Southwest Transformation: Eras of Growth and Land Change in Las Cruces, New Mexico

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Abstract

The United States Southwest is the incubator of the country's fastest growing urban landscapes, but few studies have quantified urbanization in the region. Using geospatial and archival research techniques our objectives are to assess rates, patterns, and drivers of land change in Las Cruces, New Mexico between 1955 and 2007, thereby stimulating more dialogue on the transformation of Southwestern landscapes. Our results suggest that Las Cruces may be on a path toward urban immensity. During the last fifty years, the city's population has grown at an average annual rate of 4.5%. The landscape became transformed concomitantly: almost 30% of the study area was converted from farm- and rangeland to residential and urban development. The pattern of development changed over time. Between 1955 and 1980, farm- and rangeland were perforated and dissected to make room for housing and infrastructure developments, causing the landscape to become increasingly fragmented and heterogeneous. Between 1980 and 2007, fragmentation continued, but was replaced in some areas by the shrinking and attrition of left-over farm- and rangeland and by the coalescence and growth of residential and urban clusters. Major drivers of growth included natural gain; in-migration from Mexico and the United States due to Sun Belt climate, federal employment, and other factors; as well as the conversion of a large government land base to private development. Absent viable land conservation programs, the formerly little known community of Las Cruces may face the same growth trajectory as major Southwest urban centers, slowed only temporarily by the current recession.

Keywords: Land change, urbanization, landscape fragmentation, population growth, Southwest.

Introduction

The United States Southwest is the incubator of the country's fastest growing urban landscapes—relatively young socio-ecosystems of known origins but unknown fates. The region has long served as a destination for the

American dream of a fresh start in sunlit places. Ironically, Thomas Jefferson's humid zone ideal of an eternally expanding fee-simple empire remains most robustly in force and uncontradicted in the deserts of the Southwest (Ellis 1997; Goetzmann 1986). Issues of growth are discussed in a number of publications (e.g., Logan 1995). However, few studies have actually quantified urbanization in the Southwest in a spatially explicit manner, examined potential drivers of the process or discussed potential future land change (i.e., land-use and land-cover change) scenarios in the area. The body of literature on all of these individual topics is extensive.

Multi-temporal remote sensing studies have mapped urbanization using various datasets and techniques on all continents (e.g., Banzhaf, Kindler, and Grescho 2009 in Europe; Griffiths et al. 2010 in Asia; Mundia and Aniya 2005 in Africa; Ward, Phinn, and Murray 2000 in Australia; Torres-Vera, Prol-Ledesma, and Garcia-Lopez 2008 in North America; and Henriquez, Azocar, and Romero 2006 in South America). Drivers of urbanization have been examined using a diversity of integrative geospatial approaches (e.g., Aguayo et al. 2007; Cheng and Masser 2003; Hu and Lo 2007; Huang, Zhang, and Wu 2009; Luo, Xin, and Yu 2008). Land change scenarios for urban areas are being developed using increasingly sophisticated techniques (e.g., Guanm, Clarke, and Wang 2005; Mahiny and Gholamalifard 2007; Yang and Lo 2003; Yuan 2010; Zhang and Wang 2001). Land change science has, in fact, emerged as an interdisciplinary field in its own right (Rindfuss et al. 2004; Turner, Lambin, and Reenberg 2007).

In the United States, however, most research to date has focused on the transformation of large metropolitan areas in the East (e.g., Lo and Quattrochi 2003 in Atlanta, Georgia; Xian and Crane 2005 in Tampa, Florida; Masek, Lindsay, and Goward 2000 in Washington, District of Columbia). In the Southwest, research has largely been limited to Phoenix, Maricopa County, Arizona (Jenerette and Wu 2001; Keys, Wentz, and Redman 2007; Stefanov, Christensen, and Ramsey 2001; Mack, Marsh, and Hutchinson 1995), with few notable exceptions (e.g., Xian, Crane, and McMahon 2008 characterized urban development in Las Vegas, Nevada). This is not surprising considering that Phoenix is the most populous city (1,601,587 inhabitants in 2009; U.S. Census Bureau 2010e) and core of the most populous metro area in the Southwest (4,364,094 inhabitants in 2009; U.S. Census Bureau 2010h). Phoenix is also home of the Central Arizona Phoenix Long-Term Ecological Research (LTER) site, one of only two urban LTER sites in the United States, and thus a definitive focal point for urban research. Beyond Phoenix, however, little is actually known about the spatio-temporal dynamics of urbanization and associated land change in the Southwest.

We consider this troublesome: if currently small cities in the Southwest (e.g., Las Cruces, Doña Ana County, New Mexico) followed Phoenix in its footsteps in terms of rural-urban transformation, the implications would be substantial for coupled human-environment systems in general (e.g., Alig, Kline, and Lichtenstein 2004; Larson et al. 2005; Radeloff et al. 2005) and water—the most limiting resource to life in the Southwest—in particular (e.g., Bolin, Seetharam, and Pompeii 2010; Gober et al. 2010; Morehouse, Carter, and Tschakert 2002). Phoenix metamorphosed from a small city of about 100,000 people (late 1940s) into a metropolis of more than 1,000,000 people (early 1990s) in less than half a century. The city's average annual growth rate in the last fifty years has been 5.4% (U.S. Census Bureau 1992, 2010e). The City of Las Cruces shifted from quiescence to sprint in a similar time frame, growing exponentially but at an average annual rate of about 4.5% from less than 30,000 inhabitants in 1960 to about 100,000 today. The Las Cruces Metropolitan Statistical Area (i.e., Doña Ana County) grew even faster, at an average annual growth rate of 5% from about 60,000 people in 1960 to 206,000 today (U.S. Census Bureau 1992, 1995, 2010b, 2010c, 2010h). Las Cruces started out with a much smaller population in the mid-Twentieth century than Phoenix, but the cities' average annual growth rates have been similar. Is Las Cruces just lagging behind Phoenix, but following a similar growth trajectory?

We argue it is crucial to begin monitoring the developments of smaller Southwest cities like Las Cruces now that future alternatives to present-day Phoenix can still be envisioned and realized. Moreover, in order to understand such developments, we believe it is important to see them in context by considering longer-term human and environmental changes (e.g., the introduction of the swamp cooler encouraged in-migration to the Southwest in the mid-1940s). Some of these developments can be quantified from historical remotely sensed data; however, others must be inferred qualitatively from oral or written sources. The major goal of this study is to begin addressing these issues and stimulate more dialogue on land change across the Southwest by telling the story of how the Southwestern community of Las Cruces became transformed by residential and urban development over the last fifty years.

More specifically, using remote sensing, geographic information systems, landscape ecology, as well as literature and archival research techniques, the objectives of this paper are to: (1) assess rates of land change; (2) quantify patterns of land change; and (3) discuss the role of anthropogenic drivers of land change in Las Cruces, New Mexico New Mexico. Objectives 1 and 2 are quantitative in nature and addressed through the analysis and interpretation of aerial photography from 1955, 1980, and 2007 and through the measurement and evaluation of spatial metrics for all years of photography, respectively. Objective 3, though supported through information acquired by meeting Objectives 1 and 2, is primarily qualitative in nature and addressed through an evaluation of demographic growth, federal and state land disposals, land use planning, land development, and conservation, water, and farming issues.

Historical Context: "The Quiet Centuries", 1598-1955

In order to properly evaluate land changes in southern New Mexico over the past few decades, it is important to see them in a larger temporal context.

Before we continue to some of the more quantitative aspects of the paper, we therefore provide here a brief account of the area's post-Columbian settlement history.

In 1598, Conquistador Don Juan de Oñate passed through what is now Doña Ana County on his way north to the Pueblo nations and cool forests of the Sangre de Cristo Mountains. The Spaniards saw no future here and called the area north of Las Cruces La Jornada del Muerto—the Journey of Death (Horgan 1991). The region was a frontera—a frontier—a vague border, a bridge, a corridor to be transited with deliberate speed. The Mesilla Valley was dominated by braided channels of the wild Rio Grande and a thick cottonwood bosque (riparian forest) teeming with biodiversity and malaria. The East Mesa grasslands provided forage for Spanish horses on El Camino Real but no water to slake their thirst (Horgan 1991). It was not until the 1840s that the Mexican land grant village of Mesilla became the first real community in the region, adopting a grid pattern drawn from the Spanish Laws of the Indies (Wright and Campbell 2008). Irrigation ditches were hand-dug from the Rio Grande. Suertes (parcels) were distributed by village priests (Taylor 2004). Following the Treaty of Guadalupe Hidalgo in 1848 and Gadsden Purchase in 1853, the region became part of the United States. At this time, Mesilla had 2,500 people and Las Cruces was home to just 350 (Taylor 2004, 39).

