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Original article

Increased home size and hardscape decreases urban forest cover in Los Angeles County's single-family residential neighborhoods

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ABSTRACT

Single-family residential neighborhoods make up large areas within cities and are undergoing change as residences are renovated and redeveloped. We investigated the effects of such residential redevelopment on land cover (trees/shrubs, grass, building, and hardscape) in the 20 largest cities in the Los Angeles Basin from 2000 to 2009. We identified spatially stratified samples of single-family home lots for which additional square footage was recorded and for which additional construction was not recorded by the tax assessor. We then digitized land cover on high-resolution color imagery for two points in time to measure land cover change. Redevelopment of single-family homes in Los Angeles County resulted in a significant decrease in tree/shrub and grass cover and a significant increase in building and hardscape area. Over 10 years, urban green cover (trees/shrubs and grass) declined 14–55% of green cover in 2000 on lots with additional recorded development and 2–22% of green cover in 2000 for single-family lots for which new permits were not recorded. Extrapolating the results to all single-family home lots in these cities indicate a 1.2 percentage point annual decrease in tree/shrub cover (5.6% of existing tree/shrub cover) and a 0.1 percentage point annual decrease in grass cover (2.3% of existing grass cover). The results suggest that protection of existing green cover in neighborhoods is necessary to meet urban forest goals, a factor that is overlooked in existing programs that focus solely on tree planting. Also, changing social views on the preferred size of single-family homes is driving loss of tree cover and increasing impervious surfaces, with potentially significant ramifications for the functioning of urban ecosystems.

1. Introduction

For nearly a hundred years since the establishment of North American residential suburban neighborhoods, and accelerating since World War II, single-family neighborhoods have exhibited a characteristic ratio of building to landscape, with properties reliably including a healthy proportion of tree, shrub, and grass cover (Ward, 2011; Gillespie et al., 2012). Suburban tracts being laid out through the middle decades of the twentieth century in North America reflected a cultural value of appreciation for greenery and shade, included places for children and pets to play outdoors, and provided hedges affording privacy. With the aging of the housing stock, emerging preferences for larger homes, and market forces rewarding speculative development, many homes in single-family neighborhoods are being expanded and redeveloped. This redevelopment results in larger homes (National Association of Home Builders (NAHB) 2006, 2010), with a trend toward increased hardscape, play spaces being brought indoors or moved off-site, increased indoor storage, and an overall drastic change to the relatively homogeneous landscape of neighborhoods that had been developed with similar massing and building–landscape ratios.

Besides fulfilling an aesthetic objective, the landscape design of the first wave of single-family residential tract development inherently brought with it a range of what would now be recognized as ecological services (e.g., shade, stormwater management, habitat for birds and other wildlife). These ecologically beneficial consequences occurred organically—not as the result of conscious environmental policy, but rather as an outgrowth of the cultural aesthetic and economics of the times. That these benefits were not planned does not diminish their value. In fact, the ecosystem services of such neighborhoods are an integral, although unrecognized, part of the land use baseline which forms the context in which current urban land use decisions are made (Tratalos et al.,

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2007). That is, the landscape aesthetics of the single-family neighborhood provide significant environmental benefits that can be underappreciated in current discussions over the future of cities, especially those promoting density as a sustainable urban form (Jabareen, 2006; Hassan and Lee, 2015). Furthermore, the redevelopment of these neighborhoods threatens to eliminate their environmental benefits in a way that is not readily appreciated because the zoning classification does not change. Public agencies spend significant funds on parklands and open space, with the expectation that such lands will continue to support resident and migratory species of birds and other wildlife. In truth, if the areas in between urban parklands are allowed to be filled in, paved, and denuded through redevelopment of neighborhoods, those values will be diminished (Fernández-Juricic, 2000).

In this study, we investigated trends in green cover, defined as trees, shrubs (bushes), and grass (lawn), in single-family neighborhoods relative to patterns of redevelopment of those lots on an individual basis. The study focused on the 20 largest cities in the Los Angeles Basin (that is, on the coastal side of the major mountain ranges in Los Angeles County) as an example of a landscape with mature single-family neighborhoods. The time period investigated is 2000–2009, which was a decade of rapid appreciation in the local housing market that fueled the aggressive expansion and replacement of residences. Our approach, which compared changes detected using parcel-level aerial imagery with official records of building size, additionally provided an indication of whether expansion of single-family homes is being permitted and recorded in a way that allows it to be properly taxed. With this approach, we asked three research questions:

- How has green cover changed on parcels for which the permitted building footprint increased compared with those for which no change was recorded?
- How has the rate of building modification and associated changes in green cover varied across the 20 most populous cities in the Los Angeles Basin?
- How much has green cover changed across the Los Angeles Basin as a result of the redevelopment of single-family neighborhoods?

2. Background

The size of the average single-family home has increased dramatically in North America over the past 50 years, with the size of new or expanded structures in some neighborhoods reaching proportions that have been described as “mansions” (e.g., Szold, 2005) and in some cases referred to as “McMansions” because they are developed on a speculative basis in a manner out of scale with their surroundings.

Residential areas, especially single-family neighborhoods, play an important role in urban ecosystems because they cover a large fraction of the land area in cities. For example, single-family neighborhoods consume more than half of the land area in urbanized Los Angeles County. According to the NAHB (NAHB, 2006, 2010), the average size of single-family homes in the U.S. has steadily increased from 983 ft^2 in 1950 to 2349 ft^2 in 2004. In addition, the number of bedrooms and bathrooms, as well as the number of parking spaces, has increased. For example, just 1% of single-family homes had four bedrooms and only 2% had three bathrooms in 1950; these rates had increased to 37% with four bedrooms and 24% with three bathrooms by 2005. Meanwhile, the size of the average household dropped from 3.67 persons in 1940 to 2.62 persons in 2002 (Wilson and Boehland, 2005), meaning that these newer, larger homes are resulting in a lower density of urban residents (see Ward, 2011 for similar statistics in Canada).

The environmental benefits of trees and other forms of green cover are many and varied and play a crucial role in improving residents’ quality of life and in maintaining urban environmental amenities (Akbari et al., 1997, 2001; Dwyer et al., 1992; Dwyer and Miller, 1999; Longcore et al., 2004; Simpson and McPherson, 1996). Abundant green cover helps to maintain or boost property values and brings environmental benefits such as reduction in energy use, improvement in air quality, reduction in noise, control of stormwater runoff, provision of habitat for wildlife, and enhancement of aesthetic values. Together, the tree, shrub, and grass cover of the city can be conceptualized as an “urban forest,” which meets the definition of a forest by exceeding 10% cover of trees (Rowntree, 1984).

Trees provide shade and decrease energy consumption by helping to keep buildings cool in summer (Dwyer et al., 1992; Simpson and McPherson, 1996). Trees intercept sunlight before it heats buildings and reduce wind speed by as much as 50%. Approximately $10 billion is spent annually to cool residential dwellings in the U.S. so the potential impact of these savings is considerable (Akbari et al., 1990). Akbari et al. (2001) reported that the City of Los Angeles, for example, could save $270 million annually from an expanded tree cover. Vegetation cover may also help to reduce the urban heat island and thereby reduce nighttime residential energy consumption.

Trees also improve air quality because gaseous pollutants such as CO_2, O_3, and NO_2 are absorbed by leaves and O_2 is released to the air (McPherson et al., 2005a; Nowak et al., 2006). It has been estimated that the addition of 100 million mature trees in cities in the U.S. would remove 8.16 million tons of CO_2 from the atmosphere and save approximately $2 billion per year (Akbari et al., 1998; Dwyer et al., 1992). In addition, increasing tree cover decreases O_3 concentrations (Taha, 1996; Nowak et al., 2000) and improved air quality enhances human health and can reduce expenditures for health care (Dwyer et al., 1992; Dwyer and Miller, 1999; Gauderman et al., 2004, 2005). Lovasi et al. (2008) suggest that trees play an important role in preventing childhood asthma and one cost-effective way to reduce air pollution is to increase the extent and quality of urban forest (Escobedo et al., 2008). Heavy vehicular traffic usually leads to elevated levels of noise and air pollution; both adversely affect human health. Strategically placed trees, such as near roadways, substantially reduce the perception of traffic-related noise (Dzhambov and Dimitrova, 2014).

