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RESEARCH ARTICLE

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Urban plant diversity in Los Angeles, California: Species and functional type turnover in cultivated landscapes

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Societal Impact Statement
People plant, remove, and manage urban vegetation in cities for varying purposes and to varying extents. The direct manipulation of plants affects the benefits people receive from plants. In synthesizing several studies of urban biodiversity in Los Angeles, we find that cultivated plants differ from those in remnant natural areas. This highlights the importance of studying cultivated plants in cities, which is crucial for the design and planning of sustainable cities. Residents have created a new urban biome in Los Angeles, and this has consequences for associated organisms, ultimately resulting in a responsibility for society to determine what type of biome we wish to create.

Summary
- Urbanization is a large driver of biodiversity globally. Within cities, urban trees, gardens, and residential yards contribute extensively to plant biodiversity, although the consequences and mechanisms of plant cultivation for biodiversity are uncertain.
- We used Los Angeles, California, USA as a case study for investigating plant diversity in cultivated areas. We synthesized datasets quantifying the diversity of urban trees, residential yards, and community gardens in Los Angeles, the availability of plants from nurseries, and residents' attitudes about plant attributes.

- Cultivated plant diversity was drastically different from remnant natural areas; compared to remnant natural areas, cultivated areas contained more exotic species, more than double the number of plant species, and turnover in plant functional trait distributions. In cultivated areas, most plants were intentionally planted and dominated by exotic species planted for ornamental purposes. Most tree species sampled in Los Angeles were available for sale in local nurseries. Residents' preferences for specific plant traits were correlated with the trait composition of the plant community, suggesting cultivated plant communities at least partially reflect resident preferences.
- Our findings demonstrate the importance of cultivated species in a diverse megacity that are driven in part through commercial distribution. The cultivation of plants in Los Angeles greatly increases regional plant biodiversity through changes in species composition and functional trait distributions. The pervasive presence of cultivated species likely has many consequences for residents and the ecosystem services they receive compared with unmanaged or remnant urban areas.

KEYWORDS

city plant species richness, community gardens, remnant natural areas, residential yards, socio-environmental synthesis, urban trees

1 | INTRODUCTION

Cities are recognized centers of high plant diversity (Kendal, Williams, & Williams, 2012a; Kuhn, Brandl, & Klotz, 2004; McKinney, 2006; Müller et al., 2013) and harbor a large number of non-native plant species (Clemants & Moore, 2003; Ignatieva, 2010; Kelcey & Müller, 2009; Pyšek, 1998). The ultimate causes of high diversity in cites are numerous (Luck, 2007) and potentially include: the presence of invasive species and weeds (Kowarick, 2008), the location of cities in areas that had high diversity prior to urbanization (Kuhn et al., 2004), and the importation of cultivated plants (Ignatieva, 2010; Kowarik, 2011; Müller et al., 2013; Thompson et al., 2003). While processes that affect native and invasive species have been well-studied (Kowarik, 2011), we have a relatively poor understanding of ecological processes within human-cultivated plant populations, which play an important role in urban vegetation (Kendal, Williams, & Williams, 2011; Loram, Thompson, et al., 2008; Loram, Warren, Thompson, & Gaston, 2011; Niinemets & Peñuelas, 2008; Pearse et al., 2018).

In addition to high plant taxonomic diversity, dominant plant functional types are likely to differ between urban and rural areas (Knapp et al., 2012). Within cities, the effect of urbanization on plant functional types and their traits has been investigated predominately in remnant natural areas with species that grow spontaneously (Knapp, Khn, Schweiger, & Klotz, 2008; Lososová et al., 2006; Nock et al., 2013; Williams et al., 2015), and it is less clear how functional groups differ between cultivated areas and natural areas. The dominance of specific functional types, such as graminoid versus woody species, has implications for many ecosystem functions and services (Díaz & Cabido, 2001), but remains to be thoroughly investigated in cultivated urban areas, especially those in warmer climates.

Urban plants can be categorized as growing spontaneously, species that grow and reproduce without human intervention, or as cultivated species that are planted and managed by humans, both of which can be either native or exotic to a city (Pearse et al., 2018; Wang et al., 2015). Importantly, species that were cultivated can escape and also grow spontaneously (Reichard & White, 2001). Although cultivated species have long been recognized as important components of urban ecosystems (Whitney & Adams, 1980), many previous urban plant studies have focused on remnant pockets of uncultivated vegetation, remaining native species, or exotic species that can naturally regenerate (Aronson, Handel, Puma, & Clemants, 2015; Aronson et al., 2014; Clemants & Moore, 2003; Duncan et al., 2011; Gavier-Pizarro, Radeloff, Stewart, Huebner, & Keuler, 2010; La Sorte et al., 2014; Ricotta et al., 2009). Recent reviews of cultivated species in residential parcels have focused on residential gardens as important for contributing to green infrastructure (Cameron et al., 2012; Goddard, Dougill, & Benton, 2010) or as a source of invasive species (Dehnen-Schmutz, Touza, Perrings, & Williamson, 2007). Studies that have focused on the community and functional ecology of cultivated vegetation are fewer (Loram, Warren, et al., 2008; Marco et al., 2008; Thompson et al., 2003; Wang et al., 2015), and those studies have found that preferences of residents for particular plant types are reflected in the types (Kendal, Williams, & Williams, 2012b; Marco & Barthelemy, 2010) and numbers (Avolio, Pataki, Trammell, & Endter-Wada, 2018; Shakeel & Conway, 2014) of plants found in private yards and neighborhoods.

