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Land fragmentation under rapid urbanization: A cross-site analysis of Southwestern cities

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Abstract Explosive population growth and increasing demand for rural homes and lifestyles fueled exurbanization and urbanization in the western USA over the past decades. Using National Land Cover Data we analyzed land fragmentation trends from 1992 to 2001 in five southwestern cities associated with Long Term Ecological Research (LTER) sites. We observed two general fragmentation trends: expansion of the urbanized area leading to

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fragmentation in the exurban and peri-urban regions and decreased fragmentation associated with infill in the previously developed urban areas. We identified three fragmentation patterns, riparian, polycentric, and monocentric, that reflect the recent western experience with growth and urbanization. From the literature and local expert opinion, we identified five relevant drivers – water provisioning, population dynamics, transportation, topography, and institutions – that shape land use decision-making and fragmentation in the southwest. In order to assess the relative importance of each driver on urbanization, we linked historical site-specific driver information obtained through literature reviews and archival analyses to the observed fragmentation patterns. Our work highlights the importance of understanding land use decision-making drivers in concert and throughout time, as historic decisions leave legacies on landscapes that continue to affect land form and function, a process often forgotten in a region and era of blinding change.

Keywords Land fragmentation · Exurbanization · The US Southwest · Urban ecology

Introduction

Over the last five decades, residential low density development at the urban fringe has fragmented the American landscape (Clark et al. 2009; Downs 1998; Mieszkowski and Mills 1993; Walker et al. 1997). Exburbanization, the development of land outside the urban core (York and Munroe 2010), sprawl, extensive or excessive urban development (Irwin and Bockstael 2007), and 'leap-frog' development, discontinuous development (Heim 2001) fragment socio-ecological systems, leading to a number of negative consequences. Fragmentation isolates habitats by destroying crucial corridors, (Alberti and Marzluff 2004; Dale et al. 2005; Grimm et al 2008; Wang and Moskovits 2001), increases costs for public service provision (Camagni et al. 2002), decreases agricultural (Carsjens and van der Knapp 2002) and forest productivity (Kline et al. 2004; Rickenbach and Gobster 2004), and reduces or eliminates culturally-relevant open spaces and natural amenities (Deller et al. 2001; Schipper 2008). Development of greenfield sites and

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conversion of farmland and wildlands to subdivisions while central city lots and brownfields lie vacant, underscores the inefficiencies that accompany such growth (Boone and Modarres 2006).

Despite the profound consequences of land fragmentation on socio-ecological systems, extant research on fragmentation is limited in a number of ways. First, the vast majority of land fragmentation studies focus on pattern analysis. Measuring the degree and characteristics of fragmentation is a worthwhile goal, but greater attention to the causal processes that lead to observed patterns is necessary (Irwin and Geoghegan 2001). Second, land fragmentation research typically begins from two perspectives – an ecological and principally landscape ecological perspective, and from a land use, especially planning, perspective – with very little overlap between the two literatures. As a result, the methods and analyses employed tend to focus on either the ecological or planning consequences of land fragmentation. For best management practices, as well as to better comprehend coupled natural-human systems, there is a clear need for an integrated socio-ecological framework that improves understanding of the drivers and consequences of land fragmentation (Jenerette and Wu 2001). Finally, most land fragmentation studies are single cases. The case study approach allows researchers to use specialized data sets and draw on local expert knowledge. However, the use of non-standard data, especially land use and land cover classification systems, makes comparisons across sites problematic. As such, there are relatively few comparative studies of land fragmentation. In this study we set out to reconcile these shortcomings by measuring land fragmentation using a common land cover classification scheme across five urban areas in the US southwest, and employ expert knowledge to compare the role of biophysical and social drivers in the land fragmentation process. We adapt a socio-ecological framework, developed as part of the *US LTER Decadal Plan* (Collins et al. 2007), to study the complex, interrelated

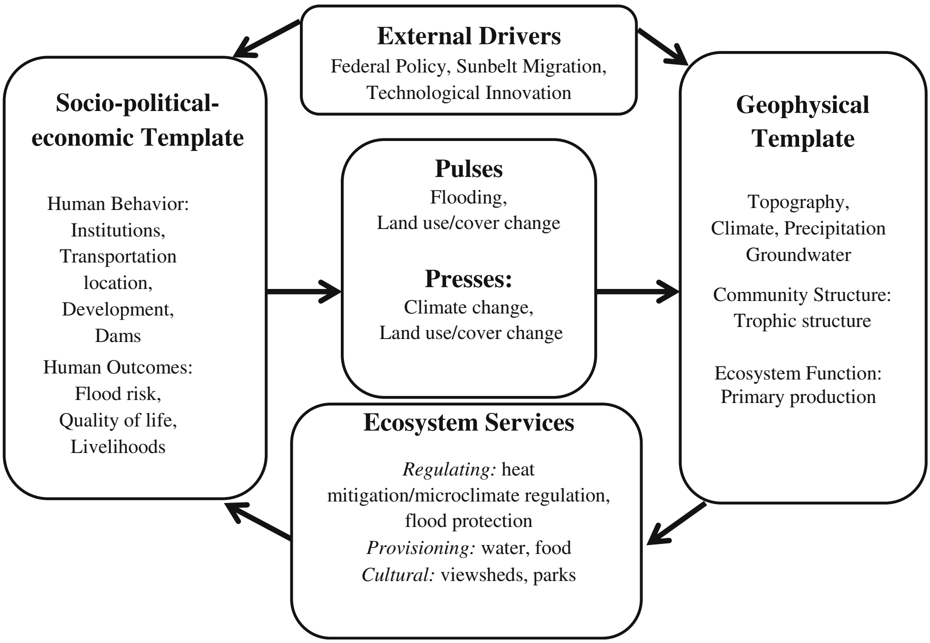

Fig. 1 Integrated socio-ecological system

processes of landscape change, land fragmentation, land use decision-making, and the socio-ecological consequences of fragmentation (Fig. 1).

The framework links biotic structure and function with human outcomes and behavior. In this study we focus on five drivers of land fragmentation patterns: water provisioning, urban population dynamics, transportation, topography, and institutional factors-these factors are components within the socio-ecological system or external drivers. For the purpose of our study, land fragmentation is conceptualized as press and pulse events, meaning that some changes, events, or impacts continue over time "pressing," while over perterbations are discrete "pulsing" events (Ives and Carpenter 2007). Many studies evaluate these press and pulse events as causes or drivers of socio-ecological changes, but in this study we unpack how processes within the socio-ecological system generate land use/cover change leading to the observed landscape fragmentation. Topography makes up part of geophysical template affecting the potential for residential, industrial, and commercial development, flooding risks, and biodiversity, including plants that make up the observed land cover. Water provisioning is an ecosystem service, partially determined by the geophysical template's climate, precipitation, and topography, but the distribution of water use and provisioning across the landscape is affected by human decisions, most notably water law and dam building. Transportation affects land use decision-making through the location decisions, but also through technological innovation such as the invention and adoption of rail road and automobile technologies, an external disturbance. Institutions affect water provisioning and also directly impact land use through economic development, zoning, and planning, and federal military and land management policies. Urban population dynamics are influenced by Sunbelt migrations and employment opportunities, particularly employment associated with military and military support industries, which are based on federal policies. The socio-ecological framework integrates social and ecological drivers allowing us to focus on system-wide impacts and the interrelationships of multiple factors and processes. It also provides a systematic approach for cross-site comparison.

We selected five southwestern cities for our study – Phoenix, Albuquerque, Las Cruces, Fort Collins, and Manhattan, KS—which are associated with the Central-Arizona Phoenix, Sevilleta, Jornada, Shortgrass Steppe, and Konza Prairie Long-Term Ecological Research Sites. Each of the sites in the LTER network maintains long-term data. More importantly, the projects have cultivated long-standing research commitments from biophysical and social scientists to analyze and understand the changing socio-ecological dynamics of their sites. This depth of experience and the development of research and social networks through the LTER enhance the ability of our team to conduct cross-site research. We chose to take a regional approach with a focus on the US southwest because of the characteristic rapid growth, emerging new geographies of exurbanization, and comparable biophysical properties related to arid and semi-arid climates (Travis 2007).