Urban green cover also plays an important role in reducing stormwater runoff because green cover intercepts rainfall and some of this intercepted precipitation is evaporated back to the atmosphere (Brooks et al., 2012). Xiao and McPherson (2002), for example, have shown that Santa Monica, California’s municipal urban forest intercepts 1.6% of the total rainfall per year. Trees and other forms of green cover also promote infiltration and groundwater recharge (McPherson et al., 2005a) and thereby help to control stormwater runoff (McPherson et al., 2005a, 2005b). Sanders (1986) estimated that existing trees reduced runoff by 7% in Dayton, Ohio and that this would increase to 12% with planned growth of tree cover. Reducing runoff volume mitigates potential flood hazard and pollutant loadings to nearby rivers and lakes (Millward and Sabir, 2011).

Urban neighborhoods support birds and other wildlife of various types (Livingston et al., 2003; Aronson et al., 2014), but the increasing urban footprints and accompanying population growth threaten habitats for a variety of wild species (Matteson and Langellotto, 2010; McKinney, 2008).

Finally, trees enhance the aesthetics of single-family neighborhoods, help sustain and improve residential property values, and provide a series of recreational opportunities (Conway and Urbani, 2007). Anderson and Cordell (1988) reported that in Athens, Georgia between 1978 and 1980 each large front-yard tree resulted in an average 0.88% increase in home sale prices, and the same authors later argued that increased property values can, in turn, increase a city's property tax revenues. Sander et al. (2010) also show a positive relationship between tree cover and property sale value such that a 10% increase in tree cover within 100 m of a home increased property sale prices by 0.48% and within 250 m of the home increased sale prices by 0.29%. Conway et al. (2010) conclude in a study of Los Angeles that proximity to greenspace has a significant impact on home prices and greening cities may be a way to elevate depressed housing markets. In contrast, Saphores and Li (2012) did not find a large price benefit of trees on single-family residential parcels, but did find such an effect for the surrounding 200 m, suggesting that people want trees, but perhaps do not want to pay to take care of them.

The mixed result on home sale prices from Saphores and Li (2012) highlights that trees do have costs for homeowners (Roy et al., 2012), including the perceived need to trim trees (although much urban tree trimming is unnecessary and violates arboricultural guidelines), potential damage to infrastructure, production of allergens, and production of volatile organic compounds.

The benefits of green cover, especially trees, within cities have been well documented and recognized. As a consequence, plans and efforts have been launched in recent decades to increase green cover in a variety of urban settings. The United Nations Environment Programme (2011), for example, launched the Billion Trees Campaign to encourage national, state, county, and city governments as well as nonprofit organizations and individual residents to plant indigenous trees in both rural and urban areas. Likewise, the U.S. Conference of Mayors launched a Community Trees Task Force to protect and increase urban green cover and increase public awareness of its value (U.S. Conference of Mayors, 2008). The Task Force surveyed local officials in 135 cities with at least 30,000 residents in 36 states and documented the methods used to manage, sustain, and expand green infrastructure as well as to share information about urban forest status. Los Angeles and New York, the two largest cities in the U.S., launched projects in 2006 to plant an additional one million trees (City of Los Angeles, 2006; City of New York, 2006), with different approaches and eventual outcomes (Pincetl, 2010).

These new programs can add to green cover only if existing green cover is retained. Increases in home sizes in single-family neighborhoods result in removal of existing vegetation, including trees, and expansion of the area covered by impermeable surfaces. The extent of these threats to urban green cover during a period of growth in the residential real estate market is the subject of our investigation.

3. Methods

3.1. Study area

Los Angeles County, California is the most populous county in the U.S. and, if it were a state, it would constitute the eighth most populous state (ahead of Ohio). The County's population grew from 4,151,687 in 1950 to 9,858,989 in 2011 (U.S. Census Bureau, 2000; California Department of Finance, 2011) and dramatically increased in urban footprint. As a result of the increase, Los Angeles County ranked first among all counties in terms of the funds ($9.4 billion) spent on home remodeling per year from 2005 to 2009. Cook County, Illinois ($4.6 billion), Orange County, California ($4 billion), San Diego County, California ($3.4 billion), and Maricopa County, Arizona ($3 billion) rounded out the top five counties in terms of remodeling expenses during this same period.

More than 90% of the population in Los Angeles County resides in the County's 88 incorporated cities and most of the remaining residents live in urbanized areas that are located near one or more of these cities. The land mass varies in elevation from sea level to 3000 m. Most of the urban population resides in relatively flat, low-lying areas that constitute the analysis units chosen for this study (Fig. 1).

The City of Los Angeles is the largest city in Los Angeles County (and in California) and the second largest city in the U.S. For purposes of this study, the City of Los Angeles was analyzed in units defined by the 15 council districts used for city governance (see Fig. 1 and Table 1 for additional details). We used the district boundaries from June 2009.

3.2. Data sources

The two main data sources were property information and aerial imagery. Property information (2000–2001 and 2009–2010), which was generated June 18, 2009, is maintained and distributed as a GIS dataset (boundary shapefile and a tabular data) by the Los Angeles County Office of the Assessor and includes sales information, property values, property built year, property boundaries, building descriptions, land uses, and other variables. The property information dataset was created for use in this study by joining the tabular data to the boundary shapefile using the Assessor Index Number (AIN).

One-foot (2000) and four-inch (2008) pixel resolution color ortho-imagery was obtained from the Los Angeles Region – Imagery Acquisition Consortium (LAR-IAC). The color ortho-imagery consists of 3 bands (red, green, blue) without an infrared band so we did not pursue an image classification approach to extract vegetation features that an infrared band would have allowed.

Both of the two main datasets were projected to the North America Datum (NAD) 1983 State Plane California V FIPS coordinate system. We also used the city boundary layer from the Los Angeles County GIS Data Portal. We chose the 2009 data to describe the 2008 imagery to account for delays in recording permitted redevelopment and renovation by the Office of the Assessor.

3.3. Sample design

The 20 largest cities in the Los Angeles Basin by population in 2010 were chosen to maximize coverage of the region and to provide a dataset with which we could compare differences between municipalities. Combining the 15 council districts of the City of Los Angeles with the 19 remaining cities yielded 34 analysis units ranging in population from 81,604 (City of Baldwin Park) to 494,709 residents (City of Long Beach) (see Table 1 for additional details).

More than 2.3 million parcels are found in Los Angeles County and among these more than 1 million parcels were occupied by single-family homes in both 2000 and 2009. For this study, we examined the 639,080 parcels in the 20 largest cities in both 2000 and 2009 that were classified as single-family homes using the land use code specified by the Los Angeles County Office of the Assessor (Table 1).

Single-family home parcels in each city and council district were extracted using the addresses recorded by the Assessor's office as well as city and council district boundaries. In some instances, however, the addresses were mismatched with geographic boundaries. The Spatial Join tool (in ArcGIS 10.3) was used with the intersecting match option, in which the features in the join features were matched if they intersected a target feature, to count the number of single-family home parcels in 19 cities and 15 council districts.