By 1910, Mesilla's population remained unchanged, the City of Las Cruces had just 4,000 residents, and Doña Ana County totaled 12,893 inhabitants (Figure 1; U.S. Census Bureau 1995; Williams 1986). New Mexico was not yet a state, and if the landscape existed in the national consciousness it was imagined as hot, dusty, and too obviously Mexican. Anglo tourists stayed far to the north in the art colony of Santa Fe. The region became peripheral to major concerns and eased into a state of contented abandonment. When statehood was achieved in 1912, private land was concentrated in the Mesilla Valley along the Rio Grande with most of the county—the desert—in federal and state hands (Doña Ana County 2010). By 1918, ditch water was supplied to fields through a system of canals and ditches built by the Elephant Butte Irrigation District following the completion of Elephant Butte Dam and Reservoir, a project of the newly-formed Bureau of Land Management (BLM) (EBID 1998). Cotton, chilies, alfalfa, onions, lettuce, and other vegetables dominated the valley. A few pecan orchards appeared in early 1930s (Herrera 2000).

The "East Mesa" adjacent to Las Cruces consists of desert bajada and piedmont slopes between the Organ Mountains and the Mesilla Valley. In early years, this expanse and millions of additional hectares of Chihuahuan Desert were administered by the Grazing Service and State of New Mexico. In 1912, the United States Department of Agriculture (USDA) created the 78,000-hectare (192,660-acre) Jornada Experimental Range as an outdoor laboratory for research on vegetation dynamics, livestock grazing, nutrient cycles, wildlife, and hydrology. In 1927, 22,000 hectares (53,340 acres) adjacent to it were designated the "College Ranch," later renamed the Chihuahuan Desert Range-

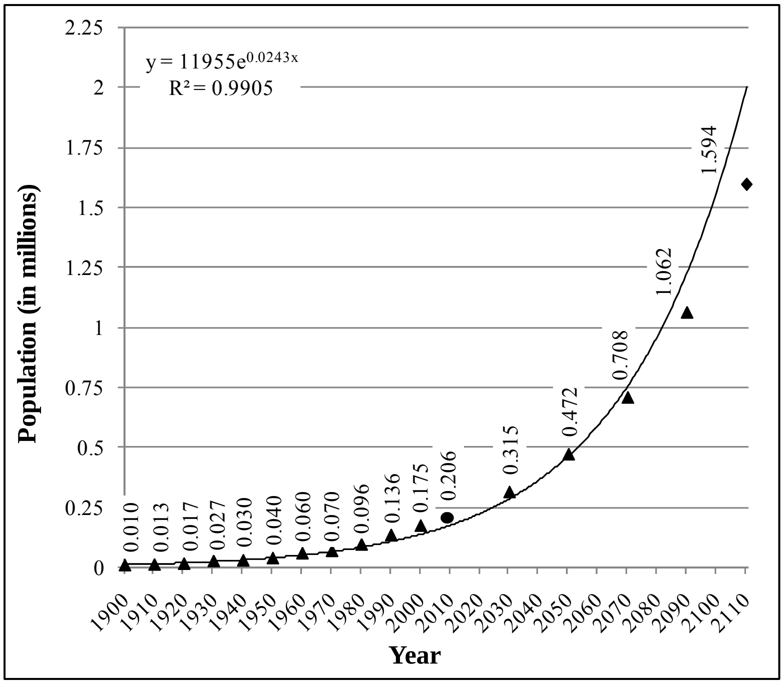


Figure 1. Doña Ana County (i.e., Las Cruces Metropolitan Statistical Area) population growth trends (U.S. Census Bureau 1995, 2010h) and projections. Triangles represent past estimates; the circle a current estimate; and diamonds projected data based on an average annual growth rate of 2.5%.

land Research Center (Havstad and Schlesinger 2006). These terrains and the entire East Mesa remained lightly settled after the homesteading period. Overstocking of cattle initiated a major transformation of the landscape, however, as black grama grasslands were degraded to creosotebush and mesquite shrublands (Gibbens et al. 2005; Grover and Musick 1990). In 1946, the BLM was created from the merger of the Grazing Service with the General Land Office and the East Mesa became largely a BLM realm. Land prices on the mesa were low—between \$50 and \$250 per hectare, if any could be bought (Simpson 2010). The BLM and State of New Mexico completed a few land disposals and trades to consolidate ownership and facilitate livestock grazing, but the idea of selling public desert lands seemed farfetched (Simpson 2010).

By 1950, Doña Ana County had grown to 39,557 people (Figure 1; U.S. Census Bureau 1995) and Las Cruces showed the first traces of rural residential growth. Modest natural demographic gain and scant immigration from Mexico generated minor, mostly local development pressure. However, the swamp cooler was invented in 1945 and by the fifties was widely used across the Southwest (Cooper 2002, 18). In the coming years, this technology would be a powerful driver of in-migration to the Sun Belt (Reisner 1993, 269). As demonstrated in this study, Las Cruces would be no exception.

Methods

Study Area

The study area encompasses 19,000 hectares (46,950 acres) of land along the current urban-rural fringe of Las Cruces, New Mexico (Figure 2; central coordinates ~ 32º24' N, 106º45' W) and is located just 80 kilometers (50 miles) north of the United States-Mexico border. The study area is bordered to the north by the Jornada Experimental Range and Chihuahuan Desert Rangeland Research Center, to the east by the Organ Mountains, and to the south by Highway 70. It extends just beyond the Rio Grande floodplain in the west. The climate in the area can be described as transitional between the midlatitude desert (BWk) and midlatitude steppe (BSk) climates (Köppen 1936; Hoare 2005). The average annual temperature is 15.7°C (60°F). July is the warmest month of the year with an average temperature of 26.5°C (80°F); January is the coolest month with an average temperature of 5.3°C (42°F). The average total annual amount of precipitation is around 228 millimeters (9 inches), but more than half of this falls during just three summer monsoon months (July, August, September). Variable rainfall and periodic droughts are the rule rather than the exception, however. With an average of 310 days of sunshine each year (NCDC-NOAA 2008), Las Cruces is a definitive member of the Sun Belt.

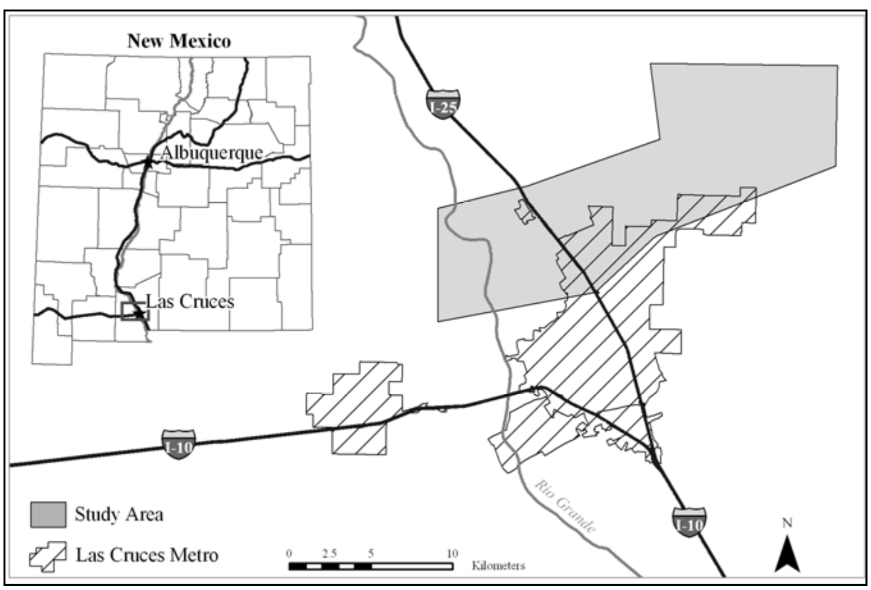


Figure 2. Location of the study area.

Other relevant study area characteristics (e.g., land cover and demographics) are discussed in the text below.

