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Evaluating the effects of turf-replacement programs in Los Angeles

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ABSTRACT

Water utilities incentivize turf replacement to promote water conservation, but the effects of such programs have received limited evaluations. In 2014, the Metropolitan Water District of Southern California (MWD) undertook an unprecedented investment to incentive turf replacement throughout Southern California in response to a serious Statewide drought. MWD devoted $350 million to the program, resulting in more than 46,000 rebate payments (25,000 in Los Angeles County) to remove 15.3 million square meters of turf. The program implementation provided a unique opportunity to address research gaps on turf replacement implementation. We analyzed socioeconomic and spatial trends of program participants and assessed landscape changes from turf replacement using a random sample of properties (4% of LA County participants in 2014–16). Specifically, we used a novel and cost-effective approach *Google Earth Street View* to characterize landscapes in front yards and created a typology of land cover types. Results showed: post-replacement landscapes had a diversity of land cover types – diverse yards with several land cover types, as well as more homogenous yards with a single land cover such as woodchips, bare soil, gravel, and artificial turf. Analysis also indicated some evidence of "neighborhood adoption" effects. We describe the need for longitudinal studies to understand long-term effects of turf replacement and associated water use, and suggest that water utilities should also evaluate results in backyards, which requires site visits. This study provides a novel contribution that can be replicated over space and time to further knowledge of turf replacement program implementations and evaluation.

1. Introduction

Lawns are dominant landscapes in many North American neighborhoods, even in drier western states with limited and seasonal precipitation (Robbins, 2007). Maintaining green lawns in such areas with grass species that are better acclimated to wetter climates requires significant irrigation and may not be sustainable. Population growth and increasing competition for water between agriculture and urban areas, as well as among cities, are straining available water resources in Western North America, raising questions about the availability of water for lawns relative to other uses (MacDonald, 2007; McDonald et al., 2011). Cities such as Mesa, AZ, Las Vegas, NV, Austin, TX, Albuquerque, NM, along with several regions in California, have funded turf replacement as a way to achieve long-term reductions in water demand (Addink, 2005; Agthe, Garcia, & Goodnough, 1986; Hollis, 2014; Sovocool, Morgan, & Bennett, 2006). Even without fully removing lawns, changing the varieties of planted species and associated social expectations of yard appearances, reducing excess irrigation, and promoting tree canopy cover to reduce turf water losses can potentially yield more drought-tolerant and amenable landscapes in arid western U.S. climates (Johnson, Rossi, & Horgan, 2013; Kjelgren, Rupp, & Kilgren, 2000; Litvak, Bijoor, & Pataki, 2013).

Despite investments by some water utilities in turf replacement, however, evaluative studies of the effects of turf replacement programs are limited (DeOreo & Mayer, 2012; Mayer, Lander, & Glenn, 2015). In general, retrospective evaluations can examine: (1) effects of turf removal on water use and conservation savings (Hollis, 2014; Sovocool & Rosales, 2004; Sovocool et al., 2006), (2) changes in land cover and the composition of plant species after replacing turf (Agthe et al., 1986; Sovocool & Morgan, 2005), (3) socio-demographic trends in program participation, (4) social preferences of implemented (and presumably water conserving) landscapes on the part of both residents and

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professional landscapers (Hooper, Endter-Wada, & Johnson, 2008; Kilgren, Endter-Wada, Kjelgren, & Johnson, 2010; McCammon, Marquart-Pyatt, & Kopp, 2009), and (5) cost-effectiveness of such programs for water savings and associated cost drivers (Addink, 2005; Agthe et al., 1986; Baker, 2017; Helfand, Sik Park, Nassauer, & Kosek, 2006; Jessup & DeShazo, 2016; Sovocool & Rosales, 2004; Testa & Newton, 1993). Here, we address two of the above topics by presenting an analysis of land cover composition and structure that results from turf replacement, as well as socio-demographic trends in program participation. We evaluate landscape changes to front yards of properties participating in a large-scale turf replacement program in the service territory of the Metropolitan Water District of Southern California (MWD). The analysis examined observed changes in landscapes directly resulting from turf replacement based on analysis of properties before and after implementation. Systematic studies of program participation and effects, in this program and similar ones in other areas, are typically not conducted or not available in research. We undertake the task of evaluating landscape effects by combining imagery data with knowledge of rebate implementation. Our study did not survey residents, nor examine back yard landscape change due to access limitations and funding constraints. Yet, despite these limitations, our research methods provided a unique opportunity to study unaddressed aspects of turf replacement effects, which can improve knowledge for implementation and evaluation.

1.1. Existing studies of urban turf replacement

Previous studies of turf replacement have especially focused on water savings and the associated cost-effectiveness of replacing turf in relation to other water supply and demand management options (Baker, 2017; Baum-Haley, 2013; Farag, Neale, Kjelgren, & Endter-Wada, 2011; Hollis, 2014; Mini, Hogue, & Pincetl, 2014a, 2014b; Tull, Schmitt, & Atwater, 2016). Early studies tended to use small data sets of participating properties, yielding mixed conclusions on effectiveness (Addink, 2005; Agthe et al., 1986; City of Austin, 1993; Testa & Newton, 1993). The size of contemporary turf rebate programs, along with available data, has grown to support more comprehensive evaluations. Larger studies with more participants have, to date, generally (but not consistently) identified water savings from turf replacement, though a host of factors influence the effectiveness of programs, especially properly-installed irrigation systems (Hollis, 2014; Sovocool et al., 2006). Controlling for those factors requires significant data collection, including detailed account-level data, well-designed experiments, advanced statistical procedures and large datasets to control for confounding factors, and imagery (Hollis, 2014; Sovocool & Rosales, 2004; Sovocool et al., 2006; Tull et al., 2016). Tailored tools and metrics, including methods to compute excess irrigation of landscapes, assist in understanding human influences on resultant water use and conservation (Glenn, Endter-Wada, Kjelgren, & Neale, 2015). Irrigation systems can help institutionalize water use savings from converting landscapes (DeOreo et al., 2011). But the existing studies of turf replacement and resident preferences have not focused on the composition of landscapes that are installed following turf removal. Those that have generally used broad landscape categorizations such as traditional yards with turf, xeric (low-water), and combinations thereof (Hurd, 2006). A gap exists in understanding not only the water savings effects that water utilities might find most interesting, but also the ecological effects of plant diversity and landscape change that could yield a broader, multi-benefit view of turf removal in arid- and semi-arid-climate cities.

Turf replacement initiatives are one type of resource conservation program that relies on voluntary participation. Determinants of participation in conservation programs vary, driven by both social attitudes and economic incentives. Voluntary conservation actions may not have sufficient public support, especially when program goals conflict with social expectations or the need for change is uncertain. Weak correlations often exist between behavioral intentions for management or conservation actions, and a wide range of beliefs and attitudes (Cook, Hall, & Larson, 2011; Field, Dayer, & Elphick, 2017; Larson, Cook, Strawhacker, & Hall, 2010). In some cases, rebate programs may have subsidized so-called free-riders, or residents who were likely to replace lawns anyway (Addink, 2005). Even philanthropic supporters of conservation can be slow to change behavior (Field et al., 2017). Conservation and environmentalist practices, including landscape choices, are not consistent with personal values or preferences (Larson et al., 2010; Yabiku, Casagrande, & Farley-Metzger, 2008). Much more work needs to be done systematically to understand landscape change and conservation choices among many programs and across many socio-demographic groups. Our study provides observational data to help inform understanding of drivers of participation actions, along with plant and landscape decisions, in southern California, a Mediterranean climate, given conventional offerings in local plant nurseries (Pincetl, Prabhu, Gillespie, Jenerette, & Pataki, 2013).