Comparative analysis depends on accessible, comparable data. In recent years, the greater availability of land-cover data derived from remotely sensed images has made it easier to study urban growth and sprawl (Dietzel et al. 2005; Stefanov et al. 2001; Vogelmann et al. 1998; Yang and Lo 2002; Wang and Moskovits 2001) and to detect urban land fragmentation (Luck and Wu 2002; Wu et al. 2010). Landsat images have been used in some cross-site studies to study urban land-use fragmentation (e.g., Luck and Wu 2002; Schneider and Woodcock 2008; Seto and Fragkias 2005; Wu et al. 2010). In this study, we use remote sensing images, landscape metrics, gradient analysis, and socioeconomic data to analyze the effects of five drivers – water, population dynamics, transportation, topography, and institutions – on the spatial and temporal patterns of land fragmentation. We selected three land fragmentation metrics that capture different aspects of fragmentation: patch density, edge density, and Shannon's Diversity Index. Patch density is defined as the number of patches divided by the total landscape area[1]; patch density is intuitive and useful for cross-city comparisons (Schneider and Woodcock 2008). Edge density is defined by the total length of edges, the boundaries between patches, divided by the total landscape area, the boundary between two different patches, divided by the total landscape area.[2] Edge density is a straightforward metric and provides information about the lengths of edges between dissimilar uses, which sometimes creates conflicts within urbanizing areas, i.e. agricultural uses and residential use, and may provide important habitat for species that prefer edge environments. In addition to these two common, simple metrics, we use Shannon's Diversity Index (SHDI), which combines richness and evenness measures into a single metric of proportional abundance and is widely used in community ecology (McGarigal and Marks 1995). SHDI increases as the number of different patch types increases and the proportional distribution of area among patch types become more equitable. SHDI reflects the basic aspects of heterogeneity including: configuration, composition and sensitivity to low-abundance classes (Díaz -Varela et al. 2009). These three metrics provide information about density of patches, length of edges, and evenness and richness of patches-important and distinct dimensions of landscape fragmentation. Figure 2

Selection of the drivers is based on expert knowledge from investigators at each of the sites and from knowledge of existing literature. Given the aridity of the US Southwest, provision of fresh water – as precipitation, surface and groundwater, and delivered through infrastructure – is a fundamental limiting factor of development (August and Gammage 2006; Gober 2006; Hanak and Chen 2007). In addition to household, commercial, and industrial uses, the provision of irrigated water and groundwater withdrawals has permitted extensive and intensive agricultural production, which often precedes urban land use development and contributes to land fragmentation (Jenerette and Wu 2001; Keys et al. 2007). Agriculture also acts as a "bank" for water rights, and since farming consumes more water than residential land use, it ensures a water supply for future development. Nearly all land use change models include population dynamics as population growth typically leads to land conversion (Agarwal et al. 2001). In addition to growth rates, population characteristics shape land use change. For example, development of isolated retirement communities has contributed significantly to peripheral growth in Phoenix (Gober 2006; McHugh 2007). From expansion of suburbs to clearing of forests, transportation is a key land conversion factor. One of the best ways to predict land change is the development of new transportation corridors. This is especially the case when combined with an understanding of existing land uses (Iacono and Levinson 2009; Yang, Li and Shi 2008). Prediction of land use change also improves by incorporating topographic characteristics (Clarke and Gaydos 1998; Silva and Clarke 2002). Steep slopes and river valleys often preclude development while higher land with attractive viewsheds may encourage high-end real estate development and increase home values (Bourassa et al. 2004). The ability to build in certain locations nevertheless is limited by regulatory institutions, especially zoning and master plans (Dow 2000; Lambin and Geist 2006). However, in the southwest, land use development can also be directly or indirectly influenced by the availability of water and the institutions that govern its delivery. An expansive view of institutions that extends beyond traditional land use planning is therefore necessary to understand the role of regulatory agencies on fragmentation. While land use change models incorporate other

[1] The unit for patch density is number of patches per hectare.

[2] The unit for edge density is meters per hectare

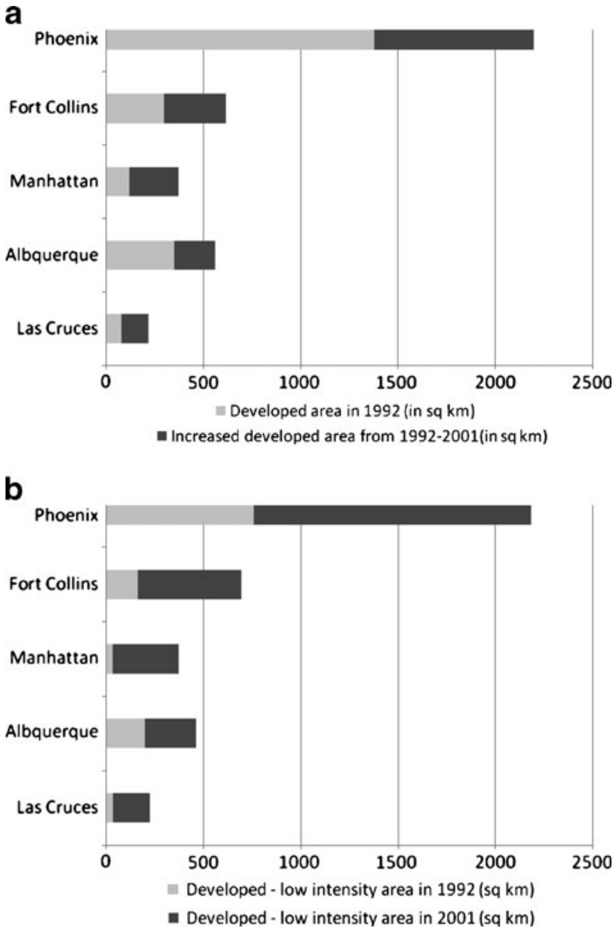

Fig. 2 **a** Developed land-use between 1992 – 2001 (based on the two land-use classes analysis). **b** Changes in the "developed – low intensity" land-use categories between 1992 and 2001

drivers, the participants of agreed that these five drivers are particularly pertinent to urbanization in the US Southwest.

Data and methods

The five chosen sites share some common characteristics and important differences. All are relatively treeless, with the exception of Manhattan, which has experienced woody encroachment from the hilly uplands onto the grasslands and rangelands, a major ecological concern (Briggs et al. 2002). There is variation in precipitation levels at the five sites, but all use diversion of surface water through major dam infrastructure and reservoirs to provide necessary irrigation water for agriculture, which has fueled urban expansion at all sites. The three desert sites – Phoenix, Albuquerque, and Las Cruces – receive less than 300 mm of rain on average, while Fort Collins and Manhattan receive approximately 380 and 890 mm. Population grew very rapidly in all but one site, Manhattan, which experienced a small decline during the study period (Table 1). However, the magnitude of the variables varies across the sites, creating a useful gradient for examining socio-ecological drivers of land fragmentation in the southwest.