To further understand the patterns of cultivated plant diversity, where urban residents closely interact with plants and immediately derive ecosystem services (Bolund & Hunhammer, 1999), we synthesized several datasets of urban plant diversity and its drivers in Los Angeles, California, USA. Los Angeles is a semiarid city with a particularly mild climate with high-plant species richness due to the large range of plant species that can thrive there, especially under irrigation (Hondagneu-Sotelo, 2014; Pincetl et al., 2013). Los Angeles has long dry summers, and due to the low plant growth of nonirrigated areas, cultivated spaces—including cultivated parks, residential yards, and community gardens—dominate vegetated spaces of Los Angeles. Therefore, Los Angeles provides a good case study to focus on the distribution and dynamics of cultivated vegetation. The urban forest of Los Angeles is particularly diverse relative to other cities in the USA (Avolio, Pataki, Gillespie, et al., 2015; Clarke, Jenerette, & Davila, 2013; Gillespie et al., 2016) and driven primarily by the introduction of exotic species (Avolio, Pataki, Gillespie, et al., 2015). However, it is unknown whether the patterns observed in trees, a functional group that is largely non-native to the lower elevations of Los Angeles, are similar to those observed for other plant types.

We synthesized a variety of datasets of attributes of urban landscapes in Los Angeles to assess the contribution of cultivated plants to total diversity, the distribution of plant functional types and traits within cultivated areas, and the importance of possible drivers of local urban diversity. We posed two research questions. First, within urban areas, how do cultivated and remnant natural areas compare in urban plant biodiversity? Second, to what extent is the distribution of cultivated species explained by institutional versus individual aspects of decision-making, such the availability of species in local plant nurseries and by the preferences of homeowners and other land managers for specific plant functional traits?

2 | MATERIALS AND METHODS

2.1 | Study site

The Los Angeles-Long Beach-Anaheim Metropolitan Statistical Area (MSA) which spans Los Angeles and Orange counties (US Office of Management and Budget), covers ~4,500 km^2, and is home to 12,828,837 people (US 2010 Census). The region includes the Los Angeles basin, three mountain ranges that surround the basin (Santa Monica, San Gabriel, and Santa Ana), and the Mojave Desert on the leeward side of the San Gabriel Mountains. The region varies greatly in elevation, from sea level in the basin to over 3,000 m in the mountain ranges. The area spans a range of native vegetation types: coastal sage scrub in the valley, chaparral, oak woodlands, and pine–oak forest in the foothills and mountains, and desert in the Mojave Basin (EPA Ecoregions III vegetation data, Ecoregions of North America; 2006). The climate is Mediterranean, characterized by dry summers and wet winters, with an average temperature of 16°C, and 562 mm rainfall annually (PRISM Climate Group at Oregon State University, Corvallis Oregon) and varies greatly within the MSA, where it is substantially warmer and drier inland than along the coast (Tayyebi & Jenerette, 2016).

Most of the urbanized land cover occurs in the area formally occupied by coastal sage scrub and chaparral at lower elevations, with less urbanization in the forested mountains and high desert. The native coastal sage scrub ecosystem was historically dominated by drought deciduous shrubs (Gray, 1982) although currently invasive annual plant species are a common component (Minnich & Dezzani, 1998). Trees are not a large component of the lower elevation ecosystems and were primarily located in riparian areas prior to urbanization (Rundel & Gustafson, 2005).

In the urbanized area of Los Angeles, most vegetation is located in irrigated and/or cultivated areas (Mini et al., 2014). As the region developed, water was imported to support the growing population and exotic vegetation—including citrus orchards in the early history of the region as well as palm trees, which became an iconic symbol of the city—replacing coastal sage scrub, which has been almost entirely removed (Pincetl et al., 2013; Woodward & Andre, 2004). In Los Angeles, once cultivated landscapes are abandoned and no longer irrigated, most planted species do not survive (Woodward & Andre, 2004). Thus, the process of urbanization gave rise to a cultivated landscape that is heavily managed (Pincetl, 2012), and poorly understood from a community ecology perspective.