1.2. Lawn replacement in Southern California

Like many places, lawns are dominant landscapes in California neighborhoods (Robbins, 2007). Preserving such landscapes in summer requires significant seasonal irrigation in almost all parts of the state. California urban areas use approximately 20% of the state's developed water supply, but in many areas, over half of urban water consumption in the residential sector is used for outdoor irrigation (Hanak & Davis, 2006). Some cities in California have supported turf replacement for a decade or more, but offerings are sporadic and unevenly distributed (Baum-Haley, 2013). During recent drought (2011–2016), water utilities incentivized and promoted outdoor water conservation to reduce consumption (Mitchell et al., 2017). As part of this effort, in 2014, MWD, Southern California's water importer serving a 13,468 square kilometer region and nearly 19 million people in the coastal and Inland Empire regions, implemented the largest single investment by a water utility to date in turf replacement. It revamped its existing regional turf replacement program, which had funded $100 million annually of incentives, and increased available funds across its service territory to $350 million. Residents received $2.00 of incentives per square foot ($0.09 per square meter) of lawn removed, which was subject to payment upon providing documented evidence of turf replacement (MWD, 2015). This was potentially boosted by additional local incentives, such as in the cities of Los Angeles and Long Beach. MWD received over 85,000 applications for the 2014 program.

By mid-2015, program funds were exhausted, paying out 46,000 rebates to replace more than 165 million square feet (15.3 million m^2) of turf (M. Hollis, personal communication, December 10, 2016). Such programs aimed to change landscapes and resident behavior, achieving long-term water savings rather than just short-term reductions (Office of the Governor of California, 2016). Turf removal incentives in California have been provided at local, regional, or state levels, but for Southern California, the availability of monetary incentives has not been consistent throughout service areas, nor year to year.

The habits of water use, including outdoor water, are subject to many factors. For instance, water demands across all end-uses in the city of Los Angeles were extensively analyzed by Mini et al. (2014a, 2014b) in longitudinal studies, including under a period of drought. Higher water prices and mandatory irrigation restrictions contributed to water conservation behavior, but was not directly related to landscape change as there were no turf replacement incentives in place. Further, lower income neighborhoods curbed water use more than wealthier neighborhoods. Recent post-drought data has shown that throughout California, sizable gains in outdoor water conservation achieved during periods of drought often reverse, though not always fully (Gonzales & Ajami, 2017; Hanak & Lund, 2011; Mitchell et al., 2017). Water use levels have tended to regress to amounts that are higher than during peak conservation, but often not as high as at the

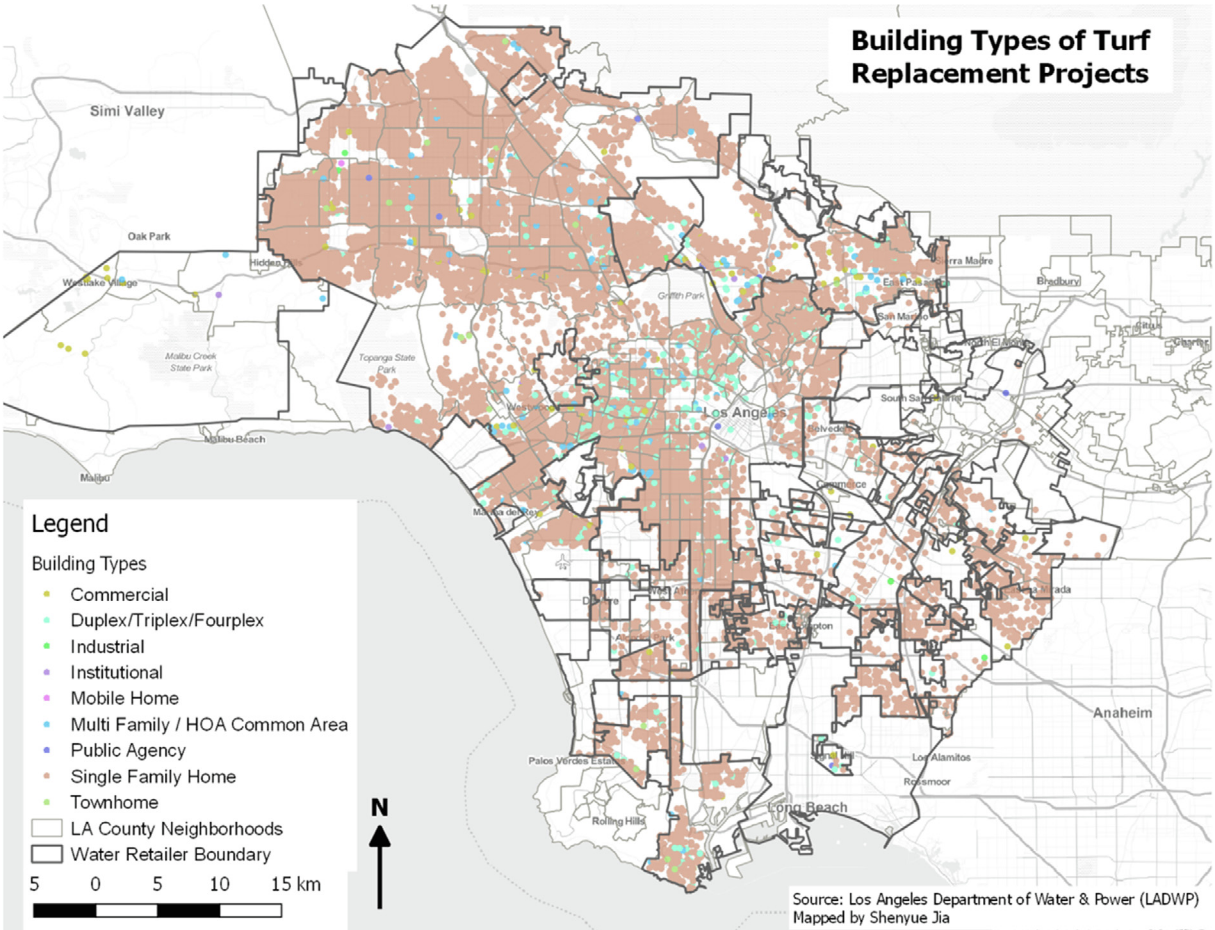

Fig. 1. Participating locations in Metropolitan Los Angeles County area and property types. Ninety-six percent of these locations were single family homes.

beginning of drought (SWRCB, 2018). Technological innovations, new fixtures, and converted landscapes help promote long-term savings, but for lawns that remain, irrigation habits tend to revert to prior practices, as evidenced by urban water use trends after past droughts (Mitchell et al., 2017).

Prior to recent drought, many southern California cities had been slow to transition to low-water landscapes, due in part to the region's access to multiple sources of imported water. The boost in program funding from MWD created a unique environment among turf replacement initiatives. Freedom to choose new landscapes resulted in a diversity of post-replacement landscapes based on participant preferences regarding design, composition, drought-adapted plants, and non-turf land cover types. A comprehensive evaluation of turf replacement habits can help summarize and understand landscape choices, including important questions such as whether all participants converted turf to drought resistant landscapes. To date, no comprehensive analysis of participants exists and there is no data on the floristic composition, species richness, or structure of these new landscapes.

1.3. Key research questions

Our research sought to answer three key research questions regarding turf replacement program outcomes:

(1) What were the socio-demographic, economic, and geographic characteristics of turf replacement program participants?
(2) What plants and landscape types were installed?
(3) Is there evidence of neighborhood adoption effects, whereby a resident who participates in a program spurs additional nearby neighbors to also replace their turf?

The results can provide critical information about the results of large-scale turf removal programs for landscape and land cover change as California is increasing broad planning efforts to address long-term water management and climate change adaptation challenges.

2. Methods

2.1. Study area

The program evaluation focused on Los Angeles County (LA County). LA County has over 10 million residents and more than 100 water agencies (Census, 2013; Pincetl, Porse, & Cheng, 2016). The climate is Mediterranean, characterized by dry summers and wet winters, with an average temperature of 16 °C and 562 mm of rainfall annually. MWD, the Los Angeles Department of Water and Power (LADWP), and the San Gabriel Valley Water District all import water to the region, with MWD and LADWP being the dominant water importing entities. Agencies also use groundwater, recycled water, and storm water capture to meet demands and recharge local groundwater basins. MWD sits atop a hierarchy of water utilities that include importer, wholesaler, and retailer agencies that are all involved in integrated water management, including both demand and supply measures, for the region. The Metropolitan Los Angeles County area where the turf replacement was studied has an average 46% home ownership rate and median household income of $57,952 (2012–2016).

