Myeong et al., 2001). Xie (2009) estimated water use of a residential neighborhood in El Paso, Texas from greenspace information obtained from 1-m resolution IKONOS images. Digital color-infrared aerial photographs with 0.61-m spatial resolution were utilized to classify Syracuse, New York into different vegetation types and impervious classes (Myeong et al., 2001). Shaw et al. (1998) also used aerial photographs within Geographic Information System (GIS) to digitize land cover of Pima County, Arizona. They classified the land cover into residential, commercial, recreational, water course and ponds, natural open space, and graded vacant land. Except for the study of Xie (2009), none of these studies showed the landscape greenspace distribution associated of a residential unit. Interestingly, Xie's (2009) monthly water use estimates did not track that of household water meter readings and among the reasons given for the inaccurate calculation of residential water use was the uncertainty in calculating greenspace.

Classification of urban areas requires high spatial (e.g. 0.15 m) resolution images (Cleve et al., 2008; Mathieu et al., 2007) because at the parcel level of urban environments, objects are heterogeneous (Landry and Pu, 2010; Grove et al., 2006a) and fine landscape details must be identified (Zhou et al., 2008). However, using high spatial resolution imagery to classify vegetation is challenging (Pu et al., 2011). Pixel-based classification could be used to classify high-spatial resolution images, but this leads to the salt-and-pepper effect (Yu et al., 2006). With this effect, the characteristics of objects are lost because neighboring pixels within the same object are considered independent and classified differently (Cleve et al., 2008; Yu et al., 2006). Object-based classification, considered to be more accurate than the pixel-based approach which is especially appropriate for categorizing land-use and land cover from high spatial resolution imagery (Cleve et al., 2008; Mathieu et al., 2007) if object spatial information is incorporated (Zhou et al., 2008). This approach overcomes the land cover internal variability that limits the utility of using high spatial resolution imagery to map urban land cover (Pu et al., 2011).

Urban areas in the city of Albuquerque, New Mexico are facing water restrictions, but residential-scale assessments of urban land cover are non-existent. Thus, the objective of this study was to use high spatial resolution (0.15 m) aerial photographs and object-oriented supervised classification to map land cover of urban residential landscapes of Albuquerque. The approach was to identify differences in greenspace and its composition (tree, shrub and grass cover) among median income groups and among zip codes within each of these income groups. In a follow-up study (Al-Kofahi et al., 2012), we used that information to estimate urban residential-scale water demand.

Methodology

Study area

Albuquerque (latitude 35°05′N and longitude 106°39′W) had a population of 545,852 in 2010 (US Census, 2011) and is the largest city in New Mexico, USA. Albuquerque residents represent around 90% of Bernalillo County's population (Earp et al., 2006). Ground water from the Albuquerque Basin is the city's main water source. While Albuquerque aspires to reduce Per Capita Water Use (PCWU) to 155 gallons (0.588 m^3)/day by 2024 (City of Albuquerque, 2010), PCWU was 167 gallons (0.632 m^3)/day in 2007. This PCWU value was in the middle of the range for major Southwestern cities.

Imagery

We obtained Bernalillo County true color aerial photographs with 0.15 m spatial resolution from Mid-Region Council of Government (http://www.mrcog-nm.gov/) in Albuquerque, New Mexico. Average Albuquerque leaf-out date is Mid-March to April and the Albuquerque office of Bohannan Huston Inc. (http://www.bhinc.com/) acquired the aerial photographs from March 29 through April 1.

Sampling method

Parcel base map, land-use, zip code and municipal limit vector files of Bernalillo County were downloaded from the Albuquerque GIS website (City of Albuquerque, 2008). These layers were edited (Fig. 1) to create an integrated city parcel base map (sampling frame) consisting only of parcels in the single and multiple family housing lands located within city boundaries and stratified by the 16 zip codes. Because Albuquerque residents identify themselves primarily by zip codes (Fig. 2) and not neighborhoods, zip codes, rather than census blocks were selected as basis for stratification. The total number of possible parcels within each zip code was determined from the base map. Two hundred parcels per zip code were selected randomly using PROC PLAN (SAS Institute, 2008). Parcel information was obtained from the parcel ownership database of Bernalillo County Assessor's Office. Parcel boundaries were exclusive of rights-of-way vegetation. Each of the selected 200 parcels per zip code was screened to verify that the parcel was owner-occupied. The first 80 owner-occupied parcels were selected to give sample size of 1280 residential addresses. Only owner-occupied parcels were chosen because owners had to give their written consent before their parcels could be included in the classification. In addition, quick preliminary analysis of non-owner occupied parcels revealed that a small number of those parcels either lacked landscapes or were devoid of functional landscapes. On May 26, 2009, forms seeking their consent to be part of the ground reference sample were mailed to the owners of each of the 1280 parcels. Follow-up postcards were sent on June 15 and July 5, 2009 to non-responders. One hundred thirty-five owners consented to be included in the ground reference sample and all were included in the classification sample. Four hundred eighty parcels (≈30 per zip code) inclusive of ground proof parcels, were selected for classification. A statistical sample from each zip code was classified because classifying large areas of high spatial resolution imagery is impractical due to the huge image size, long processing time, and the need for large ground truthing sample sizes.

Ground reference data collection

Each of the 135 respondents who consented to include his/her residence in the ground reference sample was e-mailed or telephoned to schedule a visit. An aerial photograph of the each owner's