Data & Preprocessing

We employed aerial photography from three years to document rates and patterns of land change in the study area: 1955, 1980, and 2007. The 1955 black and white Farm Service Agency air photos with a scale of 1:10,000 were acquired from the Aerial Photography Field Office and scanned at 254 dpi to yield 1-meter spatial resolution raster imagery. The 1980 natural color photos with a scale of 1:31,680 were obtained from the BLM and scanned at 805 dpi to yield 1-meter spatial resolution imagery. The 2007 digital natural color orthophotos were acquired from Doña Ana County and resampled from a spatial resolution of 1 foot to one of 1 meter. Following data acquisition and scanning, the 1955 and 1980 slave photos were co-registered to the 2007 master photo and subsequently mosaicked to yield continuous imagery. Finally, all years of imagery were subset to cover the study area and converted to the same type of panchromatic imagery so that accuracy assessment results based on the most recent imagery could be assumed to apply to the earlier imagery as well.

Assessing Rates of Land Change (Objective 1)

We assessed rates of change for a roughly fifty-year time period by analyzing and interpreting the 1955, 1980, and 2007 aerial photography described above. Once the imagery was preprocessed, we digitized land cover parcels for each year on-screen at a scale of 1:5,000. We classified parcels using six applicable categories (Stream, Cropland and Pasture, Orchards, Mixed Rangeland, Residential, and Mixed Urban) identified at Level II in Anderson et al. (1976) and defined them using the photomorphic region approach according to their size, shape, tone, texture, and pattern (Barnsley and Barr 1997; Barr and Barnsley 1997; Peplies 1974). Elements of site (e.g., elevation, slope, aspect, transportation, utilities), situation (orientation of objects relative to one another), and association (i.e., spatial autocorrelation) were also taken into consideration during the digitizing process (Table 1, Figure 3). The resulting maps had minimum mapping units of 0.0774 hectares (0.19 acres), 0.0406 hectares (0.1 acres), and 0.0452 hectares (0.11 acres) in 1955, 1980, and 2007, respectively. We assessed changes between years by applying standard post-classification comparison change detection techniques to the land cover maps and evaluating the resulting transition matrices for three time periods: 1955-1980, 1980-2007, and 1955-2007.

In order to assess the accuracy of our land cover maps, we field-checked in 2008 a number of randomly selected sites within each of the six land cover strata and compared them to the corresponding sites on our 2007 land cover map. We allocated our sampling effort roughly in proportion to the area covered by each land cover type and checked a total of 217 sites, including 2 Stream, 15 Cropland and Pasture, 10 Orchard, 130 Mixed Rangeland, 50 Resi-

Table 1. Description of photomorphic regions.*Based on Anderson et al. (1970).

Level II (Level I)*	**Description**	**Photomorphic Region Characteristics**
Streams (Water)	Rio Grande.	Intermediate tone, curvilinear shape, crisp edges, roughly 200 m wide, smooth/homogeneous texture (A in Figure 3).
Cropland and Pasture (Agricultural land)	Cotton, chile, onions, corn, cabbage, lettuce, alfalfa.	Regions are characterized by relatively bright tones, smooth textures, and irregular shapes with crisp and straight edges. Individual regions typically have a smooth texture and parallel patterns with linear stripes indicative of ploughing (B in Figure 3).
Orchards (Agricultural land)	Pecan orchards	Regions are characterized by relatively dark tones, medium texture, and irregular shapes with crisp and straight edges. Individual regions are composed of closely spaced, geometrically arranged, circular, relatively large (larger than rangeland shrubs) objects (C in Figure 3).
Mixed Rangeland (Rangeland)	Herbacious (e.g., black grama) & woody rangeland species of Chihuahuan Desert (e.g. mesquite, creosote, tarbush).	Tones range from light (soil) to intermediate (grasses) to dark (shrubs) and are highly intermixed; dark, small (in comparison to pecan trees in orchards), irregularly sized objects (shrubs) occur on light background (soil) in unsystematic pattern; bright, curvilinear, narrow features (arroyos) often dissect landscape; coarse/heterogeneous texture overall (D in Figure 3).
Residential (Built-up land)	Low-density housing developments; larger house lots (> 0.4 ha.) served by septic tank drain-field systems.	Regions are characterized by intermediate to coarse textures and relatively random patterns. Individual regions are made up of typically rectangular features of bright tones (houses) interspersed with circular features of darker tones (shrubs and trees) and rectangular features of intermediate tones (lawns); linear to curvilinear, smooth-textured features of intermediate tones (roads) often dissect regions (E in Figure 3).
Mixed Urban (Built-up land)	Commercial & industrial structures mixed with high-density housing developments; smaller house lots (< 0.4 ha.) served by a sewer.	Regions are characterized by coarse textures and systematic patterns. Individual regions are made up of typically rectangular, closely spaced features characterized by bright to intermediate tones and smooth textures; linear to curvilinear, smooth features of intermediate tones (roads) often dissect regions; in comparison to residential areas, mixed urban areas often lack lawns, woody plants, and include instead larger rectangular features of bright to intermediate tones (commercial buildings and parking lots) (F in Figure 3).

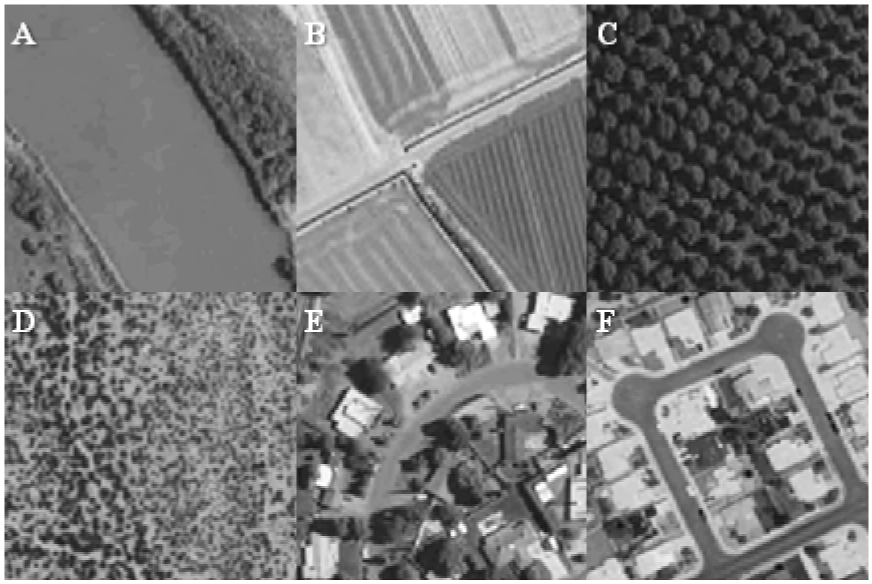


Figure 3. Visual appearance of six land cover types in the aerial photography. A – Stream, B – Cropland and Pasture, C – Orchards, D – Mixed Rangeland, E – Residential, F – Mixed Urban (see Table 1 for a description of each).

dential, and 10 Mixed Urban sites. The accuracy of our map was high, with 100 % overall accuracies for all categories except for Residential, which was occasionally confused with Mixed Urban and had an overall accuracy of 92 %. We could not directly assess the accuracy of the 1955 and 1980 maps. However, given our efforts to equalize the visual quality of all air photos (see above), we are confident that the accuracy of the earlier maps is approximately the same as that of the 2007 map.

Quantifying Patterns of Land Change (Objective 2)

We quantified spatial patterns for each year in the form of the most commonly used and most revealing class- and landscape-level landscape metrics (e.g., Herold, Clarke, and Couclelis 2005; Lausch and Herzog 2002; Schindler, Poirazidis, and Wrbka 2008) with FRAGSTATS® (McGarigal et al. 2010). At the landscape level, this included three patch size and density metrics (number of patches, mean patch size, patch density), two patch shape and edge metrics (edge density and landscape shape index), three contagion and dispersion metrics (contagion, interspersion juxtaposition index, landscape division index), and two diversity metrics (Simpson's diversity and evenness indices). At the class level, our analysis considered three patch size and density metrics (number of patches, mean patch size, patch density), three patch shape and edge metrics (edge density, mean edge length, and landscape shape index), and one isolation/proximity metric (mean Euclidean nearest neighbor distance). We recognize that the values of landscape metrics may change with scale and resolution of the input data (Lausch and Herzog 2002) and therefore calculated all of the above metrics at three different spatial resolutions: 3 meters, 10 meters, and 30 meters. While the values changed slightly at these resolutions, the overall trends for all metrics remained the same. Given that we were interested in overall trends rather than specific values of the landscape metrics and given also that our minimum mapping units were less than 0.0774 hectares (0.19 acres) in size, we felt that it would be sufficient to report here only the results obtained for the land cover maps with the finest spatial resolution.