Table 1 Study sites at a glance

	Study sites				
	Phoenix	Albuquerque	Las Cruces	Manhattan	Fort Collins[1]
County/counties	Maricopa	Bernalillo, Valencia, and Socorro	Dona Ana	Riley, Geary, Pottawatomie, and Wabaunsee	Parts of Larimer (only area below 1,830 m or 6,000 ft), and Weld
Area coverage (sq km)					
Study site	23,890	23,015	9,881	6,962	12,345
		Bernalillo: 3,028		Riley: 1,611	Larimer: 6,822
		Socorro: 17,221		Geary: 1,047	Weld: 10,417
		Valencia: 2,766		Pottawatomie:2233	
				Wabaunsee: 2071	
Est. population[2]					
1992	2,272,582	568,935	141,228	125,123	337,772
2001	3,199,440	647,497	176,536	116,368	453,794
Change	926,858	78562	35,308	-8757	116022
Growth ratio	41%	14%	25%	−7%	34%
Population density (sq km)					
1992	95	25	14	18	20
2001	134	28	18	17	26
Precipitation 1983 to 2008 (mm)[3]					
Average annual	198.16	255.65	293.71	804.77	404.08
St. dev.	92.65	71.09	90.52	193.29	92.4
Sample (No. of years)	19	26	24	26	25

In this study, the SGS site covers the whole area of Weld county and only the parts of Larimer (below 1,830 m) county; however, all parts of Larimer county is included in this table for convenience

US Census Bureau (2010)

Ecotrends (2010)

To measure land fragmentation, we employ the National Land Cover Database (NLCD) for 1992 and 2001, compiled from Landsat Thematic Mapper (TM) images, which provides seamless coverage for all sites (Homer et al. 2004). NLCD was the first nationwide initiative that provided consistent land-cover inventory for the US and it has been widely used in studying urbanization (Vogelmann et al. 1998) and landscape fragmentation (Heilman et al. 2009; Riitters et al. 2002). The dataset does have limitations for land fragmentation analyses, especially in detecting peri-urban and exurban development (see for example Irwin and Bockstael 2007; Ward et al. 2000). At the outset of this study, however, we hypothesized that the NLCD would accurately capture peri-urban development in arid environments where tree canopy is sparse. We compared NLCD to tax assessor data, similar to Irwin and Bockstael's (2007) study in suburban Maryland. In Phoenix, NLCD performed relatively well with a 66% accuracy rate for exurban areas and 81% rate for peri-urban, much better than the 8% and 26% respectively found in Maryland. Because of NLCD's performance in Phoenix and its coverage of all five sites, we opted to use NLCD. To simplify comparisons, we regrouped the land-cover classes into seven categories: developed urban (higher intensity), developed (lower intensity), agriculture, forest, deserts/undeveloped, grass/shrubland, and water (Appendix).[3] For each site we generated two maps for 1992 and 2001, validated by local collaborators at each site, which were reclassified for further pattern analysis and quantification of land fragmentation using landscape metrics (Table 2).

To analyze urban growth patterns and their spatial heterogeneity, we weighed the benefits of using a full coverage moving windows analysis (Riitters et al. 2002) and a transect analysis (Luck and Wu 2002; Yu and Ng 2007). The transect methodology was selected due to the linear form of many of the sites and our wish to detect directionality of urbanization patterns. We selected two methods to analyze spatial heterogeneity: i.) fragmentation metrics at the class level to reflect landscape composition; and ii.) fragmentation metrics at the landscape level to capture landscape configuration (Cushman and McGarigal 2002) (Figs. 3 and 4). To ensure consistency and uniformity across the five study sites, we applied the same size transect window of 15 km × 15 km. These windows move along the transect overlapping at 5 km intervals and generate a mean value for the center pixel that is used for the fragmentation analysis.

At two consecutive workshops, we identified the five socio-ecological drivers described above that affect decisions on land use and cover and consequent fragmentation patterns. At a third workshop, we analyzed the relative importance of the five socio-ecological drivers across the five sites and identified causal explanations of differing patterns and degrees of fragmentation. Each of the drivers was ranked from high to low in explanatory power using an iterative expert analysis with local scientists and drawing on relevant literature for each of the sites (Table 3).

Results

From 1992 to 2001, residential development increased land fragmentation on the fringes or the periphery of urban areas at all study sites. However, we observed three general fragmentation

[3] These are the most common categories for the Southwest and the Midwest, and these were agreed upon by all collaborators in our workshop specifically organized to come up with the common dataset and methodology. It is important to note that NLCD 1992 and 2001 originally had different classification scheme, and hence, their land-cover categories were slightly different, which were subsequently retrofitted to make them consistent (Homer et al. 2004). In our study, we used the retrofitted land-cover classes and data.

Table 2 Changes in the area covered by each land-use category in the study sites

Land-use	Phoenix			Albuquerque			Las Cruces			Manhattan			Fort Collins		
	1992	2001	%change	1992	2001	%change	1992	2001	%change	1992	2001	%change	1992	2001	%change
Developed, high density	622	774	24%	150	99	−34%	44	25	−43%	89	31	−65%	137	82	−40%
Developed, low-density	757	1425	88%	199	461	132%	35	191	446%	31	341	1000%	161	534	232%
Agriculture	1722	1445	−16%	103	215	109%	211	373	77%	1379	934	-32%	3300	3770	14%
Shrubs/grassland	1234	1167	−5%	93	143	54%	48	9	−81%	4927	4768	−3%	8347	7263	−13%
Forest	396	304	−23%	2660	2833	7%	79	59	−25%	334	711	113%	56	173	209%
Undeveloped	18992	18612	−2%	19845	19297	−3%	9454	9211	−3%	3	9	200%	67	294	339%
Water	83	78	−6%	71	73	3%	9	11	22%	203	171	−16%	211	163	−23%
Total Area	23806			23120			9879			6966			12278		

Area in km^2

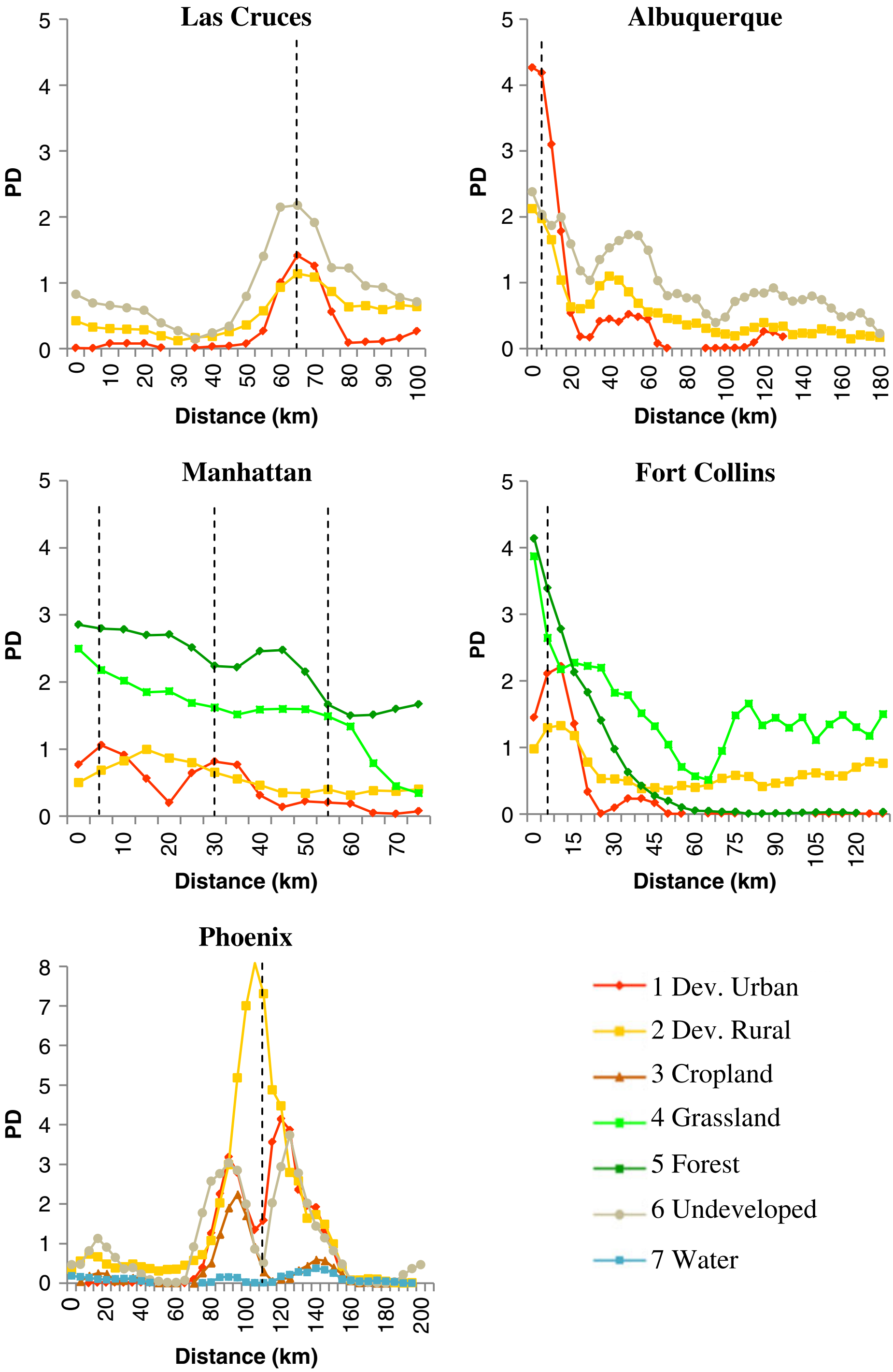

Fig. 3 Spatial distribution of PD (patches per hectare) at class-level along transect for the 5 sites in 2001. *Dashed lines* indicate the location of the center of the city or cities along the transect