We split the existing single-family homes into a treatment group and a control group. The treatment group includes those homes for which the Los Angeles County Office of the Assessor recorded a change in building area from 2000 to 2009. The control group contained a sample of developed single-family residential lots for

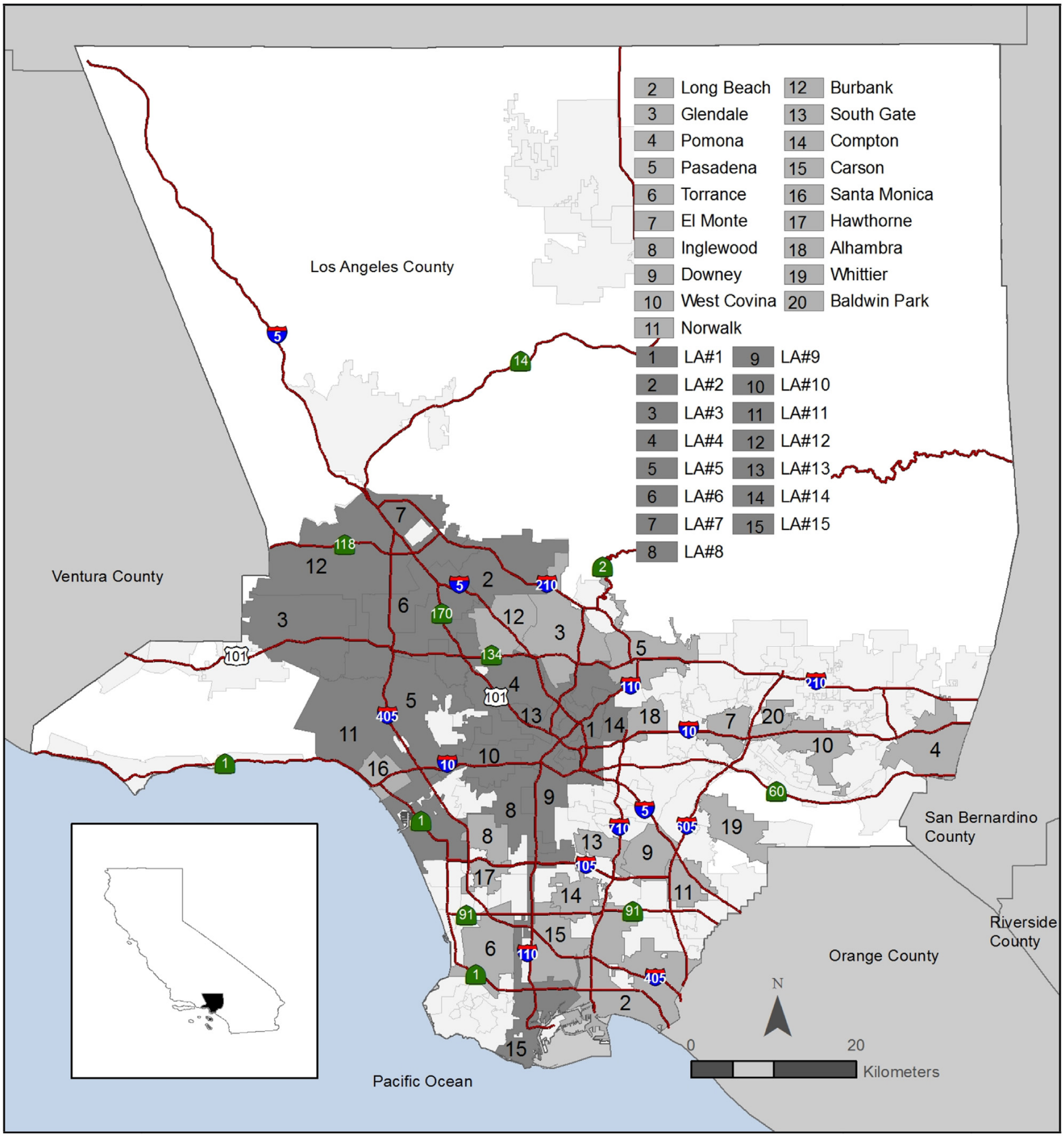

Fig. 1. Los Angeles County, California, with outlines of all 88 cities, the 20 largest cities are indicated (gray), with the dark gray area showing the City of Los Angeles divided into 15 council districts.

which no such change was recorded. For the treatment group, changes in square footage included new single-family homes on vacant lots and the occasional removal of a home. This approach eliminated the need to specify what constituted a "large" new house on a "small" lot and a "large-scale" addition and renovation to an existing home; we measured the effects of all changes in recorded building square footage. For lots where a change in building square footage had been recorded, the larger of a 1% or 30-home stratified random sample was selected in each of the 34 analysis units; for lots at which no change had been recorded, 20 homes were randomly sampled in each of the 34 units of analysis (Table 1).

3.4. Digitizing and change analysis

Five land cover types (buildings, hardscape, swimming pools, grass, and trees/shrubs) were digitized for each of the sampled home lots on the color ortho-imagery for 2000 and 2008. Shrubs were included with trees and further reference to tree cover includes shrub cover as well. Additionally, shaded (unknown) areas were identified (Fig. 2). Land cover types were digitized using the Editor tool in ArcGIS 10.3, with a single investigator (S. J. Lee) interpreting all aerial imagery (see e.g., Fig. 2). To minimize user errors, the point, end, vertex, and edge snapping tools were implemented while creating new features and segments by tracing existing features.

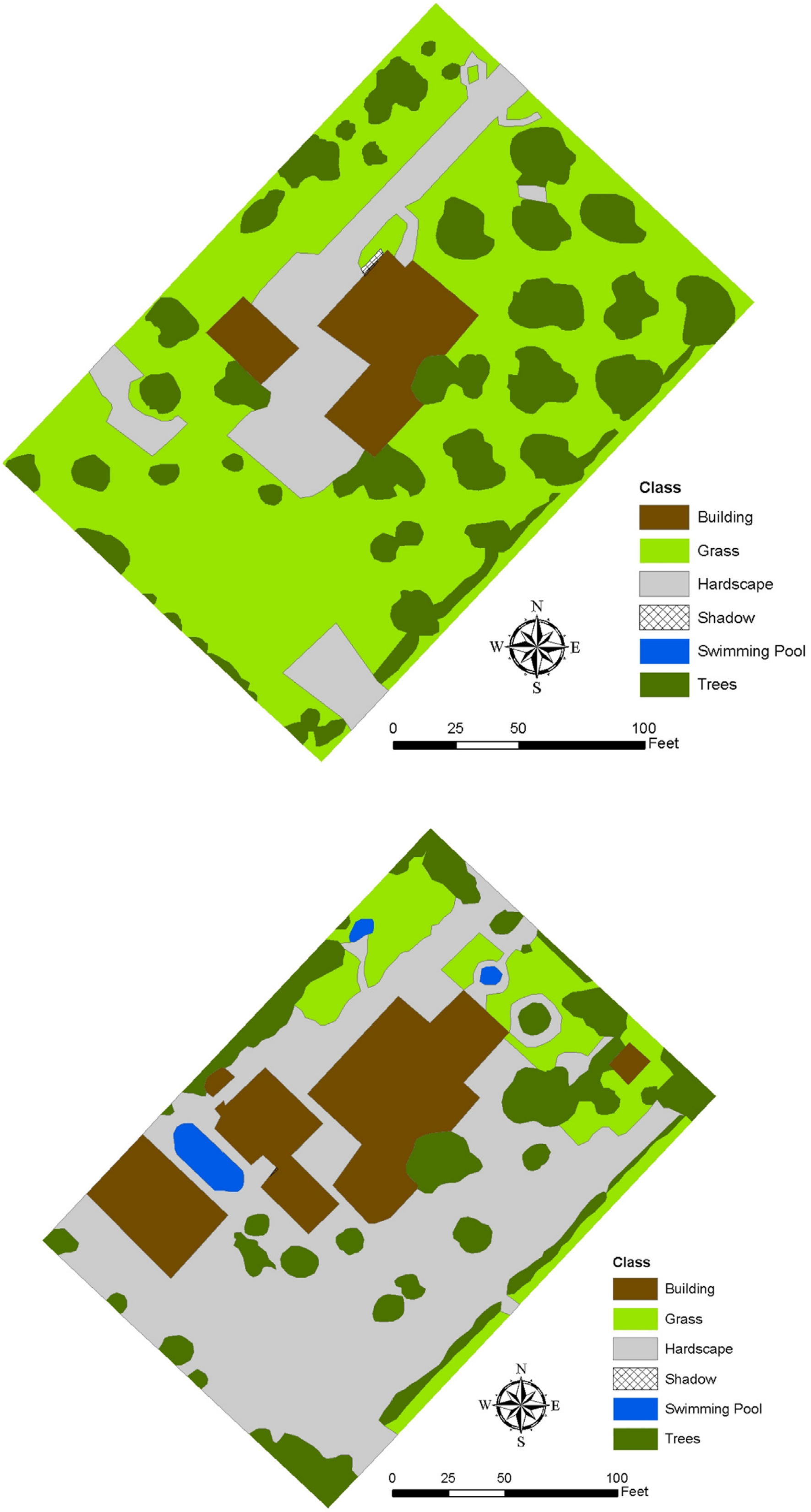

Fig. 2. Samples of digitized single-family residence lots using six classes: 1) building, 2) grass, 3) hardscape, 4) shadow, 5) swimming pool, and 6) trees (including shrubs) in 2000 (upper) and 2009 (lower).