2.2. Participant data

We received confidential program participation data for the turf replacement program directly from MWD. The database included 24,921 distinct records. Properties participating in the MWD Turf Replacement Program were provided as street addresses. The program participants were dispersed across the county's underlying water retailer agencies, with many larger agencies tending to have residents who participated in the program, while smaller agencies did not. We geocoded and mapped properties using Address Locator built for *ArcGIS* by LA County GIS Enterprise GIS. Fig. 1 shows the types of properties (municipal land use categorizations) that participated in the turf replacement program, along with boundaries for local neighborhoods and water retailer agencies. Geocoding allowed for quantifying the number of participants by the various jurisdictions used to categorize Los Angeles County, including water utility boundaries, cities, neighborhoods, and U.S. Census boundaries such as tracts or block groups that have associated statistical data.

Using the geocoded data and focusing specifically on single-family homes, which comprised 96% of the participating properties, we tallied the number of participants by U.S. Census tracts and block groups, which allowed for investigating correlations between participation and socio-demographic trends (Fig. 2). Block groups are standardized high-resolution geographic units with populations of 600–3000 people. The US Census Bureau regularly publishes block group level data with hundreds of associated descriptive characteristics based on surveys from the decadal Census and the American Community Survey (ACS). We collected median income, median household income, and owner occupation rate from the ACS, along with median parcel area from Los Angeles County Tax Assessor's parcel database and rebate rates from retailer surveys.

2.3. Landscape data

Landscapes can be classified according to plant typologies (e.g. life forms: shrub, herbaceous), water use (e.g. high, medium and low), and land cover variations (vegetated, mulched, gravel, and others) (Anderson, Hardy, Roach, & Witmer, 1976; Sun, Kopp, & Kjelgren, 2012). For this analysis, we devised a methodology to classify landscapes following turf replacement according to plant typologies, the number of distinct species, percent vegetation cover, and land cover type, which we applied to front yards. The types of plant life forms included grasses, perennial herbs, succulents, shrubs, and trees. Percent vegetation cover categories were 0–25%, 26–50%, 51–75%, 76–100%. Finally, land cover types included woodchips, bare soil, gravel, stones, artificial turf, and shrubs, grasses, and traditional turf. Properties were classified according to combinations of one or more land cover types.

We randomized all addresses in Excel and randomly selected a sample set of 1000 single family properties from the database to analyze using *Google Earth Street View* images. Selected properties had to meet criteria of having imagery available for dates after the recorded date of project installation. Using *StreetView* necessarily restricted our analysis to front yards only. Of course this means we could not classify the back yards and thus are not able to provide analysis of the overall success rate of the program. For the 1000 randomly selected properties, we used *Street View* to derive 13 variables that characterized vegetation

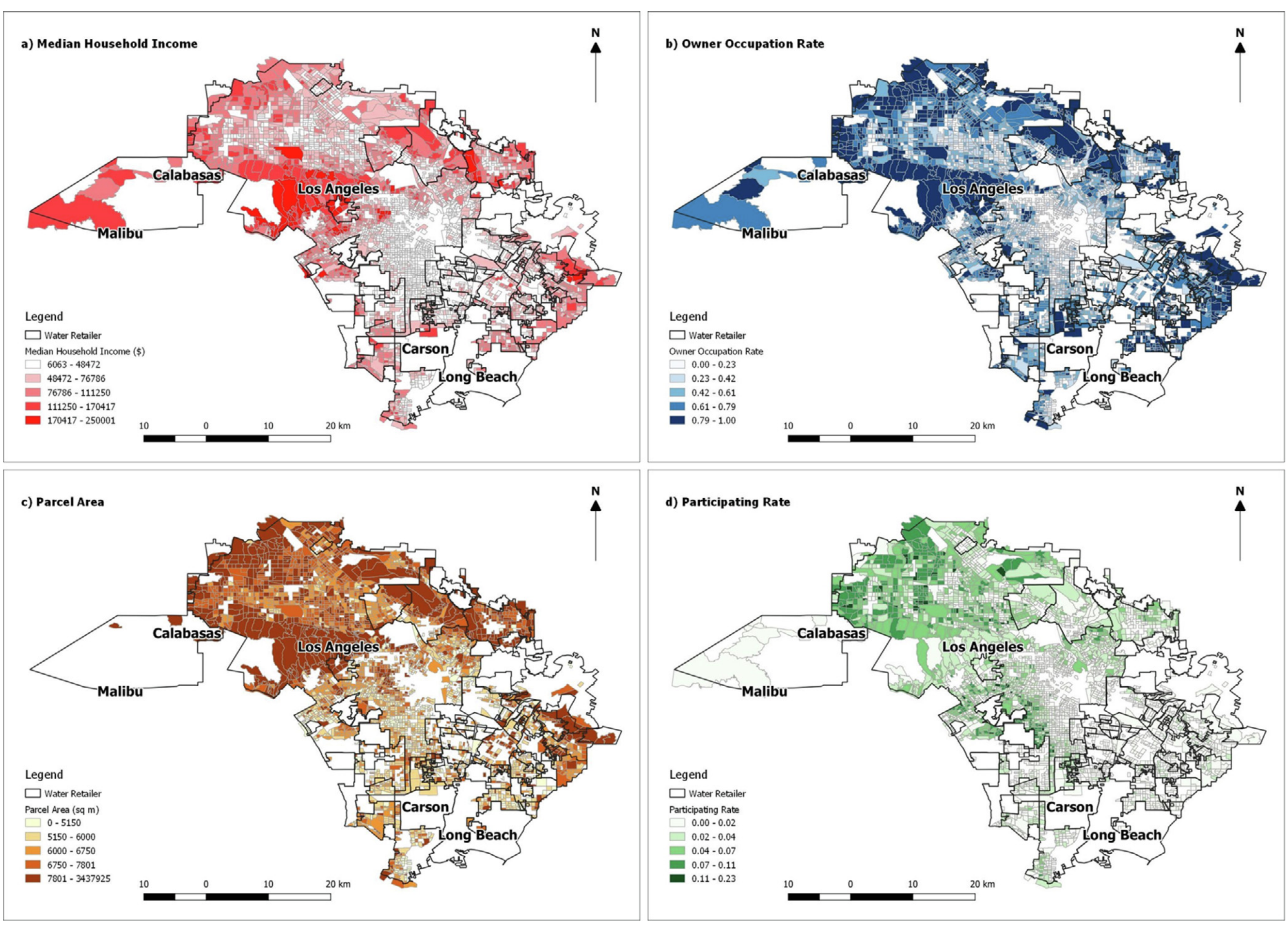

Fig. 2. Metropolitan Los Angeles County water retailer's boundaries and median household income (a), owner occupation rate (b), parcel area (c), and participating rate (d) by census tract.

Table 1
Variables quantified using Google Street View imagery for 1000 front yards in Los Angeles County.