2.2 | Datasets

We analyzed and synthesized available datasets of plant diversity collected in the Los Angeles metropolitan area to investigate the patterns of urban plant diversity (Table 1). We focus on three cultivation types (urban trees, community gardens, and residential yards) and uncultivated remnant natural areas (Figure 1). For urban trees, we compiled three separate studies on trees in Los Angeles, two that conducted iTree surveys (Avolio, Pataki, Gillespie, et al., 2015; Clarke et al., 2013) using 0.04 hectare plots according to iTree protocol (USDA 2011) and one that used 1 hectare plots randomly placed throughout Los Angeles (Gillespie et al., 2016). In all the tree datasets, each individual tree in the plot was identified to species, resulting in species abundance data. The city tree dataset spanned many land use types, including but not limited to residential, parks, and commercial and industrial areas. In each land use type, each tree was then classified as a street tree or not. The community garden data are from a study of 14 urban gardens managed by multiple residents, where all plant species were identified (Clarke & Jenerette, 2015). Plants in residential yards are from a study in which researchers visited 21 homes and identified all the plants found in both front and back yards (Pearse et al., 2018). For the remnant natural areas, we used a dataset from coastal sage scrub sites in three of the few protected nature preserves using a similar sampling effort to the residential yards (Pearse et al., 2018). These remnant areas were surrounded by an urban and suburban matrix. The community garden, residential yard, and remnant areas datasets have presence/absence data only. Additionally, we examined datasets of potential societal drivers of urban plant diversity. We used a dataset that

TABLE 1 Datasets used in the present study

Cultivation type	Dataset	Brief collection details	Publication
Urban trees	Los Angeles iTree	358 0.04 ha plots across the city of LA were sampled using iTree collection methods. Trees were recorded as planted or not.	Clarke et al., 2013
	Southern California iTree	250 0.04 ha plots were sampled in 25 neighborhoods across Los Angeles city and Orange county. Each neighborhood had 10 iTree plots.	Avolio, Pataki, Gillespie, et al., 2015
	Los Angeles Hectare	30 1 ha plots across the city of Los Angeles were sampled.	Gillespie et al., 2016
	Southern Californian Residents' Tree Preferences	1,000 + residents across Los Angeles, Orange, Riverside, Ventura and San Bernardino counties were surveyed.	Avolio, Pataki, Pincetl, et al., 2015
	Nursery Offerings	100 + years of nursery catalog offerings for 11 nurseries in Los Angeles County were inventoried. Does not include fruit species.	Pincetl et al., 2013
Residential yards	USA Homogenization Yard Visits	All the vegetation in 21 residential yards in Los Angeles and Orange Counties were inventoried. Plants were recorded as either cultivated or spontaneous.	Pearse et al., 2018
	USA Homogenization Remnant Natural Areas	All plants in 21 100 x 2 m transects were recorded. Sampling took place at three remnant areas of coastal sage scrub.	Pearse et al., 2018
	USA Homogenization Home Owner Survey	Each homeowner at the 21 households was surveyed on yard preferences.	Larson et al., 2016
Community gardens	Los Angeles Community Gardens	14 community gardens were sampled in Los Angeles County. In the garden beds all plants with cover greater than 5% were recorded and weeds were noted. Cultivated plants were inventoried for the overall garden.	Clarke & Jenerette, 2015

included the availability of plant species from local nursery offerings for 110 years (Pincetl et al., 2013) and two surveys of attitudes and preferences of local residents for specific types and attributes of vegetation (Avolio, Pataki, Pincetl, et al., 2015; Larson et al., 2016).

Defining species in cultivated areas is complicated by the number of hybrid and cultivars. Here, we focused on taxonomic species, cultivated hybrids, subspecies, and groups within species (e.g., groups within *Brassica oleracea*: broccoli, kale, cabbage, Brussels sprouts, etc.), but not varieties and cultivars within species (e.g., cultivated flower and leaf color differences within species). For each plant species we used Calflora (www.calflora.org) to determine whether the species was native to California. To study the number of species that were native or exotic and cultivated or growing spontaneously, we used three of the datasets (Los Angeles iTree, USA residential yard visits, Los Angeles community gardens; Table 1) that recorded whether the species was intentionally planted (cultivated) or growing spontaneously, to the extent that it could be determined. A species that is cultivated (intentionally planted) can spread via seed and start to grow spontaneously elsewhere; thus, species that were recorded as spontaneous in one place but cultivated in another were counted twice. For all other analyses (see below) we used all plant datasets.

For each species, we classified plants as ornamental, invasive (according to Calflora), weedy (undesirable species that were growing spontaneously but are not invasive, e.g., Dandelion), turfgrass, food, or medicinal (Clarke & Jenerette, 2015). These categories are not all mutually exclusive—for example invasive species can be planted as ornamentals—so we used a hierarchy of categories where this example species would be classified as invasive. Our hierarchy was as follows: invasive, food, medicinal, turfgrass, weed, and finally ornamental. Not all categories were present in each dataset (e.g., there were no turfgrass species in the community garden and tree datasets). We also classified species by life form (fern, forb, graminoid, succulent, vine, woody) and annual or perennial (biennials were grouped with annuals). For each species, we determined continent of origin: North America, South America, Eurasia, Africa, Australia, and Mediterranean (for species from the Mediterranean region spanning Eurasia and Africa that could not be assigned to a single continent). Eleven percentage of species were hybrids and were not assigned to a continent of origin. Lastly, Pincetl et al. (2013) surveyed catalogs of nursery offerings for 11 nurseries spanning 110 years in Los Angeles County and we used these data to compare tree species found in Los Angeles with local offerings.