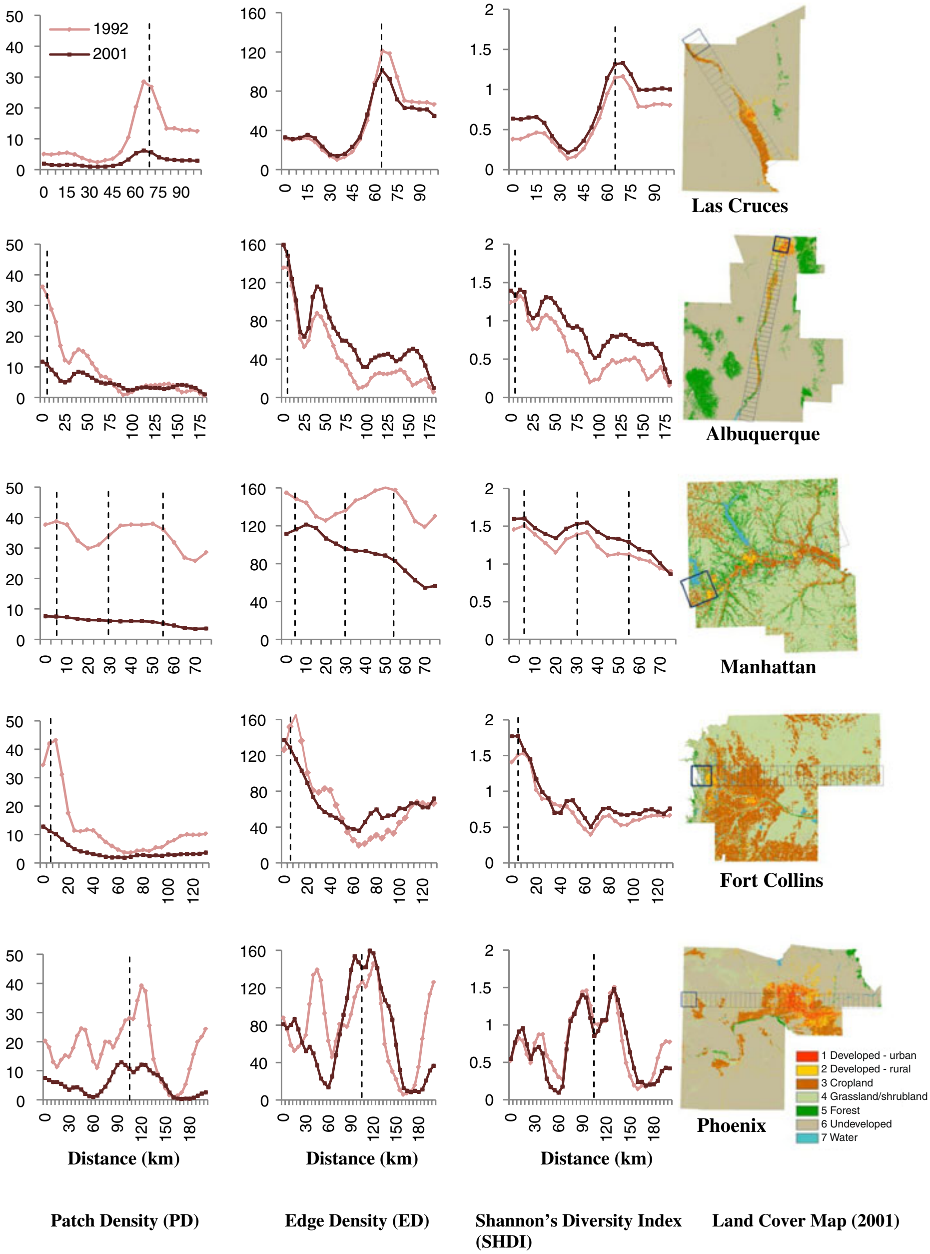

Fig. 4 PD (patches per hectare), ED (meters per hectare) and SHDI at landscape-level along transect for the 5 sites in 1992 and 2001. *Dashed lines* indicate the location of the center of the city or cities along the transect

patterns corresponding to specific urban morphologies: (1) riparian-fragmentation along rivers; (2) polycentric-suburbanization and exurbanization in disaggregated cities; and (3) monocentric-rapid urban growth in a concentric ring pattern (Figs. 3 and 4). The riparian sites of Las Cruces and Albuquerque experience a peak level of fragmentation (specifically for patch density or PD)

Table 3 The impact levels of the major drivers on land fragmentation

	Study sites				
	Phoenix	Albuquerque	Las Cruces	Manhattan	Fort Collins
Water	High	High	High	High	High
	• Diversions from rivers	• Cities along the Rio Grande, spread outward	• Allocation of ground water and surface water	• Cities along the Kansas river	• Water storage in reservoirs
	• Assured water supply plan	• Albuquerque aquifer	• Irrigated land, orchard	• Dam and reservoir built after the 1951 flood	• Water for irrigated land
	• Water rights transfer from agriculture to development	• Irrigation impact	• Cities buying water rights	• Flood plains' reliance on irrigation	• Water rights transfer from agriculture to development
Population	High	High	High	Low	High
	• Exponential growth	• Government contracts and jobs	• Steady growth – Las Cruces	• Decreased population	• Steady exurbanization
	• High density development	• Exurbanization	• New migrants	• Steady exurbanization	• Increasing retiree population
Topography	Low	Medium	Medium	Medium	High
	• Vulnerable flood plains	• Sandia mountains as a limiting factor	• Mountains – limiting factor	• Upland: less water, limestone bedrock, vulnerable plains	• Upland: tourism based and lowland: irrigated land
	• Mountains - limiting factor	• Desert	• Slope factor, dense valley	• Suppression of fire	• Leap-frog dev. in mountains
	• Desert		• Desert		
Transportation	High	High	Medium	Medium	Medium
	• Late railroad and freeway development	• Commercial hub dev. along interstates	• Interstates	• New developments along the road corridors	• New commercial development along the interstates
	• New freeways in 1990 s	• Connecting corridors	• Access creating low density residential		
Institutional factors	High	High	High	Low	Low
	• Indian lands: agri. or lease	• National labs, military	• Extensive public land holdings	• Vast majority of private lands	• National Forest, Grasslands
	• State trust land sales	• Indian lands: agriculture	• 54000 acres of land sold by BLM to developers	• Kansas State University and The Nature Conservancy	• Local attempts to regulate growth

for most classes at the city center (Figs. 3 and 4). PD declines with increased distance from the city core, but remains at a relatively high level along the length of transect along the rivers. In addition, both Las Cruces and Albuquerque show increased fragmentation in agricultural areas with very low-density residential development.

Manhattan and Fort Collins show fragmentation in multiple areas reflecting their disaggregated, polycentric morphologies. In the Manhattan region, development occurred near the three cities of Junction City, Manhattan, and Wamego, indicated by a peak PD at 5 km, 30 km, and 55 km on the transect. In the Fort Collins region, high patch densities due to suburbanization and exurbanization have also taken place. Along the transect, PD peaks at 5 km and then increases again at 50 km related to suburbanization of Greeley and Fort Collins.