Discussing Drivers of Land Change (Objective 3)

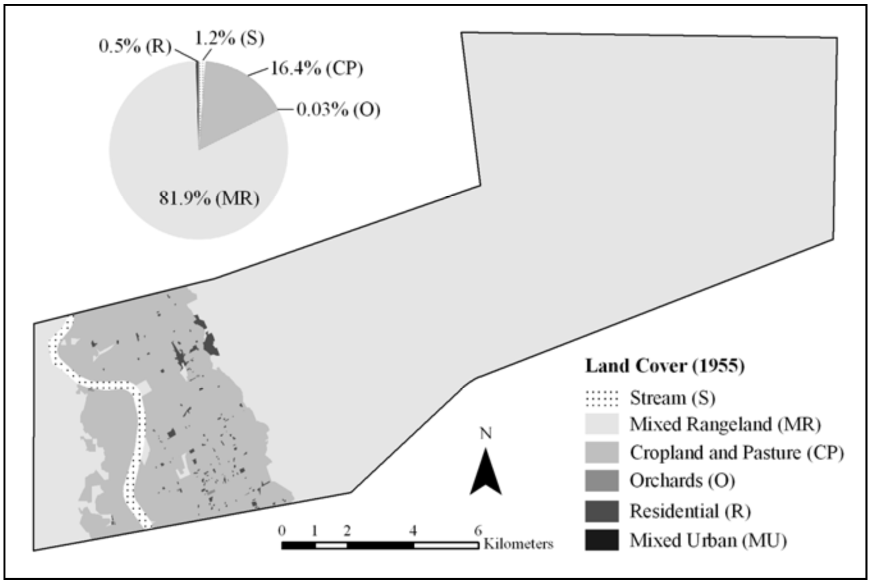
In order to provide context for the land cover data, i.e., to explain some of the observed quantitative land changes, we obtained qualitative information about the area's cultural, political, and economic history through the examination of archival materials, land use planning documents, and peer-reviewed papers. This part of our work is thus based on our qualitative analysis and interpretation and subject to alternative explanations. Nonetheless, we consider it important here, because it provides context to our data and may help stimulate dialogue about land changes across the Southwest. We also see it as a first step toward the identification of drivers in land change scenario models, which we are in the process of developing.

Results & Discussion

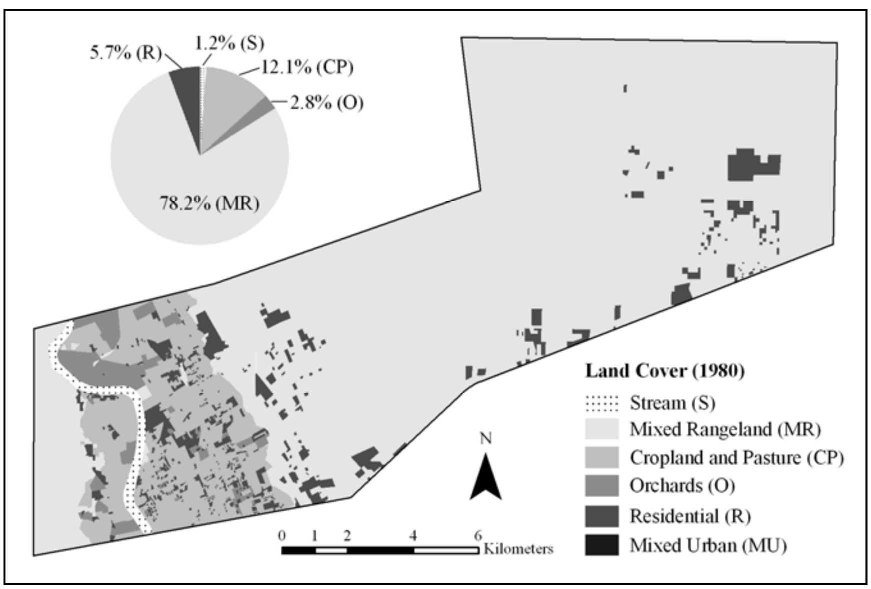
As discussed in the "Historical Context" section above, Las Cruces was a relatively quiet place for centuries. As shown below, this began to change tremendously in the middle of the last century.

Rates of Land Change (Objective 1)

The 1955 landscape was dominated (98%) by two cover types: Mixed Rangeland and Cropland / Pasture (Figure 4a and 5). Orchards were of minor importance, covering a mere 0.03% of the landscape. Residential areas were limited to a few homesteads in the irrigated valley and neighborhoods adjacent to the valley, making up about 0.5% of the study area. Mixed Urban was absent. This configuration had existed for decades but soon began to change. By 1980, the dominance of Mixed Rangeland and Cropland / Pasture weakened slightly to 90% of the study area (Figure 4b and 5). Residential areas now covered nearly 6% of the terrain, both in the valley but also on the East Mesa, in former Mixed Rangeland. The number of Orchards grew significantly, now characterizing almost 3% of the landscape. Cropland / Pasture declined from 16% to 12% due to increases in both Residential and Orchards. Mixed Urban development had not arrived. After 1980, the landscape became transformed drastically. By 2007, Mixed Rangeland had declined to 61% of the area (Figure 4c and 5), a 17% drop in comparison to 1980. The total amount of

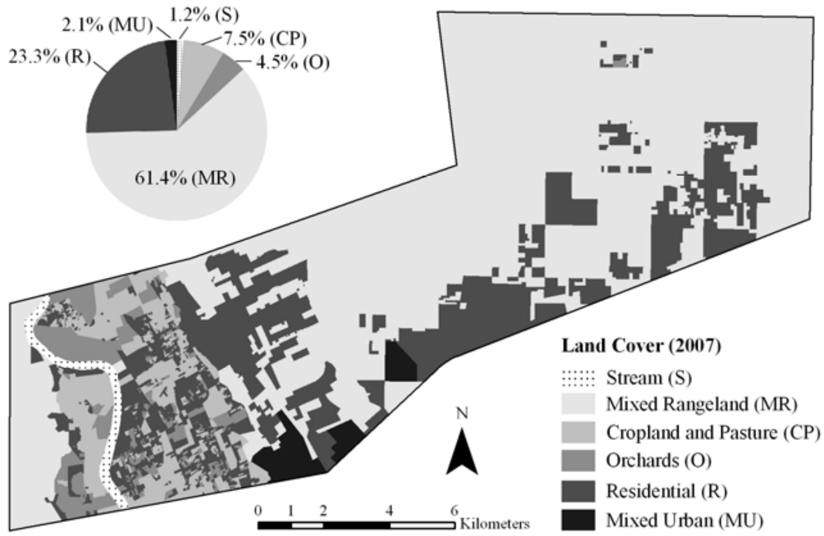


(a) Land cover in 1955.



(b) Land cover in 1980.

Figure 4. Land cover of study area through time.



(c) Land cover in 2007.

Figure 4. Cont.

irrigated agricultural land (Cropland / Pasture and Orchards) declined to a similar degree, from 15% in 1980 to 12% in 2007. During the same time, Residential lands experienced a stunning increase of almost 18% to cover 23% of the study area. Development existed in a highly fragmented pattern in both former farmlands and rangelands. Mixed Urban appeared and covered 2% of the terrain.

Overall, between 1955 and 2007, only about 70.4% of the study area remained unchanged (Figure 6). Some 20.3% of it was converted from Mixed Rangeland to Residential and Mixed Urban development (18.2% and 2.1%, respectively). Another 9% was converted almost equally from Cropland / Pasture to Residential and Orchards (4.7% and 4.3%, respectively). The latter conversion reflects the rising profitability of nuts over cotton, chilies, alfalfa, and onions. Mixed Urban development occurred on former Mixed Rangeland only. Both Mixed Rangeland and Cropland / Pasture lost ground to Residential development, however, mainly just east of the irrigated farmland areas and just along the city's northern periphery. The remaining 0.4% land changes in the study area included mainly conversions from Mixed Rangeland to Orchards and Cropland / Pasture.