Table 1
Population and housing statistics for the 20 most populous cities in Los Angeles Basin, 2010 (Population compiled from California Department of Finance (2011) and housing data from Los Angeles County Office of the Assessor (2010)). Lots with buildings in 2000–2001 and 2009–2010.

Cities/Council Districts	Population (2010)	No. of single-family homes	Fraction of modified homes (%)	No. of modified homes	No. of modified homes sampled	No. of other homes sampled
Los Angeles	4,094,764	346,006	9	30,756	463	300
LA#2	290,380	31,354	11	3420	34	20
LA#7	287,670	22,642	10	2205	30	20
LA #3	284,200	32,719	8	2737	30	20
LA#12	281,480	31,815	7	2369	30	20
LA#11	274,090	33,616	12	3911	39	20
LA#4	274,020	17,038	8	1289	30	20
LA#5	271,410	25,770	12	3033	30	20
LA#15	268,920	26,898	8	2103	30	20
LA#6	261,750	23,723	11	2493	30	20
LA#9	261,250	13,156	8	1003	30	20
LA#13	252,280	9365	8	759	30	20
LA#8	251,290	31,083	8	2485	30	20
LA#10	250,790	14,936	8	1127	30	20
LA#14	247,180	23,704	6	1432	30	20
LA#1	246,680	8187	5	390	30	20
Long Beach	494,709	51,497	11	5733	57	20
Glendale	207,902	18,133	6	1101	30	20
Pomona	163,683	18,307	5	993	30	20
Pasadena	151,576	16,923	9	1597	30	20
Torrance	149,717	25,275	8	2099	30	20
El Monte	126,464	7992	8	665	30	20
Inglewood	119,053	9798	8	792	30	20
Downey	113,715	14,134	10	1477	30	20
West Covina	112,890	14,628	7	962	30	20
Norwalk	109,817	18,694	10	1789	30	20
Burbank	108,469	14,190	13	1797	30	20
South Gate	101,914	9631	10	1000	30	20
Compton	99,769	14,226	6	898	30	20
Carson	98,047	16,052	10	1568	30	20
Santa Monica	92,703	6055	13	763	30	20
Hawthorne	90,145	6030	7	435	30	20
Alhambra	89,501	8996	8	740	30	20
Whittier	87,128	13,299	9	1138	30	20
Baldwin Park	81,604	9214	10	910	30	20
Totals	6,602,196	639,080	9	57,213	1060	680

Once land cover features on the stratified random samples were digitized, we merged land cover features by land cover in each sample to yield the total area of each land cover category. The merged data were then spatially joined by each city or council district for the statistical analysis. The digitized land cover features at each of the two dates were then compared using the field calculator within the attribute table.

3.5. *Statistical analysis*

We calculated summary statistics for land cover types in each of the sampled categories in the 19 cities and 15 council districts. We then calculated the total cover for each time period for all single-family neighborhoods in each of the units by weighting the averages by the area within each unit that either had or did not have a change in home area reported by the Assessor. This extrapolation was also used to calculate the total area of land cover changes in units and across the entire study area for the 639,080 parcels with single-family homes in our study. All calculations were for single-family residential parcels only and do not include streets and roads. Calculations were performed by extracting data with the Select by Attribute and Field Calculator tools in ArcGIS 10.3. and exporting to the JMP Pro 12.0 statistical software (SAS, Cary, North Carolina) for calculation of descriptive statistics and other analyses.

4. Results

4.1. *Distribution of lot size and building footprints for single-family homes*

The average lot size for single-family homes varied substantially (Fig. 3). The fraction of building area relative to lot size (i.e., floor-area ratio; FAR) that is recorded by the Los Angeles County Office of the Assessor on all single-family home lots (639,080) increased from 22.0% in 2000 to 22.8% in 2009. This proportion increased in all 20 cities from 2000 to 2009, ranging from 0.3% (Pomona) to 2.1% (Santa Monica). Floor-area ratio increased more than 1% in Santa Monica (2.1%), LA#11 (1.7%), LA#5 (1.3%), Long Beach (1.2%), Burbank (1.2%), and Downey (1.1%). Compton (0.4%), Glendale (0.4%), West Covina (0.4%), LA#1 (0.4%), and Pomona (0.3%) showed less than 0.5% increase in the fraction of building area from 2000 to 2009.

4.2. *Land cover change from 2000 to 2009*

From the stratified random samples (n = 1740, Table 1), the following results were extracted. Taking the cities and City of Los Angeles council districts as the units of analysis, the average proportion of each lot covered by building and hardscape increased both for lots where permitted expansion was documented by the Assessor's office and for lots where increased square footage was not documented (Fig. 4).

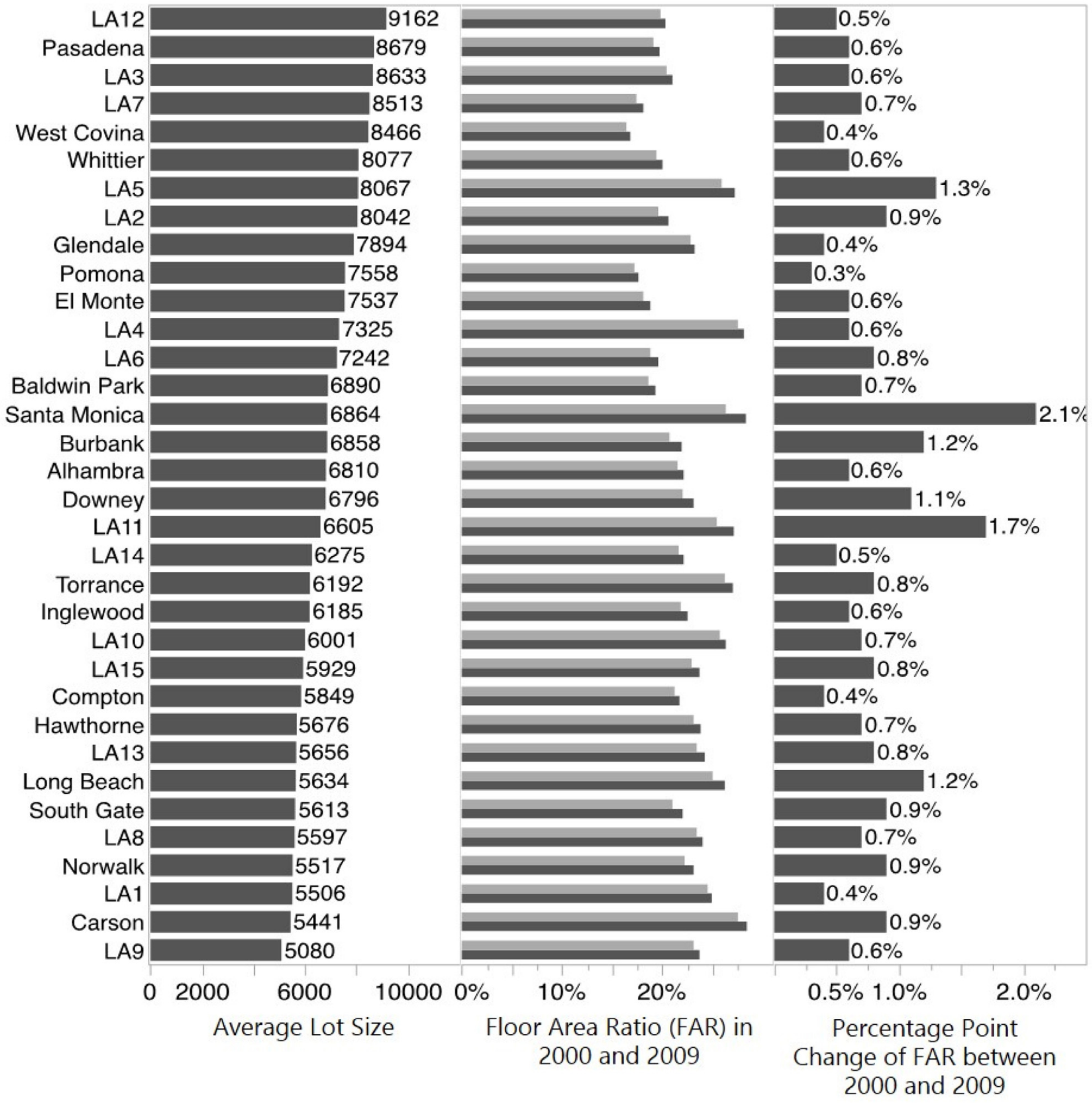

Fig. 3. Average lot size, floor area ratio in 2000 (light gray) and 2009 (dark gray), and average percentage point change of floor area ratio between 2000 and 2009 for all single-family home lots (n = 639,080) in the 20 most populous cities in the Los Angeles Basin.