Variable	Description	Unit
Current Data	Record of last *Google Earth Street View* image	Month-Year (mm-yy)
Length and Depth	Measured yards through Google distance too, does not include city property or driveways	Meters
Lawn Removed?	Describes if the lawn was removed	Yes, No, Partial
Vegetation Cover	Amount of yard covered by vegetation	Four categories of percent vegetation cover: 0–25, 26–50, 51–75, 76–100.
Grasses	Presence of lawn or ornamental grasses	Yes or No
Perennial Herbs	Presence of perennial herbs	Yes or No
Succulents	Presence of succulents	Yes or No
Shrubs	Presence of shrubs	Yes or No
Trees	Presence of trees, with a diameter at breast height (1.3 m) of 2.5 cm	Yes or No
Natives	Presence of prominent native species	Yes or No
Number of Species	Species richness, the number of different species present	Count
Classification Type	Surface type ordered from greatest present to least present	Grass, woodchips, stones, Artificial turf, groundcover, shrubs, etc.
Neighborhood Impact	One or more neighbors changed their lawn	Yes or No

cover, plant lifeforms, plant species richness, and landscape typologies (Table 1; Appendix 1). The assessment validated that landscape changes were from turf replacement by examining pre- and post-installation images. The quantified variables were recorded for the post-replacement images. After validating the classification schemes using a training set of previously selected properties, each address was entered into *Street View* between June and December 2016. For each, we recorded the date (month and year) that the *Street View* image was collected. We estimated areas of front lawns using the *Street View* distance measurement tool. We measured the length and width in meters of each front yard on private property, excluding driveways and municipal property. The length and width were used to calculate the area of the front lawn (m^2). Lawn changes were recorded as “Yes”, “No”, and “Partial”. A change was considered “Partial” if residents only changed some of the original lawn or they only added stone, brick, woodchips, or paved walkway. No rebates were available if a lawn was not replaced.

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.landurbplan.2019.01.011.

Vegetation was estimated into the four categories based on the percent vegetation cover of front yards and we identified the presence/absence of the plant types for each location to quantify lifeform diversity. We calculated plant species richness by systematically navigating the front yard from the sidewalk to the residence and identifying the number of unique plant species visible in *Street View*. We also identified species native to California and recorded their presence/absence at each location. Finally, we used *Street View* to view neighbors to the right, left, and across the street of the program participant to identify if they did turf replacement. All *Street View* imagery for the 1000 properties were archived as JPEG files.

We could not determine the exact percentage of a rebate amount dedicated to the studied front yards, as the recorded data did not include this information. We do know that most households applied for both front and back from MWD program data, but determining the amount spent for the front uniquely was beyond our capacity given available and verifiable data. Further, full turf replacement costs – whether front, back or both – likely exceeded the rebate amount and are highly variable, varying with lot size, full or partial replacement of existing landscapes, type of irrigation installed, thoroughness of replacement (e.g. pulling all the grass out, installing weed barriers), density of planting and size and type of plants.

2.4. Statistical analysis

We calculated descriptive and spatial statistics to understand program participation characteristics and geographic dispersion. Specifically, we investigated socioeconomic and spatial determinants of participation in Los Angeles County properties. We conducted statistical analyses of the data at both disaggregated (household level) and aggregated (water retailer boundary, U.S. Census block group, neighborhood level) scales. Disaggregated data was mapped and basic statistics were quantified, such as the number of rebates and associated project size. We then aggregated the data, quantifying and mapping participation by US Census block groups. We assessed participation as a standardized metric, *participation rate*, to normalize for differences in population. The participation rate was quantified by dividing the number of turf replacement projects in single-family homes within a block group by the total number of households in that block group. We included only block groups with at least one completed turf replacement project in the analysis. Only single-family homes were included, which comprised 96% of the projects reported in our study set. We then mapped the distribution of program participation by block group. The turf replacement rate by block group served as the response variable for statistical modeling of turf replacement participation. Block group size did not differ significantly other than in Bel-Air, where a large portion of the block group is mountainous with few residential dwellings. By converting the raw count of projects into participation rates, we addressed the issue of different population sizes across block groups and the extremely low participation issue (one project inside the block group). This method also ensured individual participant privacy.

We associated turf replacement rates within water agency boundaries and U.S. Census block group boundaries with associated data. Socioeconomic data was derived from the American Community Survey (US Census, 2014). We also incorporated the Los Angeles County Assessor data to include the parcel area of properties. Together, these depicted physical and socioeconomic factors potentially associated with participation. Based on an initial investigation of the spatial distribution of the completed replacement projects, explanatory variables for socio-demographic indicators and rebate program characteristics were tested for correlation with participation using a Queen’s Contiguity Weighted Matrix, which is a first step in univariate or bivariate LISA procedures (Ord & Getis, 2001). This was calculated and mapped at the block group level using the GeoDa spatial statistics software to illustrate potential clusters (Anselin, 2014).

To investigate factors that may have influenced participation, we used Ordinary Least Squares (OLS) regression and Fixed Effects regression, along with a Local Indicator of Spatial Autocorrelation (LISA) procedure to include potential spatial aggregation. We included owner occupation rate, median income, median household income, rebate rate, and the property area as the explanatory variables in the OLS model. The owner occupancy rate was used to investigate any correlations with property-level population density. The rebate rate and the property area defined the amount of rebate that could be redeemed through the turf replacement initiative. This was coupled with the block group level median income to assess whether the rebate program was attractive. Participation rate at the block group level was included as the response variable. Evidence from rebate programs in other sectors such as energy efficiency indicates that homeowner participation in rebate programs varies by geography and sociodemographic characteristics (Porse, Derenski, Gustafson, Elizabeth, & Pincetl, 2016). For instance, middle- and higher-income households are more likely to participate in large-scale projects. For turf replacement, this may indicate that higher income populations have greater access to upfront capital to supplement the rebate and information, resulting in higher participation and more extensive landscape transformation.

Spatial clustering by neighborhoods and water retailers was believed to be prominent in the turf replacement participation. Although the socioeconomic variables we applied in the OLS model can partly explain such aggregation, we also employed a fixed effects model (Eq. (1)) to address the unobserved neighborhood and water retailer level factors from the existing explanatory variables, such that:

$$y_i = X_i\beta + \alpha_i + u_i, \tag{1}$$

In Eq. (1), y_i is the participation rate of block group i, X_i is the same explanatory variable matrix used in OLS model, β is a vector of coefficients for the explanatory variables, α_i is the fixed effect parameter to address the unobserved neighborhood or water retailer effect, and u_i is the standard error term.

3. Results

3.1. Program participation factors

Program participation was not evenly dispersed throughout Los Angeles County. Properties lying within the service territory of a water retailer that offered supplemental rebate amounts in addition to MWD comprised the vast majority of participants. One retailer, LADWP, dominated the turf replacement applications with more than 20,000 of the 24,921 records used in the analysis (Appendix 2). This likely results from LADWP's significant additional rebate amount. Results from statistical analysis revealed correlations with explanatory variables and potential clustering of projects. The weighted matrix indicated evidence of geographic clustering at block group level (Fig. 3). The San Fernando Valley and areas in West Los Angeles had higher clustering of participation among block groups (in the LADWP service territory), while some eastern and southern parts of LA County showed lower participation (in other water district territories).

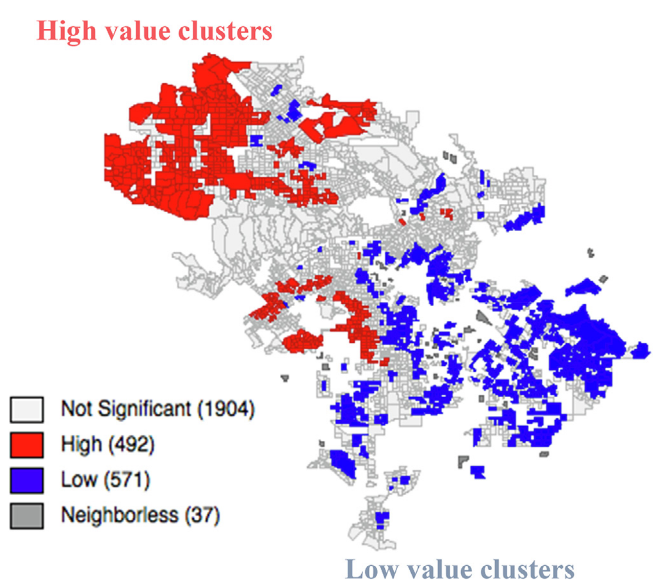

Fig. 3. High (red) and low (blue) participating clusters at the block group level based on geographically weighted regression. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The fixed effects regression indicated that participation rates were positively correlated with owner-occupancy and negatively correlated with median income significantly (Table 2). The rebate rate was also significant, but inconsistent across retailers and likely dominated by the larger number of LADWP participants. Property area (size) was not a significant contributor to the participation rates. The OLS regression model also showed similar correlations, though the coefficient of determination was lower (0.346). The significant improvement in the fit of the fixed effects model was primarily due to introducing the fixed effects term at the neighborhood level (Fig. 4). It indicated that some local factors that may contribute to the willingness of participation were not captured by the existing explanatory variables. Introducing a fixed effects term for analysis of participation by water retailer boundaries, however, did not improve the model significantly because rebate rate was powerful enough to explain the difference between water retailers.