The monocentric pattern observed at the Phoenix site is distinct from the others, with expansion of development creating a mostly continuous high-density urban area, with highly fragmented low-density patches, and almost no undeveloped parcels. Phoenix has a much higher PD of all classes at the urban fringe and a lower PD within the urban center. This pattern of sprawl radiating outward from the urban center is consistent with a classic monocentric urban form model (Alonso 1964; Mills 1967; Muth, 1969).

Overall, PD decreased at all sites during the study period (Fig. 4), a finding similar to Schneider and Woodcock (2008) characterization of development infill on undeveloped patches. In general, at all sites PD decreases as the transect moves away from the city core center in 1992, while in 2001 there is a more even distribution along the transect, indicating exurbanization trends and infill (Fig. 4). Infill is more prominent in Phoenix, while exurbanization and conversion from rural to urban and suburban land uses is more prominent at the remaining four sites, but both processes are evident at each site. Below we examine drivers that help to explain these observed patterns.

Drivers

Water provisioning

Surface water diversion, which provides water for agriculture via reservoirs, canals, and dams, altered the pattern of development at all five sites. The Bureau of Reclamation built its first major dam in Phoenix, the Roosevelt dam, in 1902, providing water for the growing agricultural interests in the valley (Luckingham 1989). The city of Phoenix and state of Arizona continued to grow and agricultural production intensified, leading to a never-ending search for “new” water sources, such as Colorado River water transported in the Central Arizona Project canals (Glennon 2009). In Albuquerque and Las Cruces, our riparian cities, current and historic water constraints (whether physical or institutional) tie development closely to the river, which can be seen in Fig. 4. Native Americans, then Spanish, and finally Anglos settled along the Rio Grande building irrigation canals and ditches to support agrarian societies (Luckingham 1982, 1989). With the completion of the Leasburg Dam in 1908 near Las Cruces (Paddock 1999) and the Isleta Dam in 1934 south of Albuquerque (USFWS 2009), agriculture and settlement expanded throughout the Rio Grande valleys. Although groundwater pumping provides water for the cities of Albuquerque (Price 2003) and Las Cruces (City of Las Cruces Department of Water Resources 2008), land use development largely follows the river and irrigation canals even today, partially because of topography and institutional factors (discussed below).

More recently, large-scale irrigation expanded onto the plains in Kansas and Colorado with construction of large dams in the mid-20th Century. In Kansas, prevention of catastrophic flooding was the primary impetus for building Tuttle Creek and Milford Reservoir dams, but both are used for irrigation and recreation. Groundwater sources largely serve the population in the Manhattan region, so the Flint Hills region, an upland area with limestone bedrock, and fairly inaccessible groundwater has remained mostly undeveloped. Around Fort Collins, the founders of Greeley, CO conceived a city built on communal irrigation cooperatives, and irrigation began in the 1880s in that community (Abbott et al. 1994). However, large-scale, wide-spread irrigation began later with the Colorado-Big Thompson project completed in 1959, which provides water for municipalities, agricultural, and power generation (USBR 2009). The extensive projects increased opportunities for settlement throughout the plains sustaining growth in the Front Range cities, including Fort Collins, and creating attractive residential sites outside of urbanized areas in Kansas. In both regions, availability of irrigated water has contributed to polycentric fragmentation patterns.

Irrigation contributes to agricultural "water banks" saved for future development in Phoenix, Las Cruces, Albuquerque, and Las Cruces. In the past six decades in Phoenix, urban housing developments expanded on former agricultural lands with senior water rights (Redman and Kinzig 2008). Assured Water Supply Rules (1994) associated with Arizona's Groundwater Management Act (1980) require developers to supply "100 years assured water" for all new residential developments outside of municipal water provision boundaries, which many achieve by purchasing farmland with senior water rights (Heim 2001). Both Albuquerque and Las Cruces historically relied on groundwater for urban water use, but increased development has put the aquifers under severe pressure. Albuquerque sought, and continues to seek, additional water supply from the Colorado River Basin (Glennon 2009), while Las Cruces and the downstream city of El Paso, Texas purchased over 2,200 acres of irrigated farmland to acquire the attached water rights. These rights allow the city to transfer water for municipal purposes, and the land may then be converted to development or allowed to lay fallow for future development (Skaggs and Smani 2005). Cities along the Front Range in Colorado battle for water rights, too, by competing for farmland with senior water rights. Cities purchase land with senior rights and annex land with water in order to increase supply. Conversion of cropland to residential land use dewaters the plains. In contrast, agricultural conversion in Kansas is associated with exurbanization trends and lifestyle choice, which we address in the next section.

Urban population dynamics

Between 1990 and 2000, total population of the American West region surged by 19.7%, the fastest among all four regions in the country (Perry and Mackun 2001). Western cities provided burgeoning economic opportunities for people in the region and for those seeking to retire in a place with better "quality of life" and amenities—especially a warmer climate, year-round sunshine, and wilderness (Duncombe et al. 2003; Frey 2003). Population and population density increased in all sites, except around Manhattan (Table 1).

Government employment opportunities, especially with the military, played an important role in the local economy of four of the sites: Phoenix, Albuquerque, Las Cruces and Manhattan. The clear skies and open spaces near Phoenix, Albuquerque, and Las Cruces drew military aviation bases and industries to the western deserts during World War II. These sites boomed in response to the influx of healthy defense contracts, which seeded high technology firms in Phoenix (Konig 1982), nuclear in Albuquerque (Simmons 1982), and weapons in Las Cruces (Welsh 1995). Establishment of large military bases created thousands of jobs, especially in Phoenix and Albuquerque with bases just outside the city. Phoenix's meteoric post-WWII growth (Luckingham 1982, 1989) and Albuquerque's economy (Nash 1994) are both linked closely to government contracts and jobs. In contrast Fort Riley, outside of Manhattan, began as a frontier outpost established to protect settlers traveling on the Oregon-California and Santa Fe Trails. After World War II, the 1st Infantry Division, nicknamed the "Big Red One," moved to Fort Riley and remained there until 1996 (Griekspoor 1996). When the unit was relocated to Germany, Manhattan experienced a significant drop in population. The 1st infantry returned from Germany in 2006 and will likely boost the population for the 2010 census (Stairrett 2006). Fort Riley served as an important outpost in settlement of the west, but never in the technological frontier of space, nuclear, and aviation. The fort has been an important contributor to the local economy, but never spurred growth in the same way as military investment in Phoenix, Albuquerque, and Las Cruces.

Booming job markets and aggressive economic growth in these southwestern cities also changed the regional migration pattern in the US (Johnson et al. 2005; Mueser and Graves 1995). Metropolitan Phoenix experienced exponential population growth between 1992 and 2000, mainly from an influx of new migrants attracted by booming economic opportunities in the valley (Gober and Burns 2002). Albuquerque grew rapidly, although population within city boundaries slowed and shifted to unincorporated Valencia County, partially due to the city's annexation policy (discussed below). Las Cruces grew by 25% due primarily to the influx of new migrants (Table 1); home builders argue that the migrants, mostly retiree populations, sought refuge away from crowded cities like Phoenix and Las Vegas (Romo 1997). At these desert sites, development of high-value recreation amenities like golf courses attract residents, especially retirees, while employment opportunities attract younger migrants (Table 3).

Much of the residential development in Fort Collins and Manhattan has occurred on the fringes on the small and medium sized cities scattered across the region. Both sites witnessed increased exurban development, although Manhattan's population decreased during the study period while Fort Collins' grew by 34%-the substantial increase in developed low intensity land area can be seen in Fig. 2b. In both cases, exurban development is driven by a desire for low-density housing, a piece of the "West", and opportunities to own hobby farms or ranchettes (Travis 2007).

Transportation

Communities in the Southwest have long recognized the importance of transportation networks; boosters enticed railroads with land grants and funds to cement their town's future as a commercial center. In the past, commercial centers grew near railroad depots, while today new strip malls, industrial complexes, and residential areas sprout near freeways.

Manhattan received the first railroad in 1866 (Miner 2002), and the railroad reached Fort Collins eleven years later in 1877 (Abbott et al. 1994). The railroad tied small towns in Kansas and Colorado together increasing the ability of farmers to export products to both eastern and western markets, yet neither Manhattan nor Fort Collins emerged from the railroad age as a dominant commercial town. The railroad did, however, contribute to the disaggregated polycentric form by stringing small towns along the historic rail lines.