To study plant attributes that may play a role in decision-making about cultivated species, we used resident survey results of stated preferences for plant attributes. We used two survey datasets of resident preferences: one for residential yards (all plants) and other for residential urban trees. In the residential yard survey, homeowners, whose income was split among high, mid, and low income, rated the importance (from not important to highly important) of plants for various ecosystem services (see Larson et al. (2016) for more information), including creating a beautiful yard, providing shade, being native, and providing food. We then classified plants that had showy flowers (that are very apparent) as having attributes that create beauty, all trees as having attributes for shade provision as well as whether the species is native or provides an edible crop. In the urban tree survey, residents, whose range of income was representative

FIGURE 1 Four types of urban vegetation and/or ecosystems included in this data synthesis: remnant natural areas, urban trees (trees found in the city, including parks, yards, streets, etc.), residential yards (front and back) and community gardens

of the overall population, were asked to rate their attitude (from strongly dislike to strongly like on a 5-point Likert scale) toward native, fruiting, shading, flowering, and low-water requirement trees (see Avolio, Pataki, Pincetl, et al., (2015) for more information). We used the Los Angeles iTree and southern California iTree datasets for this analysis (Table 1) and utilized land use data (e.g., residential, park, street, etc.) recorded in the iTree surveys about where trees were surveyed to focus on non-street trees in single- and multi-family residential land use (i.e., privately managed trees) based on iTree land use classifications. We followed Avolio, Pataki, Gillespie, et al., (2015) for trait and attribute classification of trees. Briefly, flowering was scored from 0 for trees that do not flower to 2 for trees with showy flowers (e.g., *Jacaranda* trees). We also scored trees for their water requirement from 1 with little water needs (e.g., *Washingtonia robusta*) to 3 needing regular watering (e.g., *Magnolia grandiflora*), shade potential from 0 (e.g., *Cupressus duclouxiana*) to 3 (*Ficus* trees). Lastly, we determined whether a tree was native to California or provided edible fruits. We calculated the average survey response pertaining to plant traits across all respondents and correlated the average preference for an attribute with the number of individual plants in diversity inventories with that attribute.

2.3 | Statistical analyses

All statistical analyses were conducted in R (R core development team). We used the specaccum function of the vegan package (Oksanen et al., 2018) to create species accumulation curves with data from residential yards and sampled natural areas. We ran Pearson's correlations between resident plant attribute preferences and number of plants with that attribute.

3 | RESULTS

3.1 | Characterizing cultivated and remnant natural areas

For the remnant natural areas, we found 86 species in 4,200 m^2 (0.02 species/m^2). Sixty-seven percentage of these species were native to California and 23% were exotic and invasive, the rest being exotic but not invasive (Figure 2). As for plant functional types, 50% of the species were forbs, split between annuals and perennials, followed by woody plants and then annual grasses. At the same spatial scale in cultivated areas, we found 255 species in the residential yards (0.125 species/m^2), over 2.5 times the number of species in remnant areas (Figure 2). Of the species, only 4% were native and 5% exotic and invasive, again the rest being exotics that are not invasive. We also found that the plant functional types (e.g., woody plants vs. graminoids) differed between the remnant natural and cultivated areas (Figure 2). In cultivated areas, the most common life form was woody plants, accounting for 37% of all plant species, followed by perennial forbs. We found only four tree species in the remnant natural areas compared with 79 tree species in the residential yards.