When land cover groupings are analyzed, the essential story of landscape transformation becomes clear (Figure 5). Between 1955 and 2007, Mixed Rangeland declined 25%, with almost 4,000 hectares (9,617 acres) converted to development. Substantial encroachment on the Jornada Experimental Range and other ecologically significant areas has occurred. Irrigated agricultural

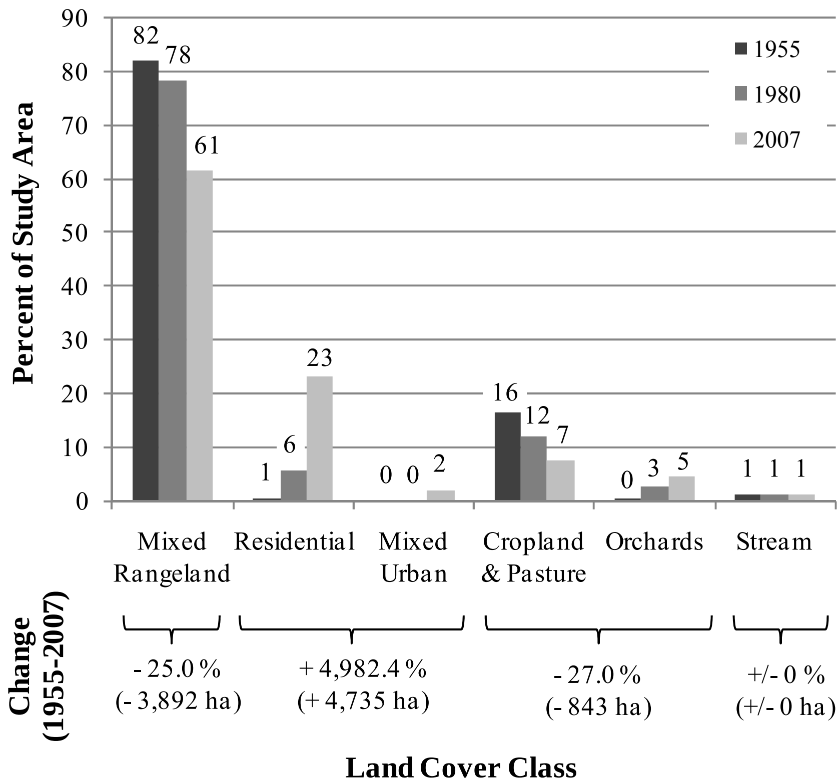


Figure 5. Land change in percent and hectares of the study area, 1955-2007.

land shrunk by 27% [843 hectares (2,083 acres)], with all of this land shifted to Residential and Mixed Urban development. Since 1955, development has risen from 0.5% of the study area to more than 25%. If the average pace of land cover conversion to Residential and Mixed Urban document here between 1955 and 2007 [91 ha (225 acres) per year] continues in the future, the entire study area will be developed by 2163, in 156 years. This estimate is very conservative, however, given the accelerated pace of development over the last fifty years (40 hectares per year between 1955 and 1980 and 139 hectares per year between 1980 and 2007) as well as demographic realities. At whatever pace growth occurs, it is doubtful that irrigated agriculture, even Pecan Orchards, will survive at any meaningful scale without implementing sensible, voluntary, financially compensating programs for conserving its land base (Anella and Wright 2008).

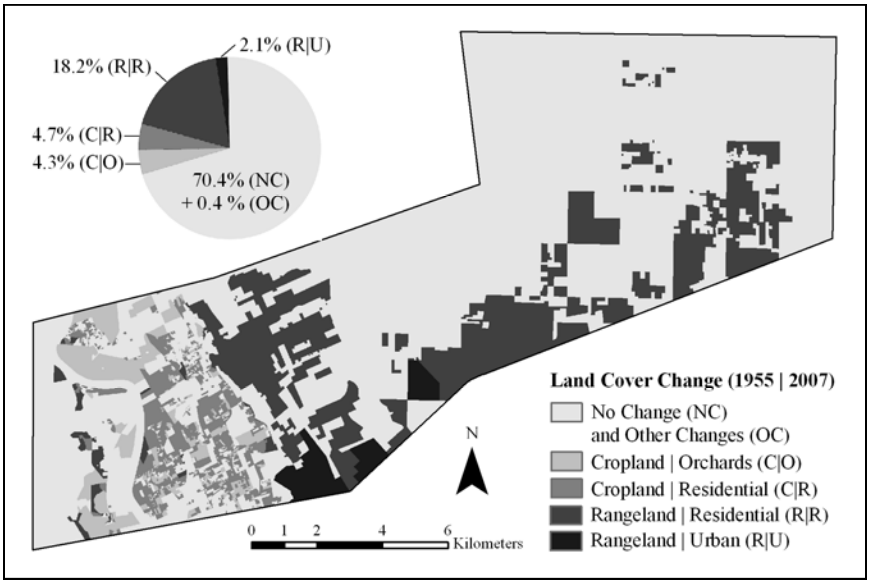


Figure 6. Major land cover transitions between 1955-2007. No change and other changes were combined in one class, because other changes were minor and not discernible on the map.

Patterns of Land Change (Objective 2)

Land changes in the study area have resulted in increasing fragmentation of the landscape, with important yet largely unquantified consequences for biodiversity, ecosystem functions, hydrologic flows, and much more (Forman 1995). Both Simpson's Diversity and Evenness Indices nearly doubled between 1955 and 2007 (from 0.3 to 0.56 and 0.34 to 0.62, respectively) (Table 2), reflecting both an increase in the number of patch types (i.e., addition of Mixed Urban) and an increasingly even proportional distribution of patch types: the dominant land cover classes, Mixed Rangeland and Cropland / Pasture, gave way to Orchards, Residential, and Mixed Urban land cover classes.

Edge density nearly quadrupled between 1955 and 2007, from about 6 to roughly 28 meters of edge per hectare of land, implying an increase in boundaries between habitat types and, given the replacement of more natural habitat (Rangeland) with human habitat (Residential and Mixed Urban), enhanced habitat loss and isolation. Both increases in landscape shape index from about 4 in 1955 to 11 in 2007 and decreases in contagion from about 83 to 68 between those years demonstrate increasing patch type disaggregation (Table 2). Patch density as well as mean patch size at the landscape level did not change in a consistent pattern, however. Patch density increased dramatically from only 0.8 to nearly 2.1 patches per 100 hectares between 1955 and 1980, result-

Table 2. Changes in key landscape-level landscape metrics, 1955-2007.

Landscape-Level Metric	Year 1955	1980	2007
Number of patches	147	406	378
Patch density (number of patches per 100 hectares)	0.77	2.14	1.99
Mean patch size (in hectares)	129.21	46.78	50.25
Edge density (in meters per hectare)	6.34	19.2	28.45
Landscape shape index	3.67	8.1	11.29
Contagion (in percent)	82.94	75.67	68.29
Interspersion juxtaposition index (in %)	58.75	70.1	60.2
Landscape division index	0.39	0.45	0.68
Simpson's diversity index	0.3	0.37	0.56
Simpson's evenness index	0.34	0.47	0.62

ing in a decrease in mean patch size from about 129 to 47 hectares. By 2007, patch density had dropped slightly to about 2 patches per 100 hectares, resulting in a minor increase in mean patch size to about 50 hectares. A similar trend can be observed in the interspersion juxtaposition index, which increased from about 59 in 1955 to 70 in 1980 and then dropped back down to only 60 in 2007, indicating that patch type intermixing increased during the first time period and then decreased during the second (Table 2). An examination of land cover class-level landscape metrics helps explain this pattern.

Cropland / Pasture and Mixed Rangeland were the big "losers" in the land transformation north of Las Cruces. Mean patch size of Cropland / Pasture decreased almost 104-fold from about 1,555 hectares in 1955 to 177 hectares in 1980 and only about 15 hectares in 2007 (Figure 7). The proportional decrease of Mixed Rangeland patches was not nearly as dramatic. Still, mean patch size of Mixed Rangeland declined by 324 hectares between 1955 and 2007, reaching a value of about 972 hectares in 2007. Residential and Mixed Urban land covers, in contrast, were the big "winners" in the land transformation. The mean patch size of Residential areas increased from a mere 0.8 hectares in 1955 and 3 hectares in 1980 to 33 hectares in 2007. Mixed Urban patches were nil in 1955 and 1980, but reached a considerable mean size of about 134 hectares by 2007. So, both Cropland / Pasture and Mixed Rangeland habitats were lost at the expense of Residential and Mixed Urban development and becoming increasingly fragmented through the insertion of human infrastructures.

The mean edge density of all land covers grew significantly over fifty years (Figure 8). It tripled for irrigated agriculture (Cropland / Pasture and Orchards) to almost 19 meters per hectare in 2007, quadrupled for Mixed Rangeland patches to about 12 meters per hectare in 2007, and increased more than 8 -fold to 24 meters per hectare in 2007 for Residential patches. The landscape is clearly becoming an increasingly complex patchwork of different land cover types.