3.2. Landscape change analysis with Google Earth Street View

The random sample set of 1000 single family properties was spatially dispersed throughout LA County (Fig. 5). Of the 1000 properties in the sample set, 653 properties showed full removal of lawns, 98 showed partial removal of lawns, and 178 showed no removal of lawns based on images of front yards available at the time of analysis. Researchers could not ascertain whether turf had been replaced in the back due to a lack of data. The remaining 71 addresses could not be validated because the front yards were visually blocked or imagery was not available for the appropriate time periods. Of just the properties with available imagery, 70% of participants had full lawn removal, 11% had partial removal, and 19% showed no front lawn removal. Front lawns had a mean length of 12.8 m (± 5.5 m), a mean width of 8.8 m (± 3.7 m), and a mean area of 117 m^2 (± 89.4 m^2).

3.3. Vegetation and plant types

Vegetation cover classes were relatively evenly distributed but a majority of replacement front lawns have less than 50% vegetation cover in Los Angeles (Fig. 6a). Most parcels contained a diversity of plant functional types following replacement of turf (Fig. 6b). Shrubs were the most common functional type at each location (67%) followed by trees (57%), succulents (30%), perennial herbs (27%), and grasses (20%) (Fig. 6c). Most locations had between 6 and 10 species (33%), followed by 11–15 species (28%), 0–5 species (8%), and 20 or more species (4%). Native California plants were identified at 131 locations (14%).

3.4. Landscape types

The dominant type of land cover differed somewhat between parcels with either full or partial replacement of turf. In parcels with full turf replacement (n = 653), land cover was dispersed among many materials. The four dominant replacement classifications for parcels with complete replacement were woodchips, bare soil, gravel, and artificial turf (Fig. 7). For properties that undertook only partial replacement of turf (n = 98), grass was still a predominant component of the resulting landscape classification (Fig. 8). It was often interspersed with other land cover types, including bare soil, gravel, and shrubs.

3.5. Neighborhood effects

We found that a sizable percentage of turf replacement sites had nearby neighbors (directly left, right or across the street) that also showed evidence of turf replacement. For a subset of properties (750)

Table 2
Socioeconomic variables and block group level participation ratios. Bolded areas were statistically significant ($p < 0.001$) prediction results (for adjusted R^2 and F-statistic) or contribution to the estimate of participating ratio.

		Ordinary least square regression	Fixed effects regression model
Adjusted R^2		0.346	0.722
F-statistic		1589	7807
Coefficient of independent variables	Owner occupation rate	**0.0451**	**0.0387**
	Median income (10 k dollars)	−0.0001	**−0.0007**
	Median household income (10 k dollars)	**−0.0950**	**−0.2100**
	Rebate rate	**0.0178**	**0.00689**
	Property area	0.0000	0.0000

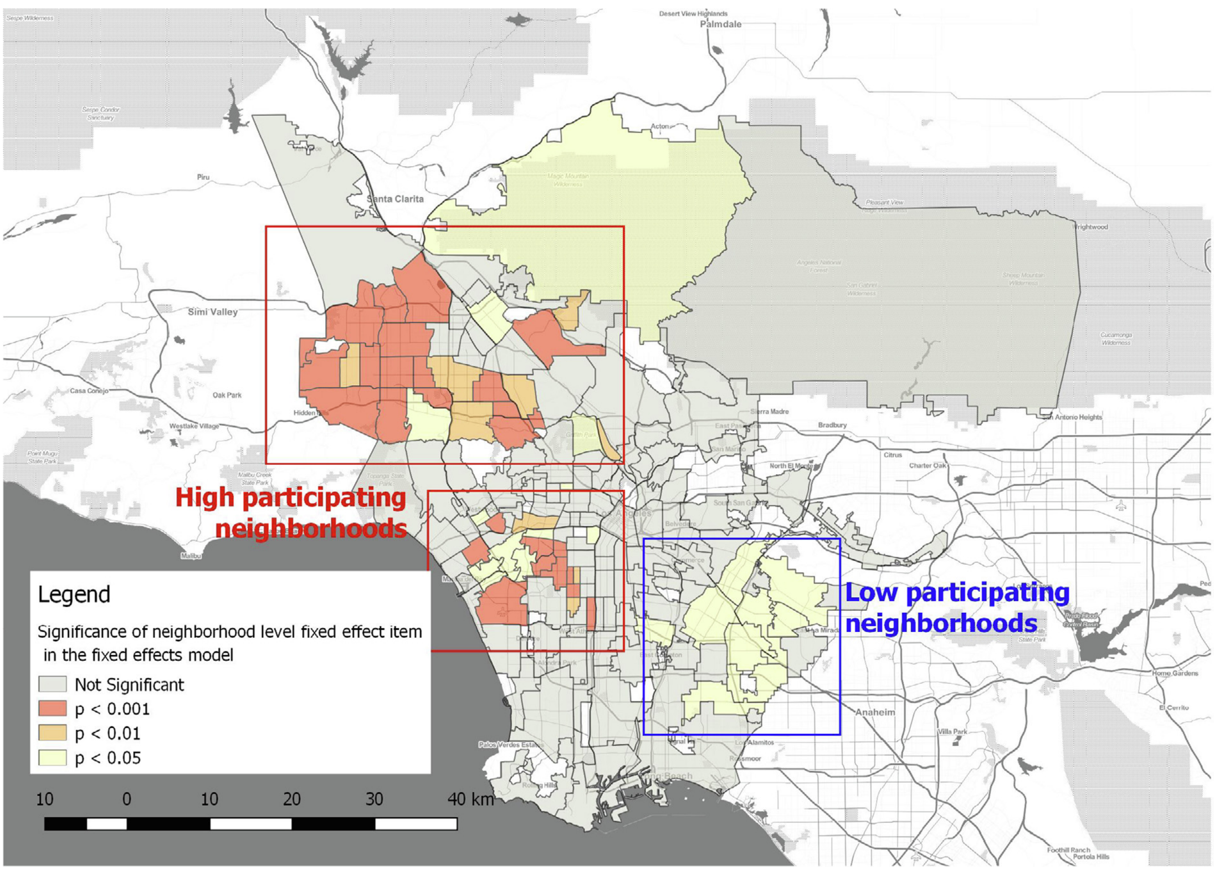

Fig. 4. Contribution from neighborhood level fixed effects to the overall model outcome. Red/blue box indicated clusters of neighborhoods with a high/low rate of participation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

showing evidence of turf replacement, 36% had nearby properties that also had partially or fully-replaced landscapes (Fig. 9a). The numbers were evenly dispersed among properties to the left, right, and across-the-street (Fig. 9b).

4. Discussion

4.1. Participation

The highest participation rates were clustered in the San Fernando Valley region of the City of Los Angeles. While likely related to the higher rebate amount offered through the combined MWD and LADWP programs, the trend also has implications for program effectiveness. The San Fernando Valley is significantly hotter than coastal areas of Los Angeles and more suburban, with generally lower population density, diverse populations, and more yard space. Replacing turf in these areas with other land cover types, or even warm-weather grasses, could result in greater per household water savings, while also yielding more significant household economic savings as a percentage of income.