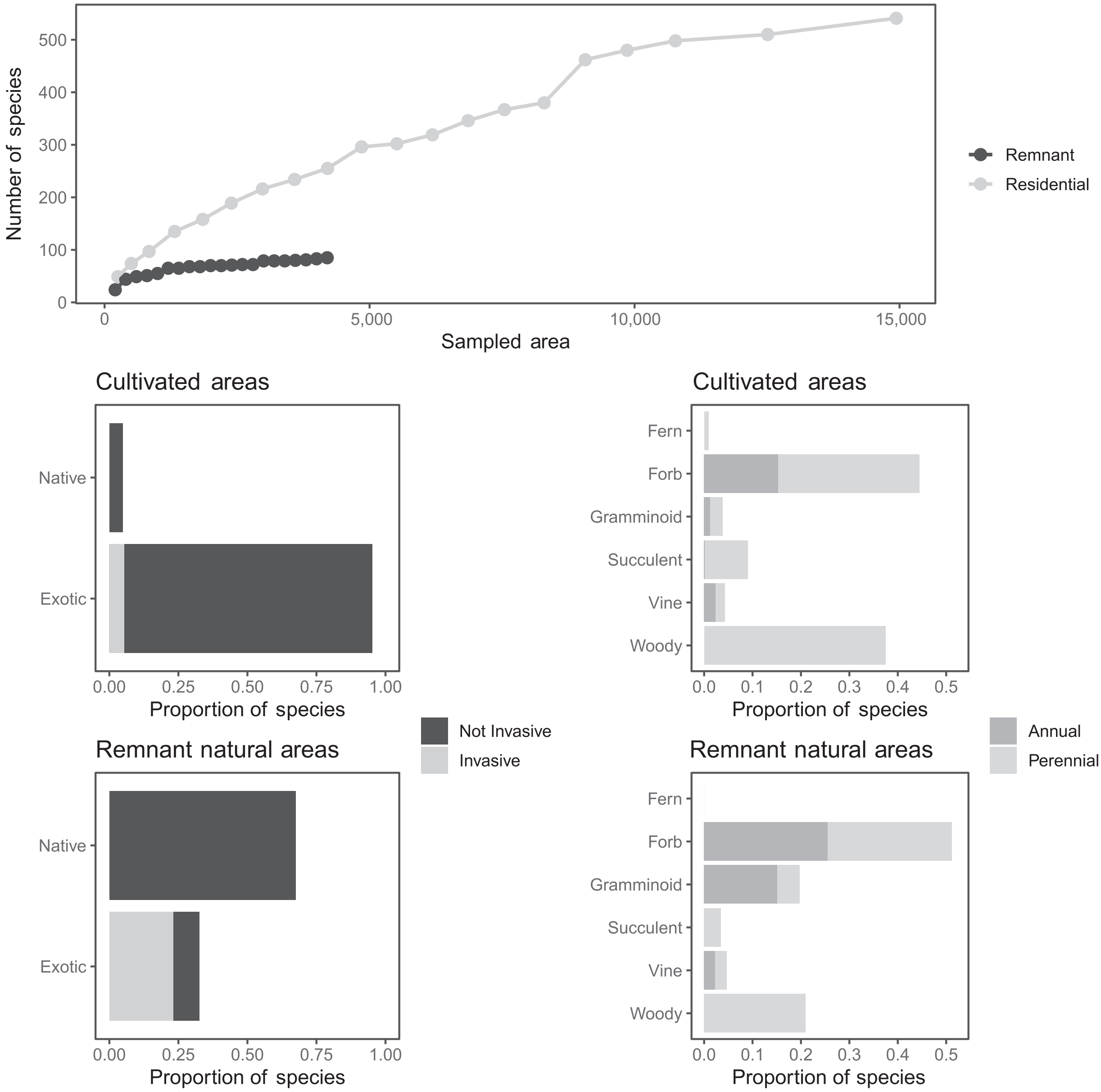

FIGURE 2 Comparing remnant natural with cultivated areas. Top panel: Species area curves of 21 remnant natural sites and 21 residential yards in Los Angeles. Bottom left panels: The proportion of native and invasive species for the remnant natural and cultivated areas (including urban trees, community gardens and residential yards). Bottom right panels: The growth form and life cycle of plant species for the remnant natural and cultivated areas

3.2 | Plants in cultivated areas

Across our inventories of cultivated areas, we found 907 plant species (including hybrids, subspecies and groups, but not varieties and cultivars within species), with 218 species overlapping between the three cultivated land types: urban trees, residential yards, and community gardens. We found 204 species in the urban tree surveys, 357 species in the community garden surveys, and 564 species in residential yard surveys. This is a low estimate of species richness, because species that were unidentified or only identified to genus were excluded (~125 plants in the residential yards alone). Only 5% of all species found in the cultivated areas were native to California and most species were cultivated exotics (Figure 3). Regardless of whether plants were native or exotic, 74% of residential yard species were cultivated (i.e., intentionally planted), 95% of urban tree species were cultivated, and 91% of community gardens species were cultivated. Most of these cultivated species were ornamental, followed by food plants (Figure 3). Relatively few species were weedy or invasive, with only 5%–6% of species classified as invasive across the plant datasets, and 6%–8% classified as weeds (Figure 3).

3.3 | The geographic origins of cultivated species

We found plants from every continent (except Antarctica), indicating a global species source pool for cultivated plants in Los Angeles. Most species were native to Eurasia, possibly reflecting global