The mean length of Cropland / Pasture patch edges declined 18-fold (1,751 meters in 2007) and that of Mixed Rangeland patch edges nearly doubled (22,525 meters in 2007) over the 52-year time period. This apparently opposite trend is largely a reflection of different spatial processes operating in the two land cover types. Mixed Rangeland is still experiencing fragmentation in its truest sense: some parcels are replaced by other land cover types, but the landscape as a whole is still being broken into pieces. Patches of Cropland / Pasture are still being fragmented to some degree as well. For the most part, however, remnants are simply shrinking and disappearing from the landscape through in-fill development. The mean length of Residential patch edges increased almost 8-fold between 1955 and 2007, reaching a value of 2,601 meters in 2007. Most of the increase occurred in the latter half of this time period, when smaller patches of Residential land began to coalesce and form larger patches with longer edges. Mixed Urban land, though not appearing in our sequence of air photos until 2007, started out with a mean patch edge twice the length (5,506 meters) of Residential patches in 2007. This is an indication that Mixed Urban development was much more planned: while one small plot after another was allocated amidst Cropland / Pasture and Orchards for Residential development, Mixed Urban development occurred quickly across large tracts of Mixed Rangeland.

Observed changes in patch density (Figure 9) reinforce some of the key ideas outlined above. Large tracts of agricultural land have become increasingly fragmented into more but much smaller tracts of land, as indicated by increases in the density of both Cropland / Pasture and Orchard patches: the average density of irrigated agricultural land was only 0.2 patches per 1,000 hectares in 1955 and increased to about 1.6 patches per 1,000 hectares in 1980 and eventually to almost 6 patches per 1,000 hectares in 2007. While the density of patches increased for irrigated agriculture, that of Residential patches first increased tremendously, from about 7 to almost 18 patches per 1,000 hectares between 1955 and 1980, respectively, only to drop back down to 1955 levels between 1980 and 2007. This supports the impression that the many small Residential patches introduced between 1955 and 1980 coalesced to form larger ones between 1980 and 2007. The mean density of urban patches was very small in 2007 (0.2 patches per 1,000 hectares), reinforcing the notion that urban development occurred quickly across large, continuous tracts of land. Changes in landscape shape index mirror the changes in patch density. By 2007, Residential patches were the most disaggregated with a landscape shape

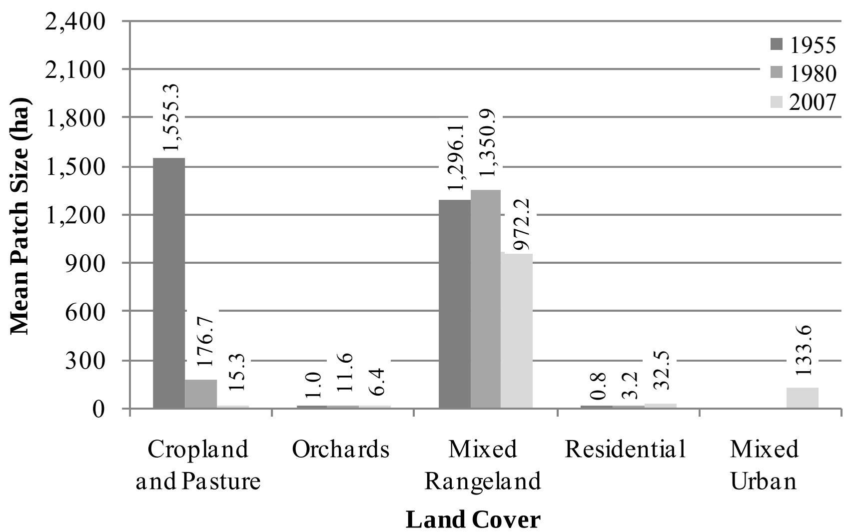


Figure 7. Changes in mean patch size, 1955-2007. Numbers of patches are given in parentheses.

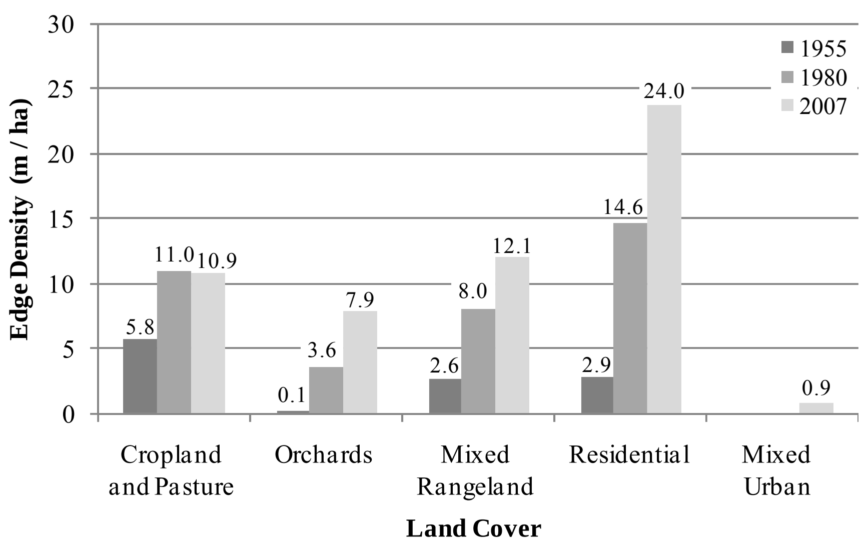


Figure 8. Changes in mean edge density, 1955-2007.

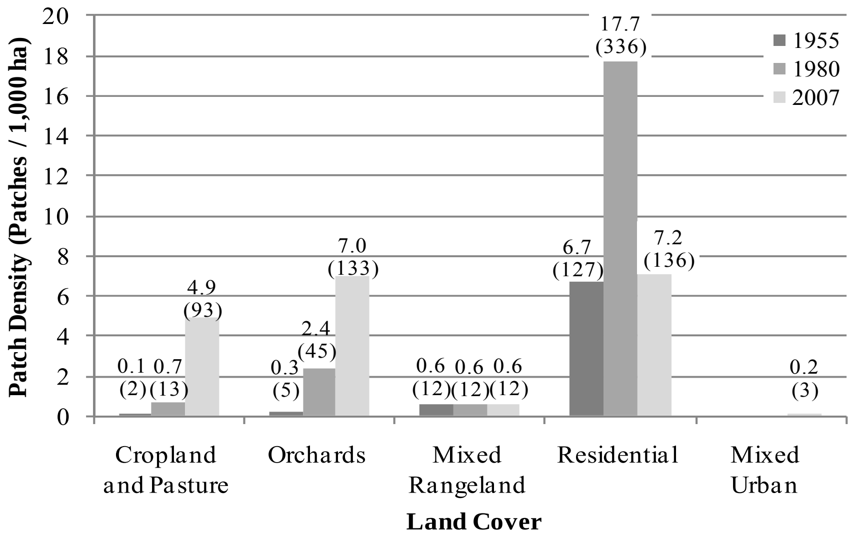


Figure 9. Changes in patch density, 1955-2007.

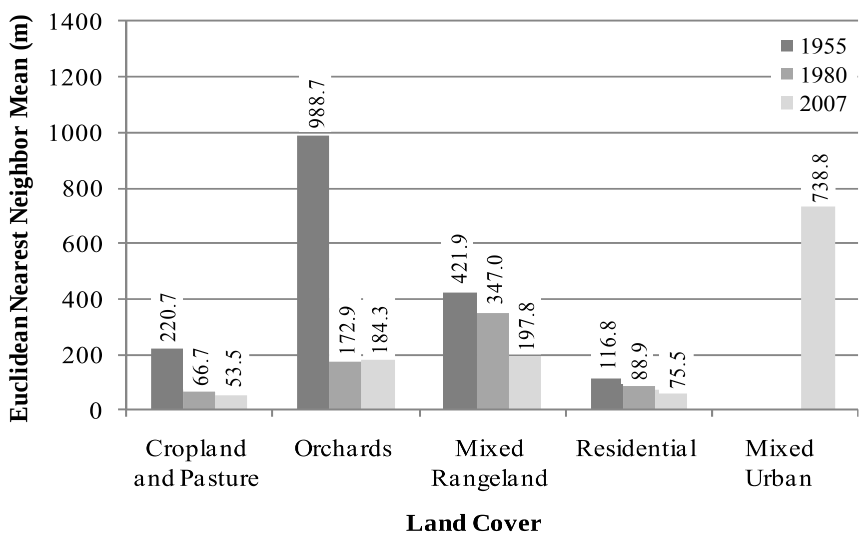


Figure 10. Changes in mean Euclidean nearest neighbor distance, 1955-2007.

index of almost 18, followed by Cropland / Pasture with 14, and Orchards with 13. Mixed Rangeland had a somewhat intermediate landscape shape index of about 7. Mixed Urban was almost maximally compact with a value of less than 3.

