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Object-based land-cover classification for metropolitan Phoenix, Arizona, using aerial photography

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ABSTRACT

Detailed land-cover mapping is essential for a range of research issues addressed by the sustainability and land system sciences and planning. This study uses an object-based approach to create a 1 m land-cover classification map of the expansive Phoenix metropolitan area through the use of high spatial resolution aerial photography from National Agricultural Imagery Program. It employs an expert knowledge decision rule set and incorporates the cadastral GIS vector layer as auxiliary data. The classification rule was established on a hierarchical image object network, and the properties of parcels in the vector layer were used to establish land cover types. Image segmentations were initially utilized to separate the aerial photos into parcel sized objects, and were further used for detailed land type identification within the parcels. Characteristics of image objects from contextual and geometrical aspects were used in the decision rule set to reduce the spectral limitation of the four-band aerial photography. Classification results include 12 land-cover classes and subclasses that may be assessed from the sub-parcel to the landscape scales, facilitating examination of scale dynamics. The proposed object-based classification method provides robust results, uses minimal and readily available ancillary data, and reduces computational time.

1. Introduction

Land change science, urban and regional planning, and landscape sustainability, among other research communities, increasingly address questions about urban areas that require fine resolution remote sensing and land classification, often at sub-parcel levels (NRC, 2013; Seto and Reenberg, 2014; Turner et al., 2013; Wu, 2013). Composed of small, land-cover patches, the complex and highly heterogeneous land systems of urban areas point to the need of an object-based approach to address the research in question (Gong et al., 1992; Shackelford and Davis, 2003; Bhaskaran et al., 2010).

Increasingly important in remote sensing at large (e.g., Cleve et al., 2008; Li and Shao, 2013; Morgan and Gergel, 2010; Myint et al., 2011; Yu et al., 2006; Walker and Briggs, 2007), object-based image analysis or OBIA uses image segmentation algorithms to generate image objects that significantly improve the accuracy of high-resolution imagery classifications (Zhou and Troy, 2008). Image objects are formed by grouping pixels together that are spectrally similar and spatially contiguous (Baatz and Schape, 2000). By doing so, the image can be classified using the spectral and spatial properties of the object, rather than by the pixel alone (Blaschke, 2010). Segmentation of objects is one of the critical aspects of OBIA, providing a wealth of new information image classification, such as the mean band values for the pixels in the object, the standard deviations object pixels, and various shape and texture properties (Blaschke, 2010). Essentially, each object contains new statistical properties that can be used for classification beyond the spectral values of single pixels. After segmentation, objects are selected according to these enhanced characteristics and assigned to specific classes (Benz et al., 2004; Zhou and Troy, 2008; Li and Shao, 2013).

OBIA has proved successful in providing the detailed land-cover mapping required for heterogeneous urban landscape research (Blaschke, 2010; Zhou and Troy, 2008; Zhou et al., 2009; Myint et al., 2011; Zhou, 2013). It does so by adding expert inputs to spectral information in order to identify homogeneous clusters mimicking

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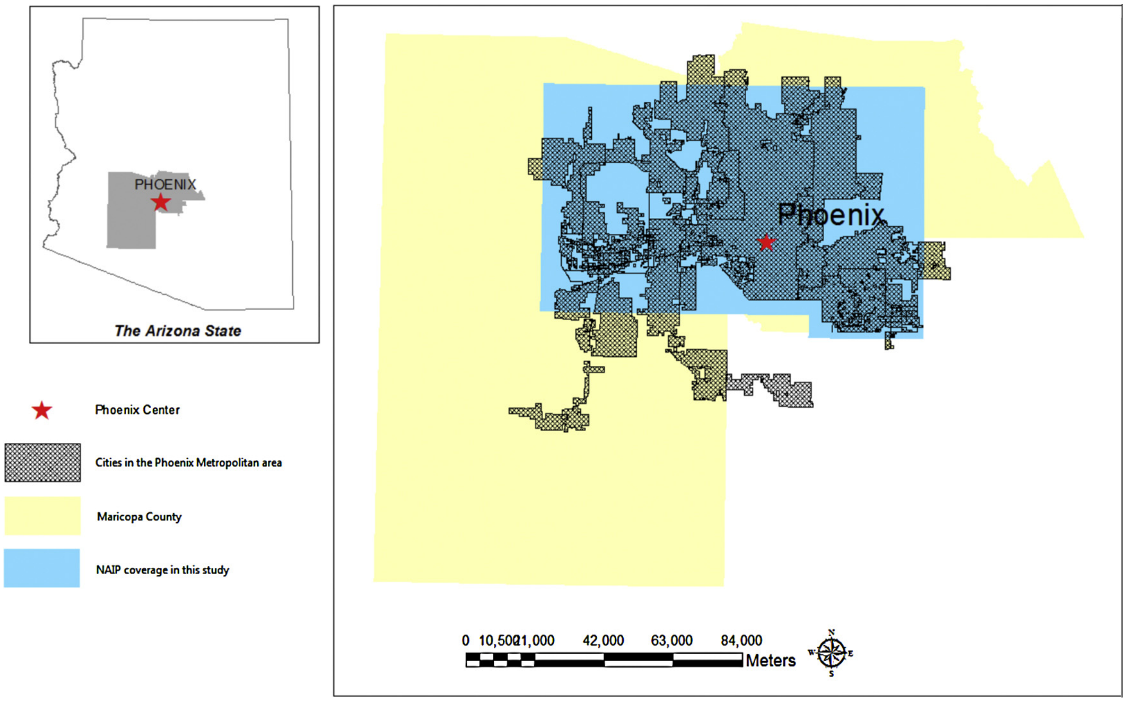