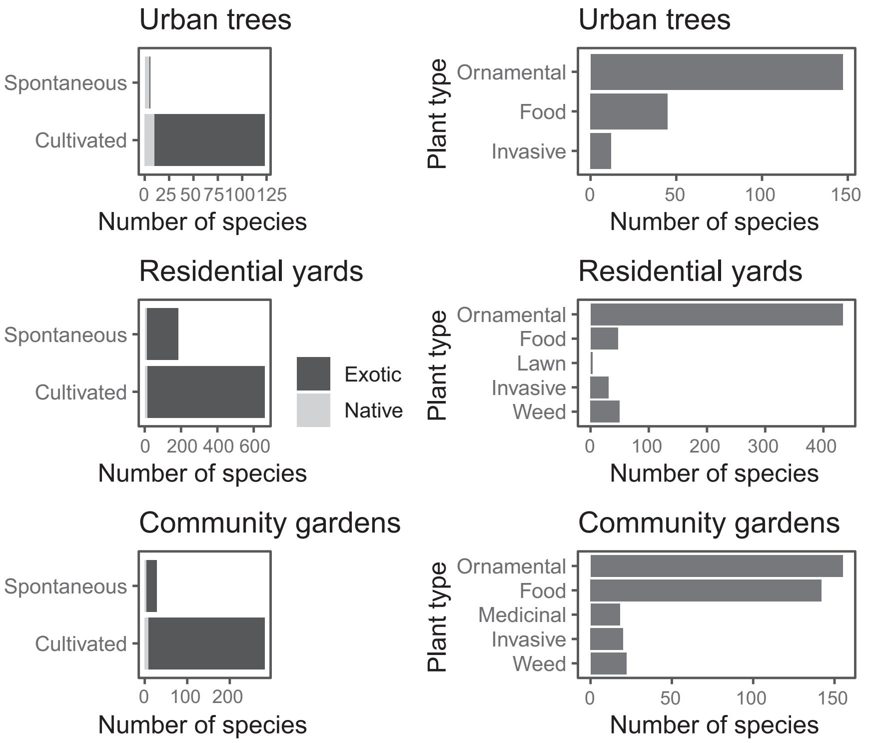

FIGURE 3 Multiple classifications of urban plants in cultivated areas. Left panel: Exotic versus native plants that are growing either spontaneously (not planted) or cultivated (intentionally planted). Right panel: Categories of plant types

landscaping trends (Ignatieva, 2011), and the fewest species came from the Mediterranean region (Figure 4), even though the climate of Los Angeles is Mediterranean. We compared the trees found in Los Angeles with catalog offerings from wholesale and retail nurseries (Pincetl et al., 2013) and found that local nurseries offered 77% of tree species that were found in the ground inventories. Of the tree species that were not offered by the nurseries, five were native to Los Angeles County, one was an invasive species and the other 24 species were ornamental. All but one of 12 invasive tree species were offered by nurseries, while eight of 13 native species were offered by nurseries.

3.4 | Patterns of diversity and preferences for plant traits

In Los Angeles, the results of household surveys about plant trait preferences indicated that 95% of residents rated beauty to be highly or moderately important, whereas 86% stated that ease of maintenance was important when selecting species to plant. These were the two most highly rated criteria out of a list of 15 possible criteria. Several other criteria were not as important; only 52% of respondents cared whether the species was native or provided food. In cultivated areas, 81% of species were perennial, which require less maintenance, and in residential yards, nonwoody ornamental plants with showy flowers (60% of plants) were the dominant growth form, which create beauty. We also found a strong relationship between homeowner preferences and plant traits in residential yards (r = 0.992, p = .008; Figure 5), but not between preferences and tree traits in residential areas (r = 0.596, p = .289; Figure 5).

4 | DISCUSSION

The process of urbanization in Los Angeles has dramatically increased plant species richness, despite greatly reducing the number of native species, by importing many cultivated species. Species richness was much higher in cultivated areas compared with remnant natural areas. This high species richness was dominated by exotic species that have been imported from all continents and appear to be planted for mostly ornamental purposes. Cultivated areas also showed increases in the proportion of woody and succulent species (e.g., *Aeonium arboreum*, *Aloe*, and *Crassula* species) relative to remnant natural areas, as well as a decrease in the proportion of graminoids and annual species. Our findings demonstrate the transformations of plant species richness, community composition, and functional type dominance associated with urban landscape cultivation.

We found a doubling to over sevenfold increase in the number of plant species in residential yards compared to remnant natural areas. Previous work in coastal sage scrub by Westman (1981) found between 0.016 and 0.063 species/m^2; our results in remnant coastal sage scrub fall within this range (0.02 species/m^2). In the residential yards, we found 0.125 species/m^2. Cultivated areas also had a different distribution of plant functional types. Woody species in cultivated areas were twice as common than in remnant natural areas, while grass species were largely absent in cultivated areas (despite the prevalence of lawns, which are composed of a small number of graminoid species) but were much more common in remnant natural areas. This turnover in plant functional types, presumably the result of residential preferences for shade trees

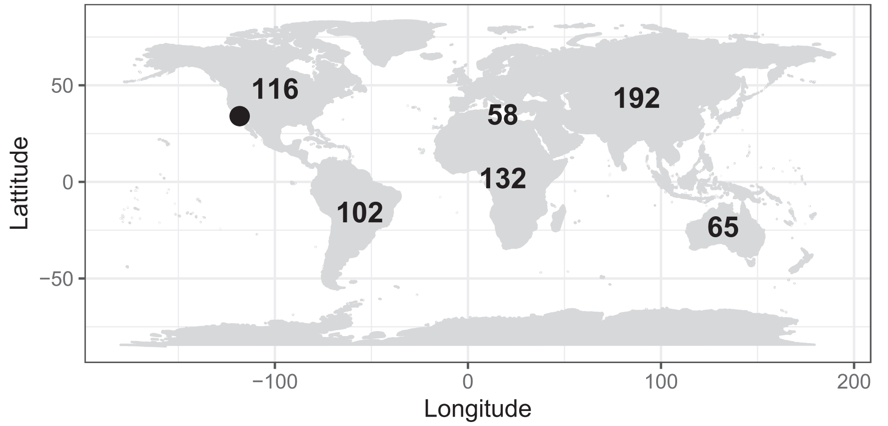

FIGURE 4 Map of plant origin (99 hybrid species are not shown). The location of Los Angeles is denoted by the black dot. The Mediterranean region includes plant species that could be from both Africa and Eurasia