Finally, mean Euclidean nearest neighbor distance (i.e., mean minimum edge-to-edge distance between neighboring patches of the same type) shows that the degree of isolation of all patch types in the study area has decreased significantly and continuously over the last fifty years (Figure 10). To get from one Cropland / Pasture patch to another required traversing a distance of 221 meters in 1955; by 2007, that distance decreased 4-fold to only 54 meters. The difference is even greater for Orchards, which are now 184 meters apart, but which were very scarce and not surprisingly far apart from each other in 1955 (almost 1 kilometer). The mean distance between nearest neighboring Mixed Rangeland patches also declined over time, but not quite as dramatically, from 422 meters in 1955 to about half of that in 2007. Residential patches were never really isolated, but became somewhat closer over time as well, from 117 meters in 1955 to 76 meters in 2007. The three Mixed Urban patches that existed in 2007 were large and aggregated but, with a mean Euclidean nearest neighbor distance of 734 meters, much further apart than patches of the other land cover types and actually but isolated in comparison.

Drivers of Land Change (Objective 3)

The preceding sections sketched changes in rates and patterns of land change around the northern periphery of Las Cruces. The following sections discuss trends, drivers, and conflicts that might explain these changes in the study area.

1955-1980: "Growth Arrives"

In this era, growth was driven largely by natural gain, job growth at White Sands Missile Range during the Cold War and the National Aeronautics and Space Administration (NASA) space race, job growth at New Mexico State University, rising immigration from Mexico, and by the arrival of the first Anglo amenity migrants (Mesilla Valley Economic Development Alliance 2009). Las Cruces also began to serve as a residential area for El Paso, Texas, which in conjunction with Ciudad Juárez, Mexico became the largest maquiladora factory district along the U.S.-Mexico border (Martínez 1977). In the 1970s, growth led to the first city/county land use planning efforts funded by Housing and Urban Development 701 Planning Grants. Local regulations were skeletal, focusing on sewer, water, and road issues. Land subdivisions in the Mesilla Valley and East Mesa were platted and approved with little controversy.

The BLM began selling "disposal lands", a practice allowed under the Federal Land Policy Management Act of 1976. About 1,400 hectares (3,500 acres) were sold to developers who subdivided the East Mesa desert into rural residential home sites. Some of the proceeds were used to buy the Dripping

Springs Ranch, a private inholding in the Organ Mountains that was turned over to the BLM for management of trails and a visitor's center. The Nature Conservancy brokered this transaction; the first of many similar deals in the coming years. At the same time, farmlands of the Mesilla Valley were being fragmented by residential development as city residents built country homes and drove to town at high speeds on Interstate 25. By 1980, in-migration helped raise the population of Doña Ana County to 96,340—a 93% increase over 1955 (Figure 1; U.S. Census Bureau 1995). Growth was transforming the region from a remote Chicano homeland to a bi-racial, Sun Belt-alternative to the urban intensity of Phoenix.

1980-2007: "Growtopia"

During this era, "Growtopia" became a guiding community goal—growth for its own sake. Several comprehensive land use plans were produced, professional planners were hired, and regulations grew (City of Las Cruces 1999). However, real estate, banking, and construction sectors remained in charge and Las Cruces / Doña Ana County became a classic Sun Belt landscape in four primary ways.

First, significant population growth continued, driven by White Sands Missile Range and military employment, in-migration of retirees, Mexican immigration, and natural gain. By 2009, Doña Ana County reached 206,419 residents, a 114% increase over the 1980 Census (Figure 1; U.S. Census Bureau 1995, 2010b). Given these past population trends and significant projected population growth [310,000 people by 2040 according to the City of Las Cruces and Doña Ana County (2010a) and more than 500,000 people by 2040 according to the Paso del Norte Water Task Force (2001)], the tone of political process became strongly influenced by pro-growth officials supporting the proposals of prominent land developers. Land use planning essentially operated to assure that developments are sensibly designed and that infrastructure and services are competently provided (Wright 1993).

Second, development exploded on former public lands on the East Mesa. Between 1980 and 2007, the BLM sold 13,011 hectares (32,137 acres) and the State of New Mexico sold 8,764 hectares (21,647 acres) of "surplus land" (Sonoran Institute 2009). Nearly all of this combined 21,775 hectares (53,784 acres) was bought by land developers who platted subdivisions and built homes on desert rangeland that just a few decades earlier could have been bought for a song. Major highway improvements, sewer and water line extensions, and re-zonings further stimulated growth. The 1992, the BLM district plan identified 63,344 additional hectares (156,460 acres) for "disposal" – more than half of it on the East Mesa (BLM 1993). This plan is currently being rewritten with unknown implications for the future of land tenure on the East Mesa. Even if disposals are scaled back, however, development is likely to further encroach on key ecological resources such as the Jornada Experimental Range, Chihuahuan Desert Rangeland Research Center, and proposed wilderness and national recreation areas, including the scenic and biologically-rich Organ Mountains. This same conflict exists in Arizona where 648,000 hectares (1.6 million acres) of State lands have been sold or exchanged in recent decades and converted to residential and urban uses (Arizona State Land Department 2010).

Third, many local residents opposed the disposal of East Mesa public lands for development, fearing a return to the Reagan Era "Assets Management" program where federal lands were sold in a failed attempt to balance the budget (Brick and McGreggor Cowley 1996). However, the sale of East Mesa land has conservation benefits that are not widely known. The Nature Conservancy acted as a real estate broker for the BLM for more than twenty years, buying key properties such as Soledad Canyon and Picacho Peak near Las Cruces. This non-profit group then sold BLM disposal lands on the East Mesa to developers, was paid back, and transferred the conservation properties to the BLM for management. The East Mesa has functioned as a "land bank" to raise funds to protect critical lands across New Mexico.

Fourth, many residents in Doña Ana County began questioning the core assumptions of the growth-centric future imagined by the real estate and development sectors, and a citizen group began advocating conserving open space, biodiversity, wildlife habitat, farmland, and recreation sites throughout the county (The Citizens' Task Force for Open Space Preservation 2005). The idea of land conservation gained political traction and a few pro-conservation officials were elected to local and state offices.

It was in this setting that irrigated farmlands of the Mesilla Valley were converted to development, in addition to the mixed rangelands on the East Mesa discussed above. The Southern New Mexico Land Management Act (Wright 2002), which advocated spending $323 million from East Mesa BLM land sales to protect more than half the irrigated farmlands in the Mesilla Valley from development, was never passed by Congress. Support for the legislation was widespread among farmers, local governments, the Elephant Butte Irrigation District, the Mesilla Valley Economic Development Alliance, several Soil and Water Conservation districts, the Las Cruces Home Builders Association, and the Audubon Society. However, the BLM and The Nature Conservancy opposed the legislation, preferring to see proceeds from public land sales only spent to acquire biologically rich lands. The 911 terrorist attacks on America and an end to Clinton-era budget surpluses also helped derail the effort.

2007-?: "Epic Urbanization?"

Aridity has not stood in the way of Sun Belt urbanization. In the battle over water, farmers and environmentalists typically lose (Reisner 1993; Worster 1985). In the past 50 years, Albuquerque, New Mexico grew at an average annual rate of about 3.3%, from 201,189 people in 1960 to 528,497 in 2009 (U.S. Census Bureau 1992, 2010a). Tucson grew at a similar rate (3.2%) from

212,892 people in 1960 to 548,555 in 2009 (U.S. Census Bureau 1992, 2010g). Phoenix, Arizona grew dramatically at an average annual rate of 5.4%, from 439,170 people in 1960 to 1,601,587 in 2009 (U.S. Census Bureau 1992, 2010e). The future of agricultural landscape preservation in these areas is bleak (e.g., Musacchio et al. 2003). The City of Las Cruces and Doña Ana County started out smaller than all of these places. However, both grew faster than Albuquerque and Tucson and only a little slower than Phoenix. The City grew at an average annual rate of 4.5%, from 29,367 in 1960 to 93,570 in 2009 (U.S. Census Bureau 1992, 2010c) and the County at a rate of nearly 5%, from 59,948 in 1960 to 206,419 in 2009 (Figure 1; U.S. Census Bureau 1995, 2010b). Absent a cohesive strategy, Doña Ana County's "Growtopia" appears to be slowed only by the current recession. Booms followed the Great Depression and several recessions, however, and it can thus be expected that a boom will follow the current recession as well. In fact, the scale of future urbanization may be enormous.