Fig. 1. The Phoenix metropolitan area.

human visual interpretation and by reducing the "salt and pepper effects" common to pixel-based classification result (Myint et al., 2011). The OBIA results prove especially useful for complex landscapes composed of fine-grain land-covers, for example the urban parcel or neighborhood.

The use of OBIA in these and other assessments is not without problems, however. Machine learning and computational costs, either too simple or too complicated algorithms, have reduced numerous OBIA-based examinations to one land-cover type, such as vegetation (Yu et al., 2006; Walker and Briggs, 2007), or to a relatively small subset of the larger area of study (e.g., Myint et al., 2011, 2013a,b). To our knowledge, Baltimore, Maryland, is the only large urban area examined to date through the OBIA approach that treats multiple land-cover classes (Zhou et al., 2008), and it is much smaller in size than the urban area that we examine here, Phoenix, Arizona. In order to balance the operational time cost and the computer recognition rules for processing images with billions of pixels, as in the highly heterogeneous case examined in this study, optimized combinations of algorithms within a hierarchical framework must be developed for accurate classification.

1.1. Research objectives

This study demonstrates an effective, ancillary data sparse, method that proves useful for fine-resolution land-cover mapping of complex urban areas in which spectral reflectance can be highly fragmented and similar among different objects. It does so through an application for the expansive Phoenix, Arizona, metropolitan area using National Agriculture Imagery Program (NAIP) four-band, 1 m data. Coupled with cadastral GIS data only (typically available for all urban areas) and a hierarchical network approach that balances computation time with classification accuracy, robust outputs are derived of use for a range of research activities. While the specific classification results are applicable only to the Phoenix metroplex—the first such produced for a desert city—the classification process developed can be employed for fine-resolution land-cover mapping of other large urban areas if parcel data are available.

2. Case study, data, and methods

2.1. Case study

The Phoenix metroplex is composed of 26 communities and several Native American lands that cover just under 38,000 km^2 of Maricopa County, AZ, on the extreme northern edge of the Sonoran Desert. Of this area, extensive research attention has been given to the 7600 km^2 that comprise the Central Arizona-Phoenix Long-Term Ecological Research (CAP-LTER) program, the area of focus for this study (Stefanov and Netzband, 2005; Wentz et al., 2006; Walker and Briggs, 2007; Myint et al., 2011; Myint, 2012) (Fig. 1). The area exhibits a high level of land-cover heterogeneity comprised of different types of impervious surfaces, urban vegetation, water sources, agriculture, bare soil and rock. Interspersed within and around the metroplex are agricultural lands and mosaics of land covers that compose desert, neither of which are considered in this study. Common housing construction and the desert setting give rise to extremely similar spectral reflectance among light-colored tile roofs, concrete surfaces such as driveways, and bare soil, generating difficulties in separation.

2.2. Data

The NAIP program is administered by USDA Farm Service Agency; it provides orthorectified imagery collected during the agricultural growing season in the U.S. (http://www.fsa.usda.gov/). The NAIP mosaic for Maricopa County, Arizona (1 m resolution) in the year 2010 was acquired. NAIP has 4 bands (Red, Green, Blue, and Near-Infrared), and a radiometric resolution of 8-bit that represent brightness values, or digital numbers that range from 0 to 255. NAIP Quarter Quadrangles were captured with a ZI Intergraph Digital Mapping Camera. Processed RAW Frames were checked for spectral compliance in Iras/C and Adobe PhotoShop by the USDA, and placed into a county format by data compression software provided by USDA (http://www.fsa.usda.gov/). 90% of the NAIP data were taken from June 6–10, 2010, 7% on August 15, 2010, and the remainder on September 9, 2010. We observed no significant