Additionally, middle- and higher-income homeowners participated at higher rates, particularly in the LADWP service territory where the increased rebate that combined MWD and LADWP incentives was likely a strong motivator. Similar effects have been observed elsewhere. For instance, an older study of a rebate program in Mesa, AZ, noted that its voluntary rebate amount could have been too low to attract higher-income homeowners with preferences for lawns (Agthe et al., 1986). Relatedly, Mini et al. (2014a, 2014b) showed that with drought restrictions and a tiered pricing structure, lower income neighborhoods curbed water use proportionately more than wealthier neighborhoods. Other factors possibly contribute to increased uptake in the San Fernando Valley as well, including geographic targeting by third-party providers of turf replacement services. Higher-income households have been shown to have more vegetation cover on yards and higher willingness (or ability) to pay for landscape amenities such as native plants (Boone, Cadenasso, Grove, Schwarz, & Buckley, 2010; Curtis & Cowee, 2010; Mennis, 2006).

The amount of the total rebate, including MWD and local agency incentives, likely contributed to participation differences throughout

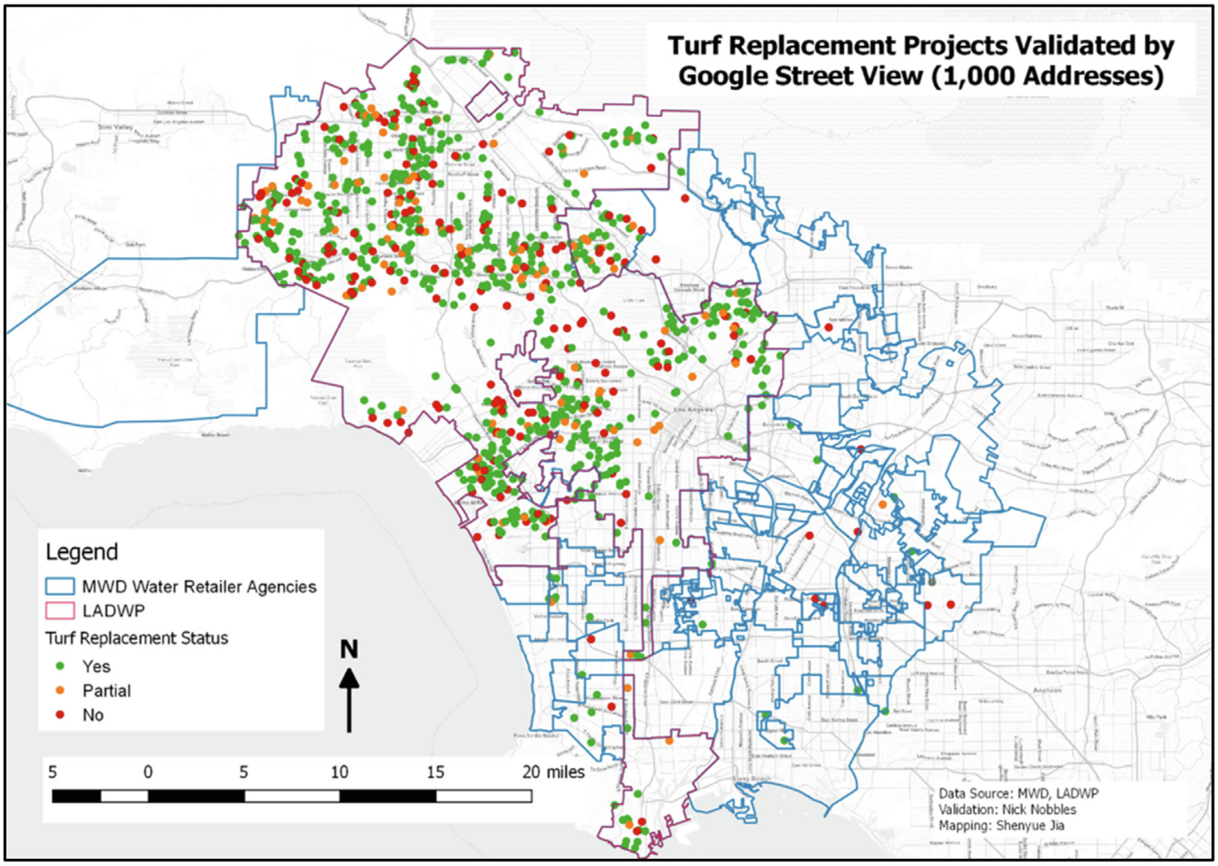

Fig. 5. Location of turf replacement projects validated by Google Earth Street View (1000 addresses).

the region. While spatial clustering of participation was found at the neighborhood level, such clustering was not sufficiently explained by socioeconomic metrics captured in the explanatory variables of the OLS model (R^2 = 0.346). The outcome of the neighborhood-level fixed effects model indicated that the fixed effects item to address the unobserved variation in socioeconomic metrics significantly contributed to the prediction. In other words, factors beyond the ownership of property, household income, and the rebate amount may have played an important role to determine participation. This finding reinforces research noting the variety of drivers for landscape preferences (Cook et al., 2011), particularly cultural and neighborhood norms in front yard design (Helfand et al., 2006). Moreover, the size, layout, and configuration of existing buildings and infrastructure can influence landscape preferences as part of legacy effects (Boone et al., 2010; Luck, Smallbone, & O'Brien, 2009).

The effects of past decisions for urban planning, such as building density, lot sizes, and other characteristics, would be a topic for further study to understand participation trends. Neighborhoods tend to have characteristic lot sizes, landscaping, and building architecture types that originate from initial construction. Our visual analysis discerned similarities in post-replacement landscapes in neighborhoods of similar style, even though they were geographically dispersed across Los Angeles County, though further study with a replicable methodology would be required to better estimate trends. Understanding these patterns through surveys and interviews could reveal landscape social and neighborhood norms.

4.2. Street View analysis

Current leading research uses vertical spaceborne and airborne imagery-derived datasets for classifying urban land cover and assessing critical variables related to urban water consumption (Cadenasso, Pickett, & Schwarz, 2007; Farag et al., 2011; Glenn et al., 2015; Litvak, Manago, Hogue, & Pataki, 2017). But these data sources and methods are often too expensive for municipalities to use in planning and evaluation, or in this case a publicly-funded study conducted by university researchers and cannot identify plants at the species level. Here, we showed that *Google Earth Street View* would enable detailed assessments of turf replacement conversions (front yards) at much lower cost, which can align with the small budgets that are typically available in municipal and water utilities for this and similar tasks. The high resolution and multi-angle imagery within *Google Earth Street View* enables the quantification of different land cover classifications, identification of general plant functional types, and even species-level identification of native plants for trained analysts.

In addition to the benefits of accessibility and cost, the *Street View* method offers other benefits. While the types of species found on properties critically influence long-term water use budgets and drought tolerance, such property-level characteristics cannot generally be determined with spaceborne or airborne imagery (Litvak & Pataki, 2016; Litvak et al., 2013; Litvak, McCarthy, & Pataki, 2017; Porse et al., 2017), in contrast to *Google Earth Street View*. For example, imagery-derived tools such as Treepedia, highly useful for tree canopy cover, cannot be used to identify specific species. Thus a manual approach, possible by using *Google Street View,* is necessary to identify types of plants visually, based on local knowledge of the plant palate generally utilized in the region, as well as native plants.