If Doña Ana County grew at an average annual rate of 2.5% in the future, a rate that is conservative given past population growth (see above), it would reach a population of about 1.6 million people one-hundred years from now (Figure 1). That same number would be reached in less than sixty years at the average annual growth rate of the last fifty years (i.e., 5%). The number may sound farfetched. However, in the booming cities of the Southwest, perhaps the past is the most reliable prologue: Phoenix had 1.6 million residents in 2009 (U.S. Census Bureau 2010e). In addition to projected population growth, there are other factors that suggest that future growth in Las Cruces / Doña Ana County is not likely going to be hindered and perhaps even be promoted.

Future growth may not be hindered by two commonly limiting factors to growth: water and land. Water, though scarce, would be available to support millions of residents in Las Cruces and Doña Ana County, if Rio Grande water currently supplied to irrigated farmlands was shifted to residential and urban uses. Groundwater from the Mesilla Aquifer could theoretically support millions of more people until it was exhausted. Future water conservation, water treatment, and importation of water from coastal desalting plants could help support more people as well (Doña Ana County 2010; Paso del Norte Water Task Force 2001; McCoy et al. 2008). Absent viable land conservation and open space programs, land is not currently a limiting factor for more growth either and it is likely that rangeland and farmland will continue to be sold for development and that more federal and state holdings will be slated for disposal (Knight, Wallace, and Riebsame 1995).

Indeed, developers buy farms for $75,000 per hectare ($30,000 per acre) and more and subdivide them into residential lots (LoopNet 2010). The City of Las Cruces buys farmland to transfer the water rights to urban uses (Stockberger 2004) and develops water plans to support the expected increasing number of residents (McCoy et al. 2008). Crops cannot compete economically. The Census of Agriculture reveals the scale of this fragmentation. In

1987, Doña Ana County had 1,104 "farms" (irrigated farms and cattle ranches) averaging 210 hectares (519 acres) in size (USDA 1989). By 2007, the number of farms grew 60% to 1,762 but the average size declined to 135 ha (334 acres) and more than 1,000 farms were two ha (5 acres) or smaller (USDA 2009). Following a national trend, only 10% of all farms earned $100,000 or more from agricultural products (Hoppe and Banker 2006). Yet, between 2002 and 2009, Doña Ana County's annual agricultural receipts grew 56% to $389 million (USDA 2009). This may have been due largely to increased acreage and rising prices for pecans, sale of alfalfa to dairy farms, and short-term plantings of corn to take advantage of the ethanol boom. Despite this good financial news, the loss of farmland continues. Future growth also seems likely given several other factors, including an absence of land conservation plans, proximity and a relatively strong cultural connection to a major immigrant source country, comparatively high fertility rates, and city size- and climate-related pull factors for domestic migrants. We discuss each of these factors briefly below.

In 2008, the City of Las Cruces and Doña Ana County began crafting the Vision 2040 Plan (City of Las Cruces and Doña Ana County 2010b). Public hearings revealed that more and more residents of Doña Ana County were concerned about the limits to growth. The Plan demonstrated the challenge at hand. A "Base Build Out" scenario under existing regulations areas would simply facilitate existing growth trends. An "Alternative Build Out" scenario included key cluster and infill aspects of the New Urbanism (Arendt 2000; Beatley 1999). However, there was no indication that lands "Not Targeted for Development" such as farmland would be protected by pragmatic land conservation tools such as cluster development regulations, conservation easements, or Purchase of Development Right. Owners of lands "Not Targeted for Development" were never individually consulted about their view of this government "decision." The Town of Mesilla completed a Farmland Conservation Plan and adopted a voluntary Cluster Development Ordinance using conservation easements. Neither the City of Las Cruces nor Doña Ana County, however, have followed suit (Anella and Wright 2008; Town of Mesilla 2009a). Of all major Southwest cities, only Tucson and Albuquerque have active open space conservation programs. Officials in Phoenix and Las Cruces reveal a clear preference for growth and no open space programs exist in either jurisdiction (Musacchio et al. 2003).

Las Cruces / Doña Ana County have Hispanic or Latino populations of 55% / 65%, while Phoenix / Maricopa County and Tucson / Pima County have Hispanic or Latino populations of only 42% / 30% and 40% / 33%, respectively (U.S. Census Bureau 2010b, 2010c, 2010d, 2010e, 2010f, 2010g). This creates a stronger cultural connection between Las Cruces / Doña Ana County and Mexico and drives continuing immigration from crossings only 80 kilometers (50 miles) away compared to Tucson and Phoenix, which are about 110 kilometers (50 miles) and 290 kilometers (180 miles) from the U.S.-Mexico border, respectively. Las Cruces and Doña Ana County have much higher fertility rates (both 65 births per 1,000 women 15 to 50 years old) than Phoenix and Tucson (both 39 births per 1,000 women 15 to 50 years old) and Maricopa and Pima Counties (46 and 38 births per 1,000 women 15 to 50 years old, respectively) (U.S. Census Bureau 2010b, 2010c, 2010d, 2010e, 2010f, 2010g), which also favors greater future population growth in southwestern New Mexico. Moreoever, while Phoenix remains a much stronger pull for internal U.S. migration, Las Cruces and Doña Ana County realtors report a spillover effect as people leave Phoenix in search of a smaller community (Steinborn 2010). Las Cruces' Sun Belt climate is milder than Tucson's and Phoenix' due to its higher elevation, which may be an additional pull factor.

Concerns abound. Is a future population exceeding that of present-day New Mexico what local residents prefer? What will be the social, economic, and environmental costs and benefits of that scale of urban transformation? Could it be sustainable?

Conclusion

Las Cruces, New Mexico was a quiet place for centuries. In the American West, "instant cities" are the norm, however (Barth 1988), and "epic urbanization" most accurately describes their sprawling character. Barely-planned growth and fragmentation define the morphology of these landscapes. While open space conservation programs are achieving some success in Tucson and Albuquerque, they remain the exception. As we have documented in this paper, for example, the small community of Las Cruces may have been on a path toward urban immensity since the mid-Twentieth century, following the introduction of the swamp cooler.

The essential story of land change in our study area in the urban-rural fringe of northern Las Cruces has been as follows. Between 1955 and 1980, residential development occurred in both the irrigated valley and desert rangeland in an almost random fashion: fields and rangeland were perforated and dissected to make room for housing and infrastructure developments. The landscape became very fragmented and heterogeneous during this time period, especially in the valley where rural residences were built amidst fields, but somewhat isolated from each other. Between 1980 and 2007, the landscape became even more fragmented as both residential and mixed urban development took over more farmland and rangeland. During this time period, however, mixed urban development occurred across large unbroken tracts of rangeland, while in-fill development of new rural residences transformed former farmland or rangeland transition zones. The overall effect of this process was a decrease in landscape heterogeneity. If past trends continue, fragmentation will soon be replaced by the shrinking and attrition of left-over fields and rangeland and by the continued growth and coalescence of residential and mixed urban clusters. The result will be an essentially homogeneous landscape dominated by residential and urban development—a drastic change from the homogeneous landscape of croplands, pastures, and rangeland habitat that existed in 1955.

Facilitating the expansion of development remains the prime motivation of local political leadership. What average residents prefer remains to be seen. The recent creation of the Mesilla Valley Bosque State Park, the Dinosaur Trackways National Monument, and the efforts of the Town of Mesilla to conserve farmland hint at an alternative future (Town of Mesilla 2009b). However, data on population growth, land change, and successes and failures of land use planning initiatives suggest that Las Cruces is likely to follow the Southwest's archetypal urban trajectory exemplified by Phoenix, for example. Unless land conservation and in-fill development become high priorities, sprawl is likely to consume all farmland and immense rangeland tracts by the turn of the next century. Ecological resources such as the Rio Grande, Jornada Experimental Range, Chihuahuan Desert Rangeland Research Center, and the Organ Mountains would be significantly impacted by this encroachment. The growth we project may or may not be inevitable or sustainable. In any case, determining the pace and pattern of development as we have done here is a central challenge faced by planners, officials, land owners, and conservationists.

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