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Land fragmentation due to rapid urbanization in the Phoenix Metropolitan Area: Analyzing the spatiotemporal patterns and drivers

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A B S T R A C T

Rapid urbanization of the Phoenix Metropolitan Area exemplifies the dominant US Southwest urban growth pattern of the past six decades. Using a combination of multitemporal land cover data, gradient analysis, and landscape metrics, we quantify and characterize spatiotemporal patterns of land fragmentation observed in Phoenix. We analyze historical, qualitative data to identify five major socio-ecological drivers critical to understanding the urbanization processes and fragmentation patterns: population dynamics, water provisioning, technology and transportation, institutional factors, and topography. A second objective is to assess the applicability and accuracy of National Land cover Database (NLCD)-—a widely used land cover dataset—-to detect and measure urban growth and land fragmentation patterns in the relatively treeless desert biome of the US Southwest. In contrast to studies in the temperate eastern USA where NLCD has proved inaccurate for detection of exurban development, our study demonstrates that NLCD is a reliable data source for measuring land use in the southwest, even in low-density environments. By combining qualitative analyses of social-ecological drivers with fragmentation analyses, we move toward an improved understanding of urbanization and insights on the human modification framework used widely in land change science.

Introduction

Rapid expansion of the Phoenix Metropolitan Area exemplifies the dominant US Southwest urban growth pattern of the past six decades (Luckingham, 1984; Wu, Jenerette, Buyantuyev, & Redman, 2010). Even with the current housing market downturn that began in 2007, Phoenix continues to grow in population and remains the sixth largest city in the nation. Aggressive real estate development, especially since the World War II, has resulted in large scale, low-density residential development in the Greater Phoenix area (Buyantuyev & Wu, 2009; Gober & Burns, 2002; Heim, 2001; Keys, Wentz, & Redman, 2007; Redman & Kinzig, 2008; Roach et al., 2008). One consequence of this development is increasing land fragmentation, which may include subdivision of land into discrete land uses, conversion from native to designed land cover, or development in a non-contiguous or "leap frog" pattern (Clark, McChesney, Munroe, & Irwin, 2009; Heimlich & Anderson, 2001; Irwin & Bockstael, 2007; Theobald, 2001). Such landscape patterns significantly alter ecological functions and processes (Alberti, 2005; Turner, Gardner, & O' Neill, 2001) with important consequences for ecosystem services, including the loss of habitat and wildlife corridors, decreases in agricultural and forest productivity, as well as reduction and elimination of culturally-significant open spaces and natural amenities (Burchell et al., 1998; Carsjens & van der Knapp, 2002; Dale, Archer, Chang, & Ojima, 2005; Schipper, 2008).

In this paper, we analyze and characterize the rapid urbanization trends in Phoenix with a specific focus on land fragmentation patterns. The paper has two primary objectives: (i) to assess the applicability and accuracy of National Land cover Database (NLCD)—a widely used land cover dataset—-to detect and measure urban growth and land fragmentation patterns in the relatively treeless desert biome of the US Southwest; and (ii) to quantify and categorize the spatiotemporal patterns of land fragmentation. We conclude with a short discussion on drivers of changes in land use, land cover, and fragmentation in Phoenix.

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Study area and methods

Study area

The urbanized area of Greater Phoenix extends 120 km from east to west and 60 km north to south, encompassing a population of 4.2 million. There are 26 cities within the Phoenix Metropolitan Area, but the City of Phoenix is the dominant municipality (Fig. 1: Map of Study Site). The Phoenix Metropolitan Area (hereafter Phoenix) is situated in the Sonoran Desert and has a mean annual precipitation of 180 mm. Large supplies of surface water diverted from the Salt, Verde, Gila and Colorado Rivers, as well as regulated groundwater pumped from local aquifers, have made possible irrigated agriculture, industrial production, and lush vegetation relative to background flora. However, all sources are considered under risk in the face of climate change (Bolin, Seetharam & Pompeii, 2010; Gober, Kirkwood, Balling, Ellis, & Deitrick, 2010). While 60% of the land in Maricopa County is still covered by deserts, the urban built-up area has dramatically expanded from 3% of the total land in 1955 to almost 20% in 2001, mostly at the expense of agricultural and desert land (Redman & Kinzig, 2008). The expansion is continuously radiating outward, except where constrained by natural and institutional barriers, such as South Mountain or federally protected American Indian reservations.

Land conversion and fragmentation is most acute at the metropolitan fringe. Communities such as Cave Creek, Queen Creek, Buckeye, and Fountain Hills have undergone significant land use and land cover change over the last decade. To capture these and other fragmentation hot spots, we selected a set of transect windows using east-west, north-south, northeast-southwest, and northwest-southeast orientations that run through the central city of Phoenix. The extent of the study area matches that of the Central Arizona – Phoenix Long Term Ecological Research (CAP LTER) project (Grimm & Redman, 2004).