Resulting landscapes in the sample set were highly diverse and novel in relation to the prevailing landscape aesthetic in the region, which is largely lawn dominated, reflecting participant preferences and templates for replacement landscapes (plant types, arrangements, density) offered by professional turf replacement firms. This time period and significant turf replacement incentives, created professional services to replace turf. These new companies (e.g. Turf Busters) offered

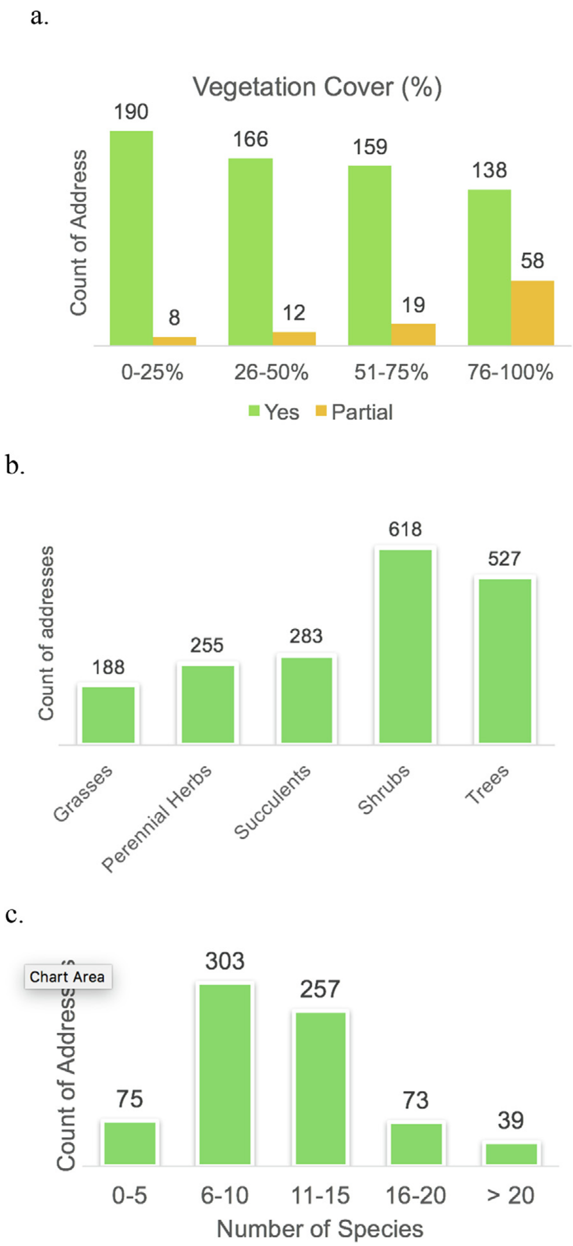

Fig. 6. Vegetation cover (a), life form diversity (b), and species richness (c) identified on properties with turf replacement.

templates from which participants could choose, with various price tags. The service providers filed for the rebates on behalf of the participants. Vegetation cover was relatively evenly distributed across the cover classes and parcels contained a diversity of plant functional types following replacement of turf. Shrubs were the most common functional type at each location, and may be an ideal functional type to promote in the future because a small number of deeply rooted species with relatively low irrigation requirements can provide vegetation cover over a relatively large area. The three-dimensional structure of shrubs and trees, the second most common functional type, supports diversity of other taxa such as invertebrates, birds, and mammals more than mono-dominant lawn species (Potts et al., 2010). The study procedure allowed for more intricately classifying land cover types in post-replacement yards than studies to date (Hurd, 2006; Sovocool et al., 2006), and suggests that the turf replacement program resulted in significant shift in plant functional types from grasses to woody species. Notably, the analysis did not specifically identify for each property that a feature such as a shrub did not previously exist, but most programs have composite lists of species that can comprise resultant landscapes.

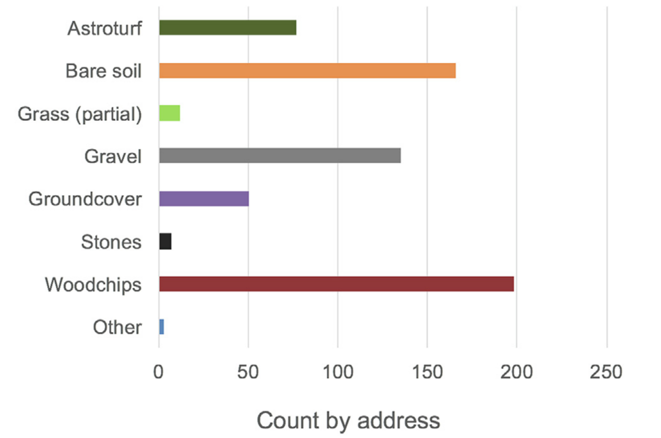

Fig. 7. Dominant landscape types on properties having undertaken full replacement of turf (n = 653).

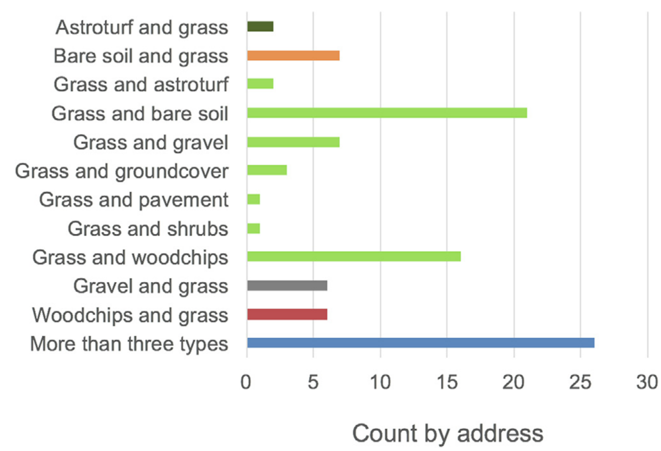

Fig. 8. Occurrences of different landscape types on properties with partial turf replacement (n = 98).

Resulting landscapes showed a higher diversity of plant species. Only 8% of front yards contained 0–5 species, while 64% of properties contained six or more species. Since front lawns on average were approximately 10 m by 10 m, six or more species is similar to native levels of perennial plant species richness for native grasslands, coastal sage, and chaparral within Mediterranean ecosystems that generally contain between 4 and 15 perennial species per 100 m^2 (Cowling, Rundel, Lamont, Kalin Arroyo, & Arianoutsou, 1996; Specht, 2012). Furthermore, 32% of front yards contained 11 or more species, which is higher than many native perennial plant communities in Los Angeles (Specht, 2012). Turf replacement with woodchips alone, or woodchips and a mix a gravel types, appeared to be associated with greater species richness.

However, native California species were not abundant in the front yards we viewed. Native trees were dominated by California sycamores (a native riparian plant) and native shrubs were dominated by California lilac, white sage, and purple sage. There is strong evidence from urban areas that native plant species increase native insect and avifauna diversity (Chace & Walsh, 2006; Isaacs, Tuell, Fiedler, Gardiner, & Landis, 2009; Potts et al., 2010), though some non-native plants can also support insects and birds too. In the future it may be appropriate to promote native perennials and shrubs from within the Los Angeles Basin (Helfand et al., 2006; Hooper et al., 2008).

4.3. Landscape types

The four dominant replacement classifications for parcels with

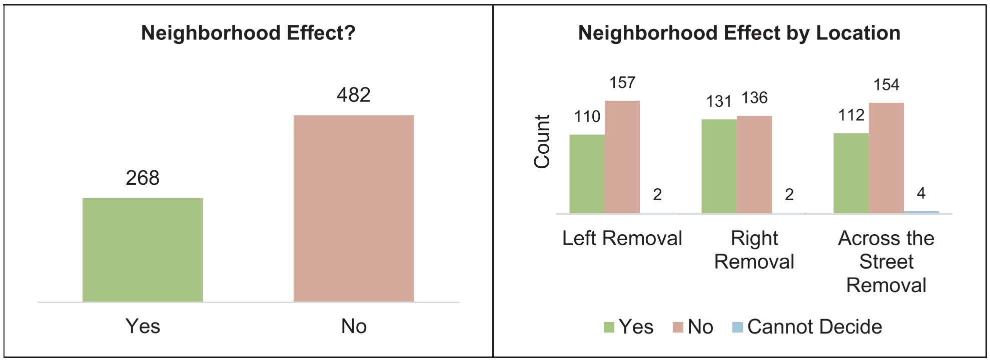

Fig. 9. Neighborhood effects of front-yard turf replacement by presence and location.

complete replacement were woodchips, bare soil, gravel, and artificial turf. Lower-income homes tended to show simpler changes, or simply let turf die. Higher-income households tended to have only pathways and xeric gardens added after replacement (Hurd, 2006). Woodchips are potentially ideal ground cover in Southern California to reduce water needs, support on-site stormwater management by decreasing run-off, and increase soil moisture and water storage (when plastic lining is not underneath). Woodchips also control non-native and invasive species, and woodchip ground covering is easy to install and replenish. Bare soil and gravel are also useful ground cover for similar reasons, though bare soil is more susceptible to seasonal weed growth, while gravel may exacerbate urban heat island effects more than wood chips. Artificial turf, however, has a number of drawbacks, including increased runoff, limited or no infiltration, local surface temperature increases, and no habitat for biodiversity (Yaghoobian, Kleissl, & Krayenhoff, 2010). Researchers were not able to ascertain whether these land covers were accompanied by plastic or other lining which could impair infiltration and affect soil microbes, insects, bacteria and other life.

4.4. Neighborhood effects

Straightforward analysis of nearby homes from program participants provided evidence of "neighborhood adoption" effects, whereby approximately one-third of program participants had a neighboring building a replaced lawn. The numbers were evenly dispersed for left, right, and across-the-street properties. This indicates a potential demonstration effect, which has been observed in other studies in the region (Johnson, 2017) and more generally (Hunter & Brown, 2012; Nassauer, Wang, & Dayrell, 2009; Zmyslony & Gagnon, 1998). More detailed and peer-reviewed analysis specifically aimed at understanding turf replacement choices and including interviews with residents, would need to be conducted to understand diffusion in this region. In discussions between researchers and MWD, the agency expressed hope that there would be significant demonstration effects, in essence furthering turf replacement by individuals beyond any funding of such programs over time.

4.5. Limitations

Google Earth Street View has notable limitations for studying urban landscapes. Images can be obstructed or taken at an inappropriate date, which reduces the number of properties that can be evaluated. *Google Earth Street View* contained imagery from before the replacement program was implemented, however, approximately 53% of the imagery on line were from 2006 to 2009 which was over five years before the turf replacement program begun. We observe turf as the dominate landscape type in front yards before the program and assume that residents removed turf for the program to receive the rebate. Age or size of trees and large shrubs can be used as was a guide to whether individuals were recently planted or had been there previous to the turf replacement incentive enrollment in the future. We were also not able to view backyards, given that *Street View* is only for front yards. Overhead imagery is available in *Google Earth* with temporal resolution to assess all yards for the implementation period of the properties in the database, but the geographic resolution is limited for determining landscape typologies. It is more useful for quick verification of rebate implementation. *Google Earth Street View*, of course, does not provide any capacity for estimating water use or savings, unlike other forms of imagery that can use derived indices of greenness to estimate evapotranspiration.

As is often the case with evaluations of publicly-funded programs, insufficient resources were available to conduct a comprehensive retrospective evaluation covering all potential research questions. For instance, MWD program data did not contain information regarding planned or resulting landscapes and designs, species composition, or land cover. Residents were required to submit photos before the incentive was paid to demonstrate their turf was removed, but *Street View* provided more flexibility to view post-replacement landscapes. Residents removed lawns with relatively few guidelines for replacement landscapes, leaving considerable uncertainty about the impacts of the turf incentive approach at household, neighborhood, and municipal scales.

We also did not have access to individual address level data on pre- and post-water use, nor backyard data. This is fundamentally related to the complex governance structures of water management in California. MWD, which funded the turf replacement program, sells water to a network of regional retailers, which actually manage the account-level data. Analyzing water use would have required acquiring water consumption data for 25 Los Angeles County water agencies and public and private utilities, all of which had residents who participated in the program. Such data is highly proprietary and is difficult to obtain by researchers. Backyard studies would have required homeowner access permission and a large field crew. Given the resources, the approach of studying landscape change and sociodemographic participation were chosen for front-yard turf change as a preliminary step to understanding how the public responds to turf replacement incentives and their landscape choice in situ.

4.6. Future research

Water agencies must engage in cutting-edge science that informs species-specific estimates of water use, which if combined with landscape architecture expertise, can produce urban landscapes that are both water-efficient and ecologically productive. *Google Earth Street View* is an efficient and inexpensive means to see the planting changes from subsidized turf replacement in front yards, but it cannot yield information about water use change. Further, longitudinal observations must be conducted to understand whether turf removal is permanent, and how these landscapes evolve.

Matching parcels that have replaced their turf with other variables, such as socio-demographic information and supplemental rebate availability, provides additional insights into potential patterns in turf replacement program participants. Such insights can be useful for targeting further turf replacement. *Google Earth Street View* also allows a preliminary classification of turf replacement typologies, though yards will change over time as plant material grows or is replaced. The typologies developed from *Street View* observations show many landscapes with shrubby plants, often surrounded by gravel, woodchips or bare soil, though as noted there is no ability to know if the yard is lined with a relatively impermeable, anti-weed material. At the same time, there is indication of a high degree of variability among the turf replacement choices. Extrapolating from these results, broader uptake of turf replacement across the region could lead to variegated landscape types, replacing the homogeneous lawn and shrub landscaping tradition. Other factors that might be important to understand include urban albedo and urban heat island effects from different landscape replacement types.

Finally, turf replacement programs have temporal and longevity aspects that need to be monitored. New plants take time to establish extensive root systems that promote drought tolerance. Between planting and full establishment, which generally takes several growing seasons, even drought-tolerant plants need frequent irrigation. In contrast, MWD boosted its program at the peak of the 2011–2016 drought. More consistent funding of turf replacement that precedes drought would increase the potential for water savings as established landscapes require less water. It could also improve the likelihood that replacement landscapes survive. Further research should understand how to refine and communicate these messages for utility rebate programs and residents.

5. Conclusions

MWD's 2014 turf replacement program was an unprecedented investment in future urban landscapes that can help reduce long-term urban water demands in California. The significant boost in funding and new program requirements in 2014 offered a prime opportunity to test the effects of such programs on landscapes and behavior using new imagery techniques and integrated large-scale data sources. We found strong correlations between rebate program participation and home ownership, income, and supplemental local rebate funding from one utility, LADWP. Eighty percent of the properties in the database were located in the service territory of LADWP, which had the largest supplemental rebate. To understand in even greater detail the landscape implications of this program, site visits to ascertain the vegetation, biodiversity, and land cover should be conducted. Further, backyard turf removal impacts are as yet unverified, as well as longitudinal impact on outdoor irrigation and landscape evolution.

Results from this analysis provided insights for both program implementation and outcomes on properties. Based on the analysis, residents made significant reductions in space dedicated to lawns in their front yards. They predominantly replaced lawns with shrubby plants and artificial turf (14.6%, 9.6% of households each). Many landscapes had mixed land cover types. Analysis of nearby homes from program participants provided evidence of "neighborhood adoption" effects, whereby approximately one-third of program participants had a neighbor that also had a replaced front lawn.

This study was the first to develop methodologies for using free imagery and mapping platforms, namely *Google Earth Street View*, to assess urban landscape change from turf replacement in an inexpensive and repeatable manner. In addition, we devised a novel method for classifying diverse landscapes within the context of a program where participants had significant freedom to select replacement landscape types. These innovations provide an important framework for future studies. Further research should evaluate biodiversity and climate effects of landscape changes as well as achieved water savings over time, based on analysis of pre- and post-project metered water use data. Such analyses would help validate current investments and guide future program improvements that improve southern California's resilience to future drought.

As regions such as the U.S. Southwest experience warmer and warmer temperatures due to a changing climate and less predictable precipitation regimes, the choice of urban landscaping becomes an important component of adaptation. Urban outdoor landscape irrigation accounts for over half of residential water use. Substituting plantings and landscapes that use less water will enable such regions to transition toward greater sustainability as residential water demand should decline. It will also lead to a dramatic shift in the look and feel of places like Los Angeles, still today dominated by lawns and plants that are high water users.

Acknowledgements

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