An additional 9.1% of lots was covered by buildings (13% for recorded development and 2.8% for no recorded increase). Hardscape increased 8.7% (10.2% for recorded development and 6.5% for no recorded increase). The average increase in impervious surfaces was 17.8% ± 5.9% s.d. (n = 34). For sites with recorded development, average increase in buildings and hardscape was 23.2% ± 8.4% s.d. and for no recorded development average increase in buildings and hardscape was 9.3% ± 5.7% s.d.

Similarly, tree cover decreased an average of 13.6% (16.9% for recorded development and 8.4% for no recorded increase). Grass cover declined 4.1% (6.2% for recorded development and 0.8% for no recorded increase). Overall, average green cover declined 17.7% ± 6.0% s.d. (n = 34). For sites with recorded development, average decline in green cover was 23.1% ± 8.5% s.d. and for no recorded development average decline in green cover was 9.2% ± 5.8% s.d.

The changes in pervious (trees and grass) and impervious (building and hardscape) surfaces were a mirror image (Fig. 5). This pattern was consistent across jurisdictions with widely variable lot sizes. This pattern strongly suggests that loss of grass cover was not the result of conversion to shrubs or trees, but rather by the replacement of grass by impermeable surfaces.

The green cover changes in single-family neighborhoods across the jurisdictions (Fig. 6) are all negative and show a highly variable spatial pattern across the Los Angeles Basin between 2000 (Fig. 7) and 2009 (Fig. 8). The decrease in green cover in single-family neighborhoods ranges from 14% to 55% (Fig. 6). In 2000, single-family neighborhoods in the study area ranged from 42% green cover in Hawthorne to 70% green cover in Baldwin Park, with

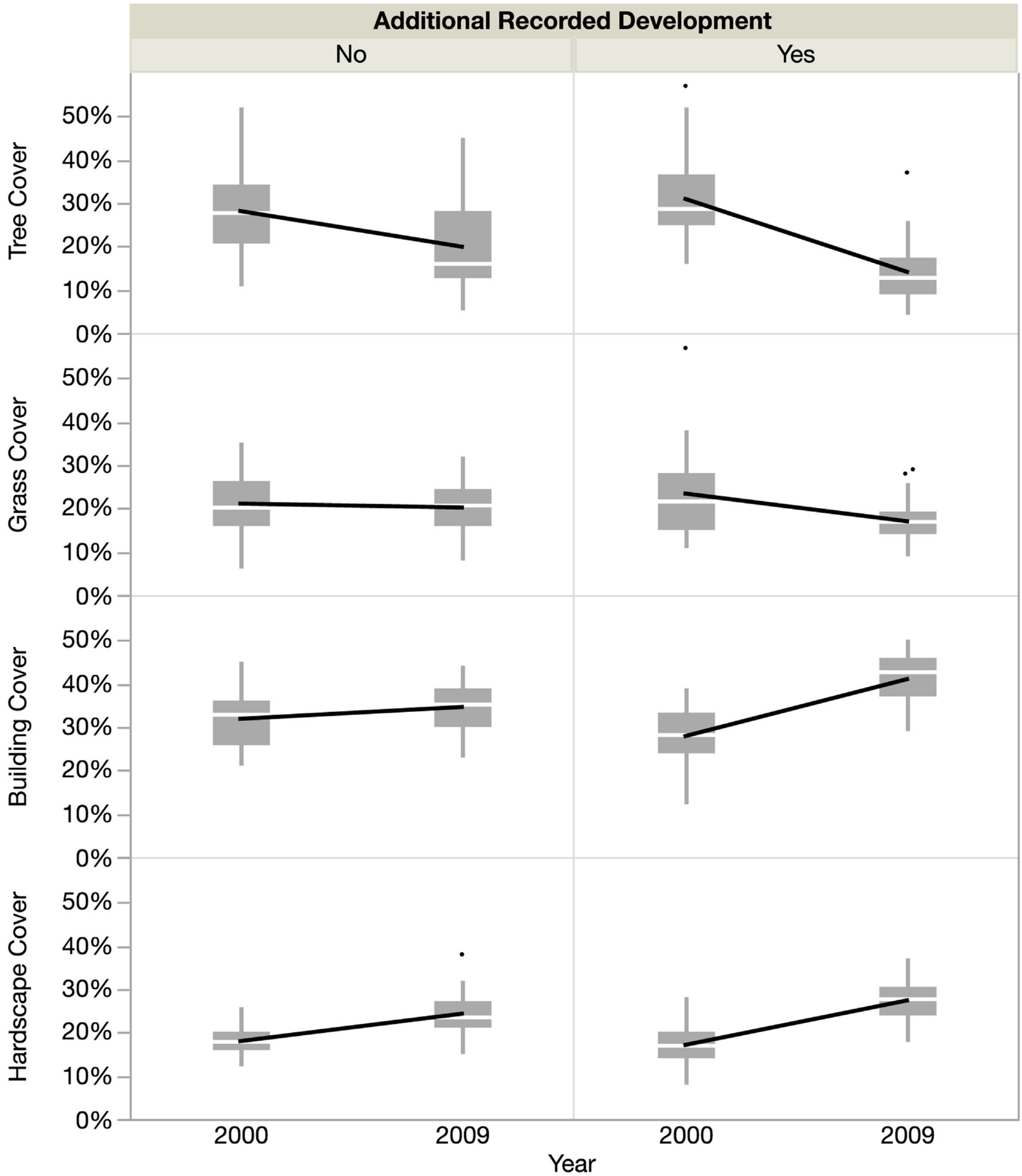

Fig. 4. Change in lot cover for trees/shrubs, grass, buildings, and hardscape between 2000 and 2009 for single-family residences in 15 Los Angeles City Council Districts and 19 cities that either did or did not have additional development recorded for the property by the Assessor. Whisker plots show median value, first and third quantile, and outliers. Solid black lines connect means.

an average of 52%. By 2009, the green cover in Baldwin Park's single-family neighborhoods had declined 39 percentage points (from 70% to 31% green cover, a loss of 55% of the existing green cover in 2000), indicating the most dramatic loss of cover within a city or council district.

Looking specifically at lots where building additions were recorded, the loss of tree and grass cover was not consistent across jurisdictions. For example, developed lots in Baldwin Park lost 55% green cover and those in Compton lost 41%, while the developed lots in Pasadena lost only 14% and Glendale only 15% of the green cover present in 2000. As a whole, the average green cover for sites with reported increases in building area dropped by nearly a third, from 52% in 2000 to 35% in 2009.