Methods and data

This study combines land cover data, landscape metrics, gradient analysis, and socioeconomic data. The major source of land cover data is the National Land Cover Database (NLCD), which provides seamless coverage for the United States. NLCD was the first nationwide initiative that provided consistent land cover inventory for the US and it has been widely used in studying urbanization (Burchfield, Overman, Puga, & Turner, 2006; Vogelmann, Sohl, Campbell, & Shaw, 1998) and landscape fragmentation (Heilman, Strittholt, Slosser, & Dellasala, 2009; Riitters et al., 2002). Due to problems arising from differences in source data and classification systems of NLCD in 1992 and 2001 (for details, see Homer et al., 2007), we "retrofitted" 1992 land cover classes to match 2001 classes (Fry, Coan, Homer, Meyer, & Wickham, 2009). After we generated land use maps for 1992 and

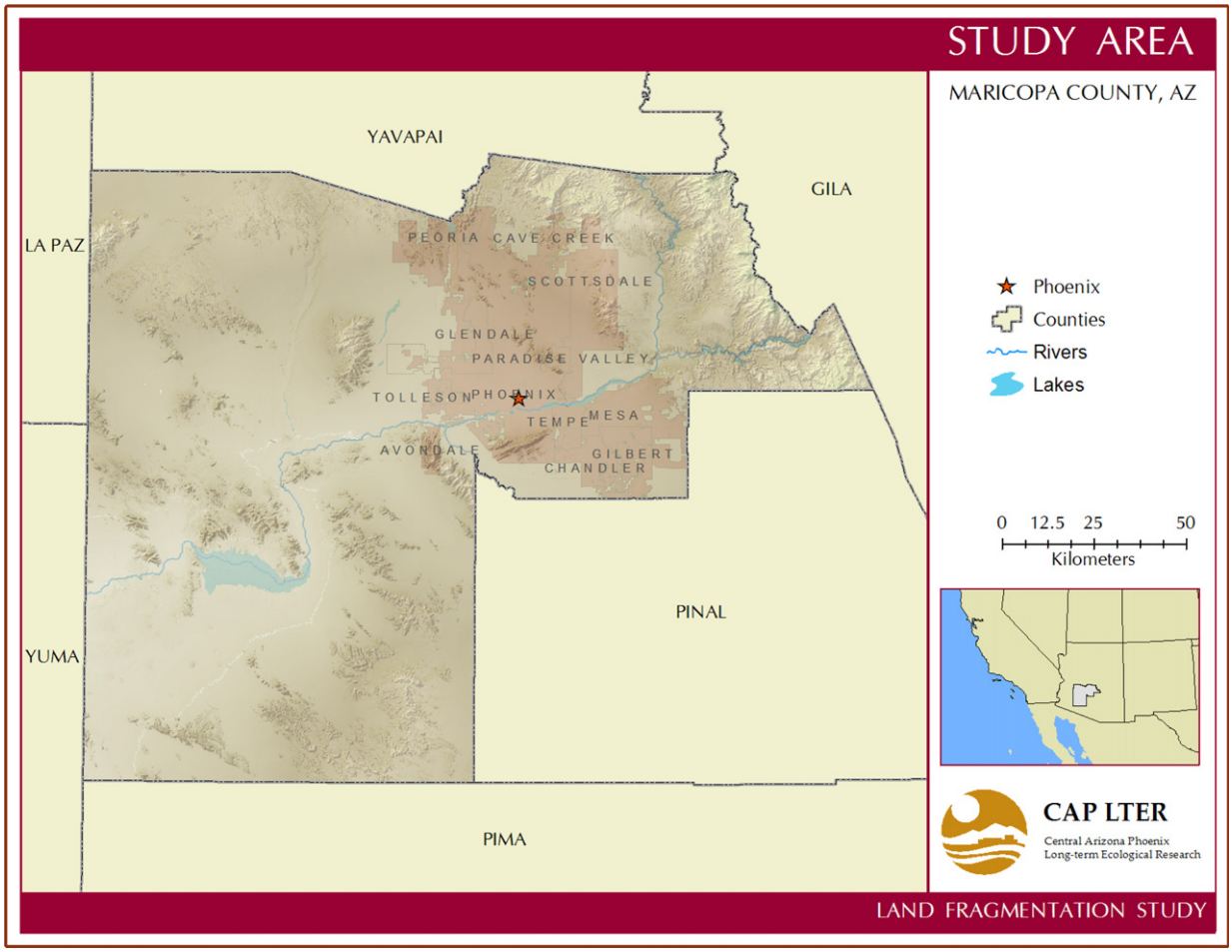

Fig. 1. Study area.