Between 1880 and 1887 railroads reached the three desert cities (Luckingham 1982, 1989; Myrick 1990). In Las Cruces the railroad replaced much of the traffic along the Santa Fe Trail enabling cattle to be picked up in Texas and shipped to urban markets on rails instead of drives to northern rail lines (Luckingham 1982, 1989). Las Cruces was a city on the line, but was not a hub for the railroad, so the impact on commercial growth and land use was limited. Similar to Manhattan and Fort Collins development in Las Cruces has followed the railroad, which in turn traced the river and old freight roads. In Albuquerque, with the growth of the railroad, trade along east-to-west routes increased while the historically important trade along the freight roads with Mexico and towns to the south decreased in importance, although the volume increased with the extension of the railroad to El Paso (Luckingham 1982, 1989). Today this southern railroad route is being revived with a new commuter rail system connecting towns along the Rio Grande to Albuquerque. Although the impacts of this change are not detected in our study period, it will surely continue the trajectory of exurban development. Phoenix was the last of our cities to welcome a railroad in 1887. City boosters quickly pursued completion of a second railroad connecting to the northern transcontinental Atchison, Topeka &Santa Fe, which reduced fares and increased access to the city (Luckingham 1982, 1989). Like Albuquerque, access to multiple railroads fueled the growth of the agricultural sector and commercial center (Luckingham 1982, 1989).

New roads in the form of freeways fueled development in the 20th century. Freeways in Manhattan, Las Cruces, and Fort Collins link the cities to the interstate system, although only in the past few decades have the interstates fueled growth along the corridors. Las Cruces connects to Albuquerque via I-25 and to El Paso, Phoenix, and Los Angeles on I-10. I-10 connects to I-25 from the west and merges in a mostly southern direction toward El Paso, reinforcing the north-south urban form along the river. Many of the state highways connecting the communities in Kansas were constructed along higher terraces or more elevated portions of the Kansas River valley, parallel to the railroad, while construction of I-70 south of Manhattan in the 1960s (Kansas Department of Transportation 2009) shifted commerce and interstate travel south of the city. In the Fort Collins region, many cities (Fort Collins, Longmont and Loveland) fall along I-25 and the parallel Route 287 connects the communities. Completion of the interstate has led to intensified development in the exurban areas between these communities. In the three cases, the interstate highways contribute to the observed riparian pattern (Las Cruces) and polycentric pattern (Manhattan and Fort Collins), as well as the decreased grassland, rangeland, and farmland and increased fragmentation of rural lands during the study period.

Like the railroad, Phoenix did not construct a major transcontinental freeway until relatively late when Interstate-10 was completed in 1990s. Automobile dependence combined with a lack of freeways led to traffic congestion and fueled expansion of the state highway system in the 1990s, looping around the city and pushing development outward (Gober 2006), which can be seen in the increased edge density between 70 to 120 km with the peaks moving outside the city center during the study period (Fig. 4). Expansion of freeways began earlier in Albuquerque; Route 66 ran through downtown in the 1930s (Price 2003), but completion of Interstates 25 and 40 in the 1960s pushed development, service stations, and commerce out to the West Mesa away from the city center (Price 2003). Because of Indian communities and topography, discussed in the following sections, the extent of Albuquerque's eastern and western expansion has been somewhat limited compared to Phoenix.

Topography

The topography in each study area strongly influences the dynamics of how developed areas expand within the region, particularly differences between the uplands and lowlands. Mountains are important in Phoenix, Fort Collins, Albuquerque, and Las Cruces. The basin and range topography with isolated mountains in Phoenix has created opportunities for leap-frogging of residential development beyond the mountains (many of which are held by public entities). In the Fort Collins region, the slope and foothills of the Rockies' draw tourists and new exurban residents. As land prices increased during the 1990s western boom, exurbanites increasingly encroached on former rangeland and farmland (Travis 2007). In Phoenix, the northern part of the valley generally is at higher elevations with cooler micro-climates, and has grown rapidly in the past few decades (Gober 2006). This area is in contrast to the floodplains, such as South Phoenix, which has been "a stigmatized zone of racial exclusion and economic marginality" (Bolin et al. 2005). For well over a hundred years, the area south of the Salt River, which historically has been subject to large flood events, has been the domain of poor and immigrant communities while the northern part of Phoenix was reserved for Anglos. The Rio Grande, the bosque along it, and the numerous arroyos also hinder some forms of expansion in Las Cruces and Albuquerque. In addition to the river, in both New Mexican cities, mountains constrain development on their peaks, but draw rural residential development to the foothills. In Kansas, exurbanites are also drawn to lots perched on hilltops, although access to groundwater is restricted in the Flint Hills ecoregion, which has limited development; the limited development in this area away from the Kansas River can be seen in Fig. 4. Thus, similar to Albuquerque and Las Cruces much of the residential development in Manhattan is located in portions of the landscape located between the river floodplain and uplands. Slopes leading to the rocky uplands offer areas without flooding risks that is highly suitable for development.

Institutional factors

Policymakers and property ownership determines or influences whether land may be developed. In each of the study sites, public land, military bases, Bureau of Land Management (BLM) lands, state trust land, and Native American lands influence urban form. This is especially true in Las Cruces where public land, especially BLM and military lands, surround the city (Nash 1994). Public land sales and land holding provide constraints and opportunities for development at Las Cruces, fueling exurban expansion and increased fragmentation as well as historically constraining residential development to the river valley (Fig. 4). In Phoenix, the Tonto National Forest, four military bases, large city mountain parks, and state trust land surround the city. Growth on Forest Service or city park land is unlikely, but conversion of state trust land is relatively common (Gammage 1999). Similar to Las Cruces, decisions of a land holding public agency, the State Land Department, affect the pattern of future urban growth in Phoenix and drive much of the exurban expansion during the study period, especially into the north and west valley.

In Albuquerque, Fort Collins, and Manhattan, federal landholding agencies have very different missions from those in Phoenix and Las Cruces, resulting in fewer land sales, such that public land primarily functions as a growth constraint or obstacle. In Albuquerque, the Kirtland Air Force Base, Sandia National Labs, and University of New Mexico hold extensive tracts of land, but most of this land will not likely be sold (Nash 1994). At the Fort Collins site, federal ownership includes the Arapahoe-Roosevelt National Forest in the foothills and mountains, Rocky Mountain National Park, and Pawnee National Grasslands. In Manhattan, private lands dominate, with the exception of Fort Riley and lands utilized for agricultural and ecological research owned by Kansas State University and The Nature Conservancy.

Complex property rules, trust doctrines, and community or council decisions impact development in Indian communities throughout the west and play an important role at two of our sites: Albuquerque and Phoenix. Some of the lands belonging to Native American communities are leased to outsiders for commercial agriculture, or developed by the community for tourism, but most land remains agricultural with very low-density housing. Because of these policies, a bird's eye view over the cities show striking differences in land-use between the communities and neighboring cities. In Phoenix, urbanization "leap-frogged" from the suburbs of Mesa to Scottsdale, Fountain Hills, and Paradise Valley, leaving rural landscapes on Indian community land in between (Gober 2006). Similarly, the city of Albuquerque is surrounded by tribal lands, with Laguna Pueblo lands to the west, Sandia Pueblo land to the northeast, and Isleta Pueblo land to the south (Simmons 1982) again fueling leapfrogging.

Aside from public ownership, development depends on the suitability of potential sites, the desire of landowners to sell or retain their lands, and local land use policy: zoning, planning, economic development, and annexation. In Phoenix and Las Cruces, large public land sales often result in extensive developments on formerly state or federal lands while at Fort Collins and Manhattan land sales typically occur in the private market and are often smaller acreages than in the southwestern deserts, a process similar to that found throughout the Midwestern and Eastern US (Lang and LeFurgy 2007).

In Manhattan, partly in response to losses incurred with the military base relocation in the 1990s, the city has focused on diversification strategies and promotion of Kansas State University as an incubator, especially in the area of biotechnology. Similarly, Albuquerque has suffered from an overreliance on government money throughout the 20th century. The city was known as "Little Washington" because of the dominance of federal agencies in the local economy (Nash 1994). Beginning in the 1980s, Mayor Rusk and later administrations have attempted to diversify the local economy. Cities in the Fort Collins, Phoenix, and Las Cruces regions also pursued diversification strategies, but the rapid growth in the housing sector and service economies dominated these regions (Travis 2007). In the aftermath of the housing bust in 2007, these and other western cities are now reeling from an overdependence on housing construction.

With regard to residential development, Albuquerque's anti-growth debate has primarily concerned annexation policy resulting in slowed annexation post-1960s (Logan 1994). Similar to Albuquerque, Phoenix expanded rapidly due to annexation (Luckingham 1982, 1989), although unlike Albuquerque large annexations continue. "Annexation wars" between neighboring jurisdictions, such as the battle for Ahwatukee by Tempe, Chandler, and Phoenix, were attempts to increase the property tax base and incorporate middle-class and wealthy regions. In the case of Ahwatukee, Phoenix won with an emergency midnight city council meeting (Heim 2001). Similar annexation conflicts have erupted between Gilbert, Mesa, and Chandler in the southeast valley, illustrated by the debacle surrounding annexation of Williams Air Force Base (Lang and LeFurgy 2007). Much of the conflict surrounding growth and annexation of undeveloped land in the Phoenix valley is associated with the growth imperative of the cities and emergence in the 1990s of numerous "boomburbs," cities with double digit growth, over 100,000 in population, and an increasingly voracious appetite for city expansion (Lang and LeFurgy 2007).

In the 1990s in Colorado, Longmont and Greely emerged as "baby boomburbs" with double digit growth and populations above 50,000, prompting many debates about growth. This concern is not new to the region; Fort Collins' rapid residential growth along the Front Range in the 1970s led to the election of "no-growth" councilmen, something quite rare in American politics generally and western local politics in particular (Abbott et al. 1994). Loveland wrestled with growth adopting development impact fees in the 1980s to deal with the costs of residential expansion (Singell and Lillydahl 1990). Even though the Fort Collins' communities attempted to deal with growth issues, rapid exurban development persisted throughout the past few decades with continuous population growth pressures (Travis 2007); this exurban expansion can be seen in Fig. 2b. Las Cruces experienced significant sprawl during the 1990s (Fulton et al. 2001), but local attitudes about growth and sprawl has been largely skeptical (Van Splawn 2001) until the 2007 mayoral race when it became a contentious topic of debate (Ramirez 2007). Finally, because of Manhattan's mostly stagnant economy and population declines, the city has largely allowed low density peri-urban and exurban residential development; the significant increases over the study period are highlighted in Fig. 2b. Local policy responses to growth have been mixed across our sample partially reflecting communities' experiences with growth. Institutions in combination with water, population dynamics, transportation, and topography shape the growth opportunities, urbanization and exurbanization rates, and fragmentation patterns.

Discussion

The review of drivers demonstrates that *water* is a key variable in understanding land change in the US Southwest. At all five sites, damming major rivers for storage or prevention of flooding, coupled with prior appropriation laws, strongly affect land use decision-making.[4] Water provision has dominated historic settlement patterns, although the mechanisms vary. In Phoenix, the extensive canal network opened up much of the valley to agricultural and urban development-groundwater pumping, particularly prior to 1994, and diversions from the Colorado River through the Central Arizona Project further opened up the valley contributing to the monocentric fragmentation pattern. At Las Cruces and Albuquerque historic settlement patterns along the Rio Grande persist, creating a riparian fragmentation pattern, as agricultural lands are developed, while reservoir construction and water provision has maintained a polycentric pattern in Fort Collins and Manhattan.

All five sites are affected by agricultural to urban conversion. With increased urban water demand and the institutional backdrop of prior appropriation, cities and developers frequently purchase agricultural lands for the associated senior water rights in Phoenix, Las Cruces, Albuquerque, and Fort Collins. Around Las Cruces and Fort Collins, cities strategically purchase or annex properties with water rights while in Phoenix, developers typically convert agricultural properties to residential or commercial to comply with Assured Water Supply Rules. Water provisioning contributes to the fragmentation patterns at all sites, but it is highly influential at Phoenix, Las Cruces, Albuquerque, and Fort Collins, and moderately influential at Manhattan.

Population dynamics and lifestyle changes fueled much of the historical land use patterns and trends during our study period. Federal aid (e.g., for water control and regulation, highways, military bases), low state and local income tax, growing labor and housing markets, amenity-driven migration, and an extraordinary pro-growth booster spirit fueled regional migration (Abbott 1981; Glaeser and Tobio 2008; Travis 2007). The legacies of WWII-era high technology industries have continued to propel development in

[4] Kansas adopted this doctrine with the Water Appropriation Act in 1945, while all other states have applied the first in time rule since the 1800s.

Albuquerque, Las Cruces, and Phoenix, while Manhattan suffered population losses as a result of military base relocations.

Even Manhattan, with its population loss, experienced exurbanization with shifting consumer preferences for low density housing. The entire southwestern region has championed growth largely dependent on amenities, mild winters, sunshine, and proximity of "wilderness" (Barcus 2004). Regional migration and lifestyle choices drive exurban development, although the process is tempered by locally-specific characteristics. In the case of Manhattan, population decline coupled with exurbanization has generated what some have termed "rural sprawl" (Pendall 2001). In Fort Collins, new low density housing has proliferated along the Front Range, a formidable barrier to expansion but also a very attractive amenity for home buyers. At Albuquerque and Las Cruces preference for low-density, semi-rural environments increased low density residential development, fragmenting agricultural areas, while in Phoenix agricultural conversion frequently connected disaggregated urban parcels allowing infill of existing urban areas.

Historic transportation location decisions also contributed to the observed patterns at all sites. Recent construction of freeways has shifted development into the exurban fringes. Towns in the Manhattan and Fort Collins regions grew along paths of railroads and freeways. Albuquerque and Phoenix grew into major metropolitan areas because of railroad connections. Because of Phoenix's freeway loop expansion during the 1990s development has moved outward in a monocentric pattern. Polycentric, riparian, and monocentric patterns were reinforced by the location of transportation corridors.

Transportation may create opportunities for development, while in some places topographic barriers hinder urban growth. Topographic variation also influences microclimates and creates aesthetically pleasing and valuable viewsheds driving exurban development to the foothills and mountains. Topography of the five sites is extremely varied, but rivers dominate the landscape and land use decision-making at all sites.

Transportation corridors spur development and topography may either limit or attract development, but institutions constrain or direct development. Public land holdings and sales are especially important in Las Cruces and Phoenix, similar to many western cities (Lang and LeFurgy 2007), while Indian communities have played an important role in the development of Phoenix and Albuquerque. Land use policy at the local level also affects fragmentation. Manhattan pursued a laissez-faire attitude about exurban development, perhaps due to its slow economic growth, while Fort Collins has attempted increases in impact fees and even "anti-growth" policies. Las Cruces experienced tremendous growth and sprawl during the study period that only recently led to local debate among politicians about urban growth. Phoenix and Albuquerque originally pursued annexation as a growth strategy, although Albuquerque abandoned its aggressive expansion in the 1960s while Phoenix continues today. Economic development diversification strategies were attempted by Manhattan and Albuquerque, although changes to the local economies have been rather limited. These community policies define and influence land use patterns, although the complex socio-ecological system and multiplicity of drivers limits the ability of a community to manage its growth rates and land use patterns.

We find evidence of three distinct fragmentation forms: riparian, polycentric, and monocentric, although some of the sites exhibit a more "ideal" form than others. The monocentric form of Phoenix is distinguished by expansion in all directions during the study period-the pattern observed is not a set of perfectly circular development rings. Because of institutions and topography growth leap-frogs or is constrained, but where unhindered by mountains and Indian communities the expansion in all directions has been tremendous. Phoenician urban has not always been monocentric. Prior work on has shown an early riparian form along the Salt River (see for example Jenerette and Wu 2001), but after War II this riparian form ballooned into a monocentric pattern. Las Cruces and Albuquerque still maintain riparian forms, particularly further along the transect away from the city centers, but the area closest to the city of Albuquerque has expanded in a somewhat monocentric pattern. Like Phoenix institutional constraints of the Indian communities impede expansion in some directions, yet the Albuquerque site still exhibits a riparian form when compared to Phoenix. Both Manhattan and Fort Collins exhibit polycentric forms, although the influence of the Kansas River can be observed from pattern analyses, so we argue that Fort Collins has a more distinctly polycentric form than Manhattan. In Manhattan, like Albuquerque and Las Cruces, transportation location decisions paralleled the river, which reinforced the riparian form. Unlike, Las Cruces and Albuquerque Manhattan exhibits more extensive development away from the river, due to the water provisioning services via access to groundwater, except in the upland Flint Hills, and higher precipitation. Phoenix represents the most monocentric pattern, Las Cruces the strongest riparian, and Fort Collins the most distinctly polycentric in our study.

While we explore each of the drivers separately, we recognize that drivers are interrelated and work through the socio-ecological system. In Las Cruces, the river defined a north-south development toward El Paso through the geophysical template and water provisioning ecosystem services, which was reinforced by the freight roads, railroads, and interstate highways human decisions. At Albuquerque, the pueblos and public land holdings, institutional factors in the human decision-making domain, help to maintain the riparian form even with the countervailing east-west pressure of Route 66 and I-40, complementary human decisions. In Manhattan, the railroad and freeways, locations based on human decisions, access to water, an ecosystem service, and topographic differences between the floodplains and Flint Hills maintain a disaggregated residential form with development concentrated on the land along the Kansas River Valley. Fort Collins' rapid rural residential expansion in a polycentric form has been due to changes in lifestyle drawing residents to the west, an external driver, access to water on former agricultural lands, a combination of water provisioning ecosystem services and institutional human decisions, conversion of private ranches and farmland scattered throughout the plains, human decisions, and transportation corridors linking Greeley, Loveland, and Fort Collins, another type of human decision. Phoenix's monocentric pattern has been driven by aggressive annexation policy of all valley cities, an institutions in the human decision-making domain, regional migration, an external driver, and expansion of the freeways, transportation location decision, agricultural land conversion, human decision and state trust land sales, institutions. Historically our five drivers shaped land use decision-making resulting in the patterns and trends we observe today through a complex and interconnected socio-ecological system.

Conclusions

Throughout the post-WWII period the west changed rapidly with an influx of new residents and ever increasing demand for low-density, exurban housing. Even in the case of Manhattan, KS, a community with limited economic growth and devastating short-term loss of a major military installment in the 1990s, rural lands have become increasingly fragmented. Yet, the patterns of fragmentation and rates of change are not uniform. In our study, we found three general fragmentation patterns: riparian, polycentric, and monocentric. Riparian growth trends occurred along the historically important Rio Grande Valley and were reinforced by transportation decisions and public land holdings. The polycentric patterns on the plains of Colorado and Kansas began with frontier towns connected by railroads and were later amplified by freeway construction and private agricultural land conversion. Finally, the monocentric pattern observed in Phoenix was due largely to the increased water available through diversion of the Salt, Gila, and Colorado rivers and the massive canal works throughout the valley. Public land sales, freeway development looping around the city, and conversion of agricultural land to residential because of Assured Water Supply Rules help to explain the monocentric patterns of growth in Phoenix. In addition to the three patterns, we observed two general trends in fragmentation: expansion of the urbanized area and decreased fragmentation within the previously developed area. The first trend was prominent at all sites, while the second was strongest in Phoenix. These two general trends and three fragmentation patterns illustrate the recent western experience with growth and urbanization.

Cross-site projects studying land use patterns are challenging because of the legacies of land use decision-making and the particularities of each community and landscape, yet it is imperative to pursue comparative work to better understand general trends. Using a national land cover database, expert local opinion, and existing literature, we analyzed trends in land fragmentation and linked these results to relevant historical, contextual information. We identified five relevant drivers – water provisioning, population dynamics, transportation, topography, and institutions – that shape land use decision-making and fragmentation in the southwest. We developed an approach for integration of qualitative and historic analyses with land fragmentation metric and pattern analyses within a socio-ecological systems framework. The approach allows us to uncover the processes for observed fragmentation patterns driven by the integrated components of the socio-ecological system: the geophysical template, ecosystem services, human behavior, disturbance presses and pulses, and external factors. The socio-ecological framework and use of a common land use/cover classification system enabled cross-site comparison within a regional context. We contribute to a new cross-site approach to the urbanization and urban ecosystems literatures, which we hope will lead to more comparative work and spark new hypotheses about socio-ecological urbanization processes. Our work highlights the importance of understanding land use decision-making drivers in concert and throughout time, as historic decisions leave legacies on landscapes that continue to affect land form and function, a process often forgotten in a region and era of blinding change.

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Appendix

Table 4 NLCD Recoding Scheme

NLCD 1992 land cover classes	1992 recode to 7 classes	NLCD 2001 land cover classes	2001 recode to 7 classes
11 - Open water	7 – Water	11 - Open water	7 - Water
12 - Perennial Ice/Snow	6 – Remnants/desert/ undev.	12 - Perennial Ice/Snow	6 – Remnants/desert/ undev.

Table 4 (continued)

NLCD 1992 land cover classes	1992 recode to 7 classes	NLCD 2001 land cover classes	2001 recode to 7 classes
21 - Low Intensity Residential	2 – Developed – rural	21 - Developed, Open Space	2 – Developed – rural
22 - High Intensity Residential	1 – Developed – urban	22 - Developed, Low Intensity	2 – Developed – rural
23 - Commercial/Industrial/ Transportation	1 – Developed – urban	23 - Developed, Medium Intensity	1 – Developed – urban
		24 - Developed, High Intensity	1 – Developed – urban
31 - Bare Rock/Sand/Clay	6 – Undeveloped/desert	31 - Barren Land	6 – Undeveloped/desert
32 - Quarries/Strip Mines/ Gravel Pits	6 – Undeveloped/desert	32 - Unconsolidated Shore	6 – Undeveloped/desert
33 - Transitional	6 – Undeveloped/desert		
41 - Deciduous Forest	5 – Forest	41 - Deciduous Forest	5 – Forest
42 - Evergreen Forest	5 – Forest	42 - Evergreen Forest	5 – Forest
43 - Mixed Forest	5 – Forest	43 - Mixed Forest	5 – Forest
51 – Shrubland	4 – Grassland/shrubland	51 - Dwarf Scrub	4 – Grassland/shrubland
(in case of JRN, it is 6 – Undeveloped/desert)		52 - Scrub/Shrub	6 – Undeveloped/desert
61 - Orchards/Vineyards/Other	3 – Cropland		
71 - Grassland/Herbaceous	4 – Grassland/shrubland	71 - Grassland/Herbaceous	4 – Grassland/shrubland
		72 - Sedge Herbaceous	4 – Grassland/shrubland
		73 - Lichens	6 – Undeveloped/desert
		74 - Moss	6 – Undeveloped/desert
81 - Pasture/Hay	4 – Grassland/shrubland	81 - Pasture/Hay	4 – Grassland/shrubland
82 - Row Crops	3 – Cropland	82 - Cultivated Crops	3 – Cropland
83 - Small Grains	3 – Cropland		
84 - Fallow	3 – Cropland		
85 - Urban/Recreational Grasses	1 – Developed – urban		
91 - Woody Wetlands	5 – Forest	90 - Woody Wetlands	5 – Forest
92 - Emergent Herbaceous Wetlands	4 – Grassland/shrubland	91 - Palustrine Forested Wetland	5 – Forest
		92 - Palustrine Scrub/Shrub	1 - Undeveloped
		93 - Estuarine Forested Wetlands	5 – Forest
		94 - Estuarine Scrub/Shrub	4 – Grassland/shrubland
		95 – Emergent Herbaceous Wetlands	4 – Grassland/shrubland

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