Remarkably, only a quarter of lots (24%; 170 of 720) without additional recorded development had more tree canopy at the end of the study period than at the beginning and for lots with addi-

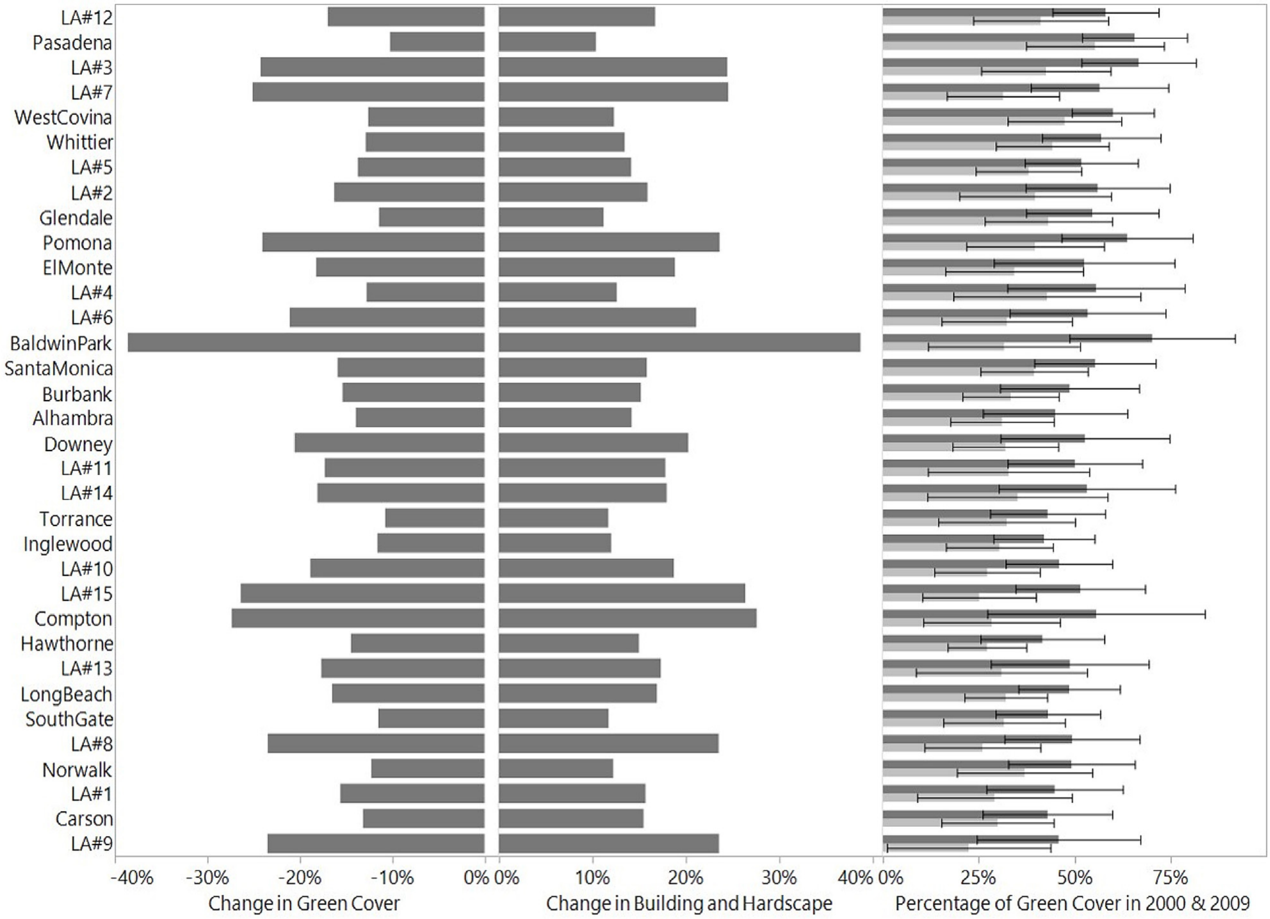

Fig. 5. Bars (ordered by average lot size) show changes in green cover (left) and building and hardscape (center) between 2000 and 2009; and percentage of green cover (right) in 2000 (dark gray) and 2009 (light gray) with standard deviations in the 20 largest cities in Los Angeles County.

tional development that proportion declined to 12% (126 of 1020). The cover of grass increased on 381 of 1020 sampled lots (38%) for which building footprint additions were recorded and on 308 of 720 sampled lots (42%) for which building footprint additions were not recorded. Increases in both trees and grass occurred on only 9 lots for which building footprint additions were recorded (0.8%), and on 25 single-family home lots for which building footprint additions were not recorded (3.5%).

4.3. Cumulative green cover loss

One of the most important consequences of the trends in single-family neighborhood redevelopment is the resulting decrease in green cover in neighborhoods across individual cities and the metropolitan region as a whole. The green cover losses (Fig. 4), not surprisingly, closely tracked the building and hardscape gains. Baldwin Park, Compton, LA#7, LA#15, and Downey were the top five study units in terms of green cover loss on single-family home lots for which building footprint additions were recorded.

Taken as a whole, the results show that the 20 cities studied have lost approximately 6.9 km^2 of tree cover and approximately 1.6 km^2 of grass cover on single-family home lots for which building footprint additions were recorded by the Los Angeles County Office of the Assessor, and 34.8 km^2 of tree cover and approximately 4.0 km^2 of grass cover on single-family home lots for which building footprint additions were not recorded. This result represents a 9.6% decrease in tree cover and a 1.0% decrease in grass cover across all of the 639,080 single-family lots in the 20 cities studied.

4.4. Digitizing errors

The aerial photographs contained only red, green, and blue color bands without an infrared band, which restricts implementing image classification approaches. We found that heads-up digitizing can generate interpretation errors so we tried to minimize errors by comparing total area of land cover with lot size. Digitizing errors as measured by a comparison of the digitized areas with the total lot size were less than ±20 ft^2 (<0.2% of lot size), which we believe is acceptable, given the magnitude of the differences in land cover detected.

5. Discussion

Green cover changed substantially on residential lots in single-family residential neighborhoods across Los Angeles County during the decade examined here. These results present a troubling reversal of the long-term trend in urban forest cover in Los Angeles. This reversal was also detected for 2005–2009 (Nowak and Greenfield, 2012) and points to a failure of existing policies to protect and increase tree cover in various jurisdictions. Furthermore, the discovery that homes for which no additional legal building area had been reported to the Assessor nevertheless had both increased building area and lost tree cover has potentially significant ramifications for municipal finance.

Gillespie et al. (2012) reported long-term tree cover increase between the 1920s and 2006 in representative areas of urban Los Angeles. Their results show that since the 1950s tree density

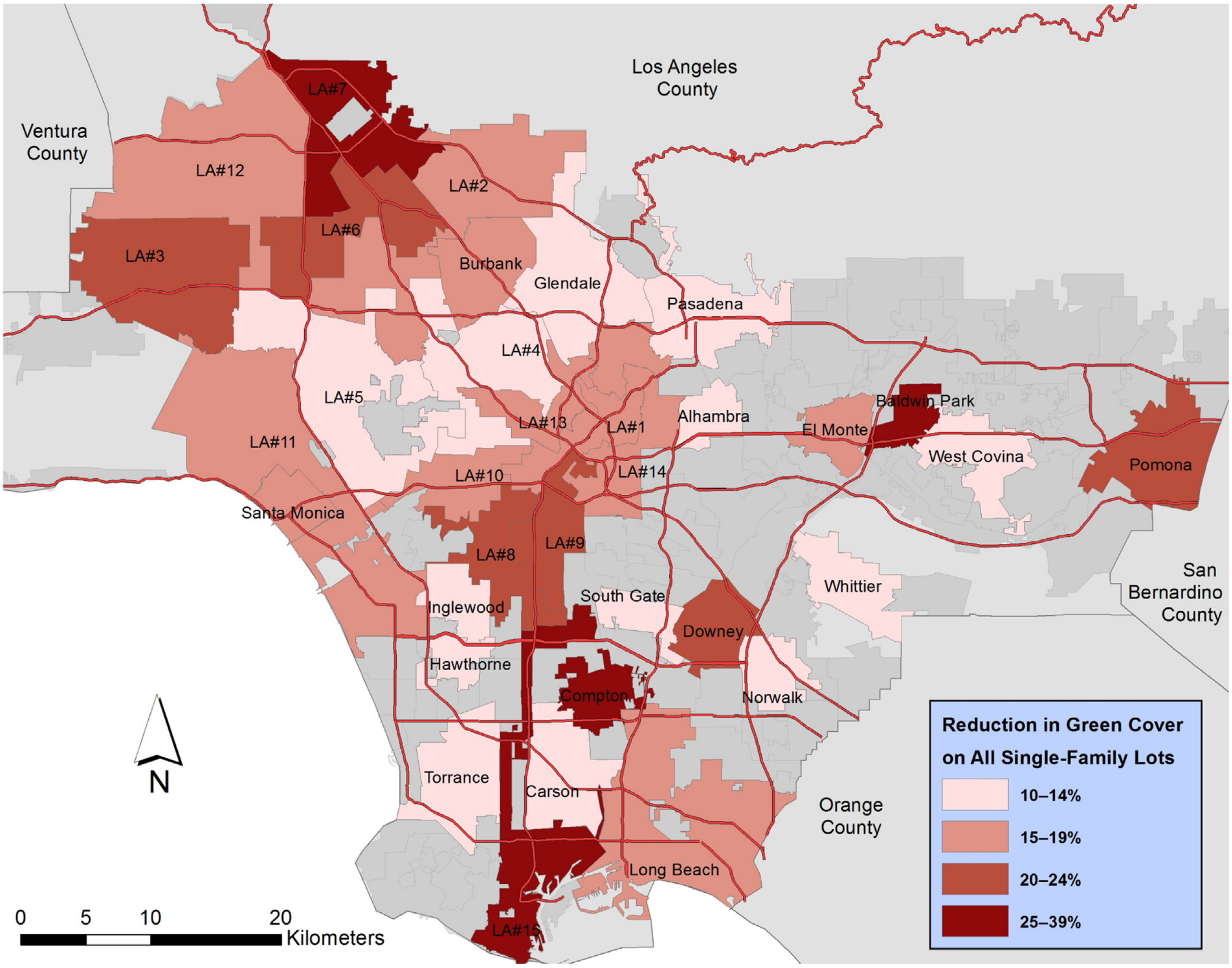

Fig. 6. Percent point reduction in green cover between 2000 and 2009 in single-family neighborhoods across the 15 City of Los Angeles council districts (LA#1–LA#15) and the next 19 largest cities.

increased much more substantially on private land than on land under public ownership. Although we measured tree canopy area, which is not directly comparable with the tree stems per acre measured by Gillespie et al. (2012), our results indicate a reversal of the long-term increase in urban forest cover dating from the 1920s through 2000 and underscore the vulnerability of the urban forest to the changing attitudes about trees on private property and especially in residential neighborhoods.

The relatively recent and rapid decline in urban tree cover in the Los Angeles Basin undermines the ability of jurisdictions to adapt to increased urban temperatures, manage urban stormwater, and maintain urban nature and quality of life. Two important processes may explain these patterns.

First, as documented in this study, the redevelopment of single-family homes through both additions and replacement construction has resulted in homes filling more of each parcel, with an associated decrease in space for green cover. In addition, property owners are increasing hardscape area significantly. For the neighborhoods across much of the region that were laid out in the post-World War II housing boom with homes that were scaled to their parcel size, this redevelopment results in large houses on small- or medium-sized parcels and a dramatic decline in green cover. Such redevelopment is seen in cities in this study with large areas of wealthy, single-family neighborhoods, such as Santa Monica, and in socioeconomically similar council districts in the City of Los Angeles (e.g., LA#3, LA#11). Our results provide evidence that the aggressive, lot-filling redevelopment of these neighborhoods (i.e., mansionization) is indeed resulting in significant changes in the urban fabric.

Second, we observed a familiar pattern from the urban forestry literature, which is continued low levels of green cover in the poorest areas, where we documented significant declines as well. The disparity between rich and poor neighborhoods in terms of tree cover is so prevalent across the U.S. that recent scholars have observed that “trees grow on money” (Schwarz et al., 2015). Such is the case in Los Angeles County, where poorer cities and council districts show both low green cover and significant declines in green cover (e.g., Compton, LA#9) during the decade we measured. We assume that these declines are associated with either owners or absentee landlords removing trees to avoid the expense of their care or to make way for legal or illegal housing densification. Ironically, both rich and poor neighborhoods alike saw reductions in green cover and increases in hardscape during the study period, but the poorest neighborhoods started with less green cover and the smallest parcel sizes to accommodate additional development. It is our observation that speculative development drives the increased home and hardscape extent in middle and upper income neighborhoods, while economic necessity leading to densification drives the pattern in low income neighborhoods and future research could investigate these overlapping forces in the market.

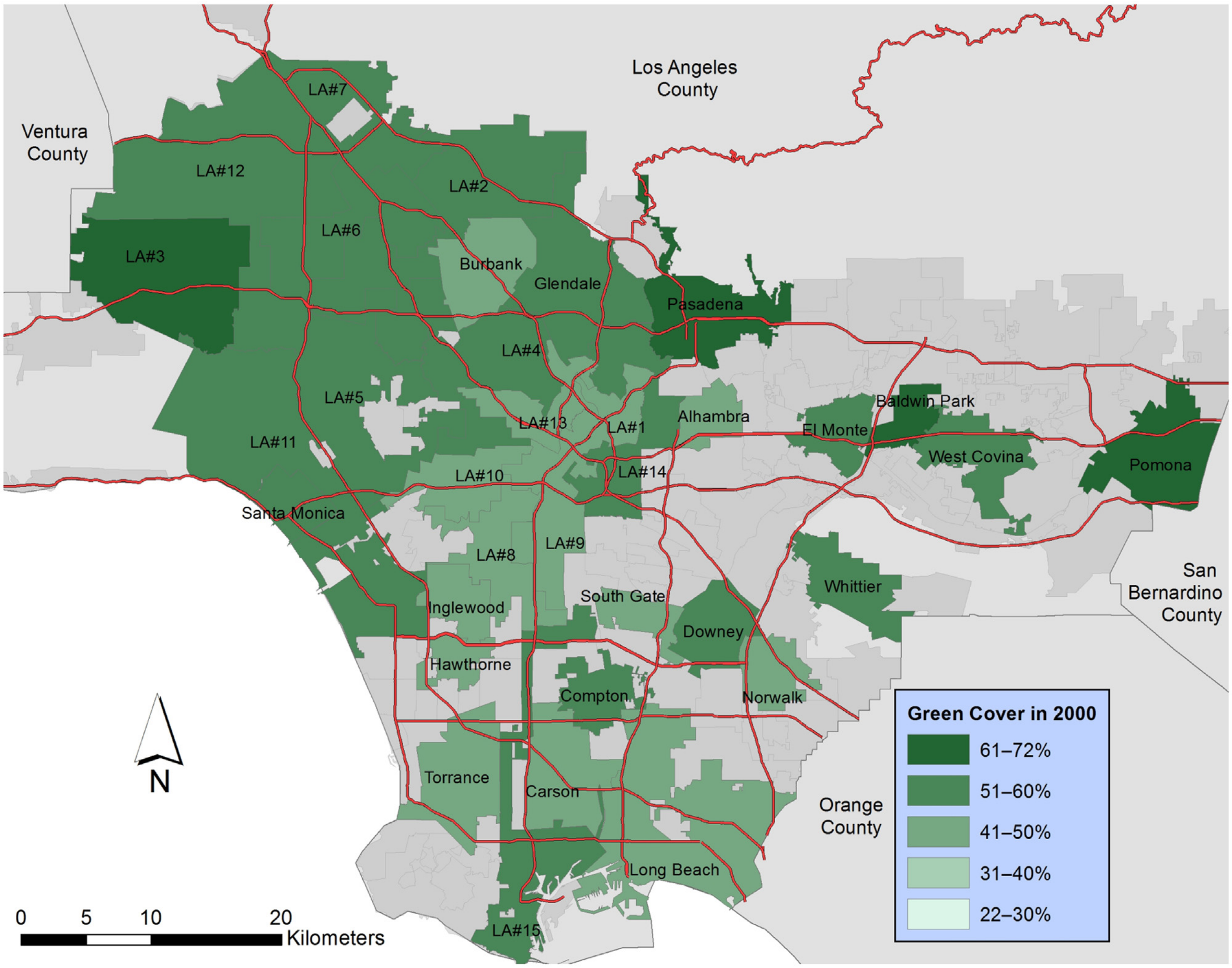

Fig. 7. Percentage green cover in 2000 in single-family neighborhoods across the 15 City of Los Angeles council districts (LA#1–LA#15) and the next 19 largest cities.

5.1. Efforts to increase tree cover

In 2006, then-Mayor Antonio Villaraigosa established the “Million Trees LA” initiative, which focused on planting new trees on private land rather than public land (McPherson et al., 2011; Pincetl, 2010). McPherson et al. (2008) developed tree-planting scenarios in which the City of Los Angeles planned to encourage residents to plant 290,000 new trees through 2010. Although the benefits of such a program would take many years to manifest, our results from 2009 indicate that if any increases in tree cover on single-family residential properties resulted from the program, they were more than offset by tree removal to accommodate additional hardscape and larger homes.