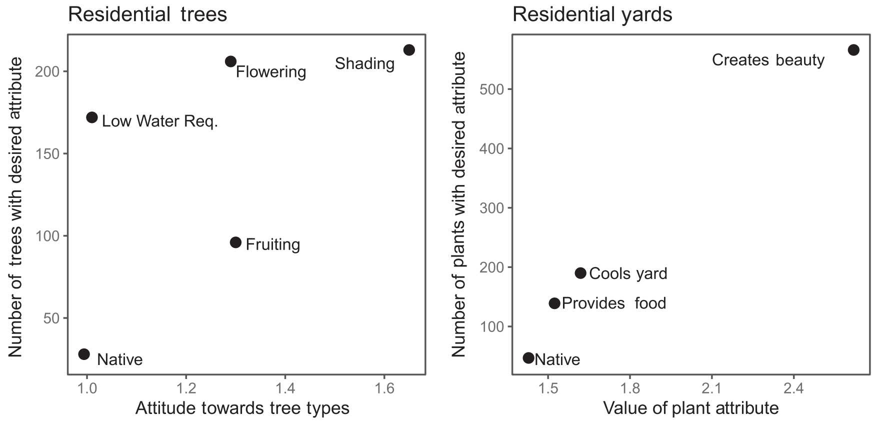

FIGURE 5 Relationship between residents' preferences toward plant traits and the number of individual plants that have the desired attribute. We took the average of each stated preference across all respondents (residential trees: n = 1,029 survey participants, residential yards: n = 21 survey participants) and correlated this with the number of plants that had the desired trait (residential trees: n = 703 trees, residential yards: n = 1,780 plants). Stated preferences ranged from −2 to 2 (strongly dislike to strongly like) and values ranged from 0 to 3 (unimportant to very important)

and plants with showy flowers, has implications for urban ecosystem function and derived services, such as ecosystem cooling and beauty.

Focusing only on cultivated areas, we found that most plant species are exotic and depend on human maintenance (particularly irrigation) in Los Angeles (e.g., *Begonia* and *Rosa* hybrids). While many studies have shown that a large number of non-native species are commonly found in gardens (Bigirimana, Bogaert, Cannière, Bigendako, & Parmentier, 2012; Loram, Thompson, et al., 2008; Marco et al., 2008), in Los Angeles it is cultivated plants, not weeds or exotic invasive species, that drive this pattern. Plants in cultivated areas also differ vary markedly in how they are distributed among functional types relative to the surrounding natural areas: across all three urban land cover types, the dominant plant functional type was ornamental plants, followed by food crops. Similar patterns have been found in other cities, where the majority of species in cultivated areas are desired ornamental, food, or medicinal species (Bigirimana et al., 2012; Jaganmohan, Vailshery, Gopal, & Nagendra, 2012; Lubbe, Siebert, & Cilliers, 2011; Wang et al., 2015). Here, we found this pattern of dominance of ornamental species in both residential yards, city trees, and community gardens.

Cultivated plant species in Los Angeles originated from every continent but Antarctica, and previous research has found plant species originating from biomes ranging from wetland and riparian areas to semiarid areas in Los Angeles (Pataki et al., 2013), demonstrating that exotic species are imported from all over the world. The extent to which species are drawn from a global species pool may depend on local temperature extremes, which affect what may persist locally. Within the USA, Los Angeles has an unusually mild climate, lacking both extreme cold and hot temperatures, and many plant species can tolerate the temperature range experienced in Los Angeles. Most nurseries limit the plants they grow and sell by hardiness zone, which is based on minimum temperatures. A recent synthesis showed that urban tree species richness in cities across the USA is associated with freezing temperatures, with lower diversity in colder cities compared to more mild climates (Jenerette et al., 2016) and other studies have found temperature to be a key driver of differences in the cultivated species composition of cities

(Cubino et al., 2019; Kendal et al., 2011). Our findings in Los Angeles fit into this climatic framework, given the vast importation of species into Los Angeles, especially tropical species such as the palm trees, *Cordyline* hybrids and *Strelitzia* species that are typically grown in greenhouses in other cities (Ignatieva, 2011). More comparative work across cities with very different temperatures is necessary to further distinguish climatic from cultural factors that influence urban species composition.