Monitoring of urban forest cover would have been a valuable tool for this program, which merged with another tree program in 2010 to create a new program known as City Plants. The tree-planting initiative was arguably a failure in policy direction because it did not recognize that tree canopy was already being eroded rapidly for construction and hardscape. Rather than focusing on protecting trees that had been grown and nourished over decades (see Gillespie et al., 2012), it attempted to increase canopy cover by planting new trees. In retrospect, this effort was shoveling sand against the tide.

Many cities in the U.S. implemented large-scale tree planting programs in the mid-2000s because of a growing recognition that urban forest cover can improve human health, socioeconomic conditions, and the environment (Arnberger and Eder, 2012; Clarke et al., 2013; Gillespie et al., 2012; McPherson et al., 2011; Nowak and Greenfield, 2012; Pincetl et al., 2013). Similar to our results, however, Nowak and Greenfield (2012) investigated 20 U.S. cities over the previous decade and reported that tree cover had decreased in 17 of them (including Los Angeles). Tree cover had been reduced by about 0.27% per year and impervious surface had increased by 0.31% per year (Nowak and Greenfield, 2012).

5.2. Legal or illegal residential development

Our results also uncovered a pattern we were not originally investigating—widespread increases in building footprint for parcels where no legal increase in square footage had been reported to the Assessor. We had included samples of parcels where the recorded building footprints had not changed as a control to compare with the effects of increasing building footprints on land cover, expecting that changes in tree cover at such parcels would be the result of natural changes in landscaping over time, impacts from re-landscaping, and other factors. Instead, we discovered that the remotely measured footprints of buildings in many instances had increased without being recorded by the Assessor. The two likely explanations are that 1) the owners of these properties had building permits to increase building area but those increases were not reported to the Assessor or were delayed in being reported, or 2) the owners did not have permits for the additional building

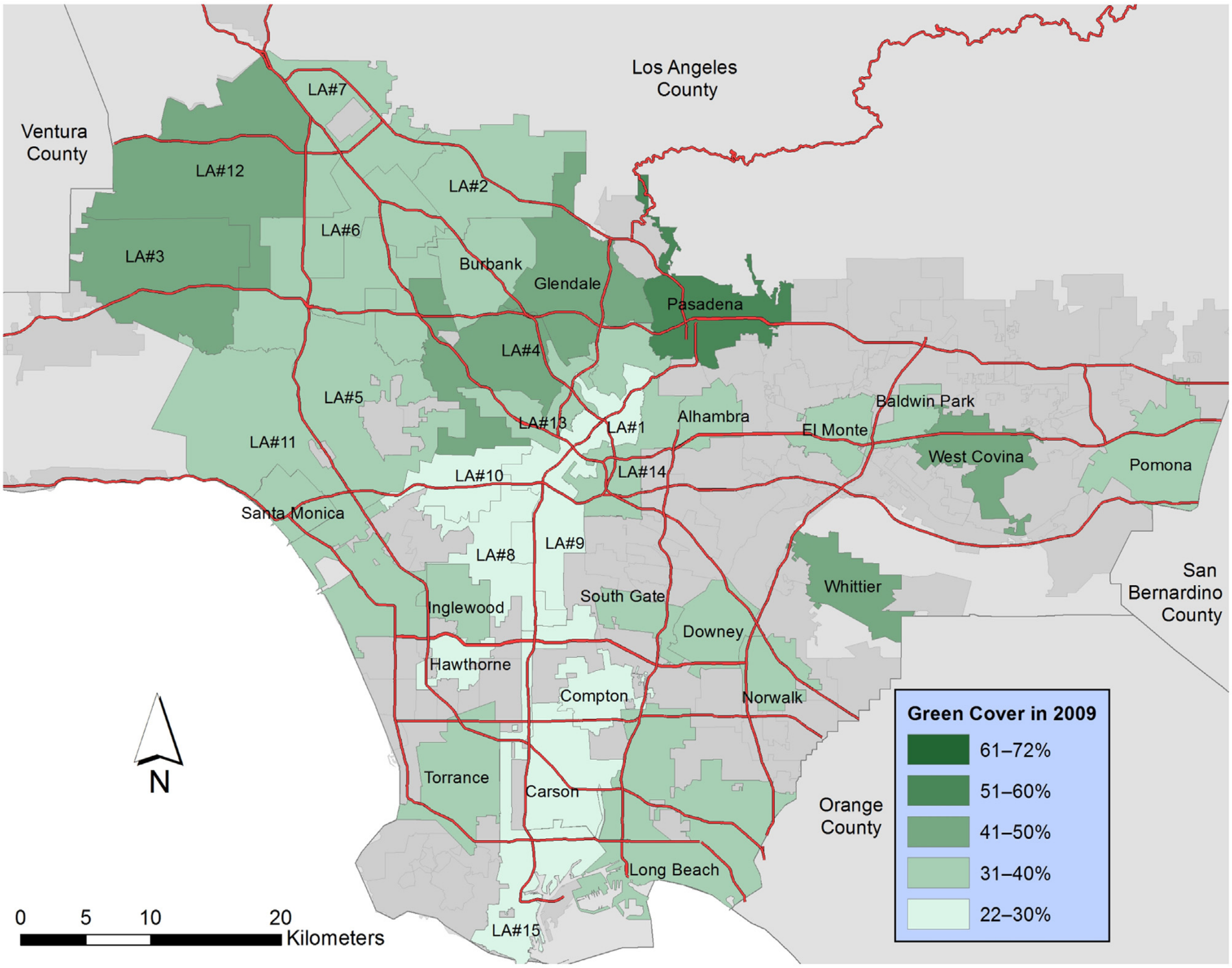

Fig. 8. Percentage of green cover in 2009 in single-family neighborhoods across the 15 City of Los Angeles council districts (LA#1–LA#15) and the next 19 largest cities.

area. In either scenario, the Assessor had not recorded the full area of the houses in many instances. Furthermore, the level of additional, unrecorded development was significantly greater in the City of Los Angeles compared with all other cities. The two possible explanations for this pattern are that the City of Los Angeles is ineffective at ensuring compliance with its building codes and/or it is much slower at reporting new permitted building to the Assessor. Smaller cities with good reputations for a well-functioning city government (e.g., Burbank, Glendale) have much lower levels of presumably unpermitted development and far lower rates of urban forest removal as a result.

Our discovery of apparently widespread expansion of home size without associated recording by the Assessor has important implications for municipal finance. Because of the tax system in California, upward assessment of property values is significantly constrained. One of the few opportunities for municipalities to increase tax revenues is when properties are redeveloped. The existence of many properties for which redevelopment has occurred but reassessment for tax purposes (tied to the legal square footage) has not is therefore extraordinarily problematic because it represents the annual loss of millions of dollars of uncollected property taxes.

6. Conclusions

Fully one-third of the existing green cover of each single-family residential lot is lost during the average home expansion in the Los Angeles Basin. The rate of redevelopment in our study area was sufficiently high that green cover is declining cumulatively at a substantial annual rate across single-family neighborhoods as a whole. Because low density residential land uses represent a substantial portion of the land area of most cities, actions to address these private land uses will be necessary to protect the ecosystem services and natural amenities provided by trees and green cover.

The pattern of residential redevelopment seen in the decade we measured may have been subsequently slowed by an economic downturn, but the following economic recovery has seen an equally rapid increase in housing prices and associated development. Indeed, for all cities with population growth and appreciating real estate prices over the long run, increases in home size and resulting decrease in green cover are likely, and this factor may be at the root of at least part of the documented national patterns of urban tree cover decline (Nowak and Greenfield, 2012). Furthermore, the trend toward increased densification across all land uses as manifested by efforts to weaken single-family zoning and densify multi-family zoning in cities with high housing pressures (e.g., Los Angeles, Seattle) also seems likely to continue. As we have shown previously (Lee et al., 2010), residential density decreases green cover in Los Angeles cities while laws that protect tree species on private property and limit floor-area ratios are associated with higher green cover, similar to findings in other regions (Troy et al., 2007; Landry and Pu, 2010). Without regulations that specifically protect existing tree and green cover the ability of cities to maintain a healthy and ecologically vibrant urban landscape will be hampered.

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