In Los Angeles, the majority of tree species found in ground surveys were also offered by the local nurseries cataloged by Pincetl et al. (2013). It is likely that the 15% of cultivated species that were not offered by the nurseries were obtained from other commercial sources that were not inventoried by Pincetl et al. (2013), or possibly through seed saving/sharing by local residents. Nurseries were the source of most urban species in a semiarid city for trees (Avolio et al., 2018) as well as in a subtropical city (Torres-Camacho et al., 2016), and in this study, suggesting that the dynamics of the nursery industry, including the cultivation and commercialization of horticultural varieties and decision-making by local growers, and individuals in the landscape design industry are key drivers of urban biodiversity.

Nursery offerings in Los Angeles are quite diverse and mostly non-native (Pincetl et al., 2013) and within these offerings it is useful to consider how local actors select from available species and cultivars. Research on nurseries has found that they respond to many market-driven parameters (Safley & Wohlgenant, 1995), including novelty and susceptibility to disease and pests, cost, ability to thrive in a given location, ease of propagation, and physical attributes (Pincetl et al., 2013; Townsley-Brascamp & Marr, 1995). Our results show the importance people place on flowering perennial species in cultivated areas of Los Angeles (e.g., *Clivia miniata*, *Hemerocallis* hybrids, and *Dietes iridioides*) which was also reported by Marco et al. (2008) in southern France and in cities across the USA (Larson et al., 2016). Creation of beauty is typically cited as key reason for choosing species for planting (Avolio, Pataki, Pincetl, et al., 2015; Clayton, 2007; Goodness, 2018; Kendal et al., 2012b; Larson et al., 2016; Marco & Barthelemy, 2010). This results in a unique floral species composition (Loram et al., 2011; Whitney & Adams, 1980) that affects other ecological properties such as animal diversity (Faeth, Bang, & Saari, 2011) and other ecosystem services (Avolio, Pataki, Gillespie, et al., 2015). In addition, residents commonly cite ease-of-maintenance as an important attribute in species selection (Avolio, Pataki, Pincetl, et al., 2015; Clayton, 2007; Kendal et al., 2012b; Larson et al., 2016), and perennial species require less year-to-year maintenance than annuals, which need to be replanted each year. Given the important role nurseries play in importing plants the societal responsibility of the horticultural industry should be more formally studied and addressed.

In this study we found a strong relationship between resident preferences for specific plant traits and actual plant attributes in yards; however, we did not observe this relationship for residential urban trees. Trees are long-lived and current species patterns may reflect planting legacies from an earlier time period (Boone, Cadenasso, Grove, Schwarz, & Buckley, 2009; Cook, Hall, & Larson, 2012). Other studies have found that attributes of garden plant communities, such as flower colors and vegetation types, reflect homeowner preferences (Kendal et al., 2012b; Larsen & Harlan, 2006), and residential tree attributes can reflect homeowner and/or manager preferences for some, but not all, attributes (Avolio, Pataki, Gillespie, et al., 2015; Avolio et al., 2018).

Cultural and social norms have also been shown to strongly influence urban landscaping practices (Cook et al., 2012; Larson, Casagrande, Harlan, & Yabiku, 2009; Larson et al., 2016). It is important to realize that the esthetic norms that prevail today are largely derived from an English garden typology. There was no local esthetic when the settlers arrived. The diffusion of this landscape type is historical, originating in the late 19th century with the strong relationships between emerging landscape and park designers such as Frederick Law Olmsted and his British counterparts (Lawrence, 2006). While in Los Angeles, tropical plants may be mixed in, such as birds of paradise or palms and ficuses, the orderliness of the landscape came from Europe (Ignatieva, 2011). When Easterners and Mid-Westerners came to Los Angeles, they brought their landscape preferences at the turn of the 20th century, perceiving the existing plant palate as either unattractive or unvaluable. A few early California native plant enthusiasts did emerge, such as Theodore Payne who began seed collection and a native plant nursery, but these were exceptional.

Previous studies have shown that the current norms of urban landscape design balance esthetics with concerns about maintenance and other factors (Larson et al., 2009, 2016). Overly "unkempt" landscapes may convey cues of landscape neglect and social disorder (Lyytimäki, Petersen, Normander, & Bezák, 2008; Nassauer, 1995). Hence, while there are many individual and demographic differences in specific landscape and species preferences across urban populations, regional landscaping norms may frame the very low prevalence in Los Angeles of native landscapes that utilize the seasonally dry, deciduous plant palette of the coastal sage shrubland. These species tend to be dormant during the late summer without supplemental water and convey a brown and "unkempt" esthetic. Instead, the cultivated environment shows a turnover of species and functional types from shrubs, forbs, and grasses to the woodland type mix of large-statured trees and low vegetation that is characteristic of many cities.

This unique cultivated "biome" in Los Angeles has markedly different characteristics than the ecosystems that it replaces. In particular, our results show that the urban cultivated "macrosystem" (Groffman et al., 2017) is predominantly perennial and forested relative to the native ecosystem, with a longer growing season that lasts through the summer dry season due to supplemental irrigation. It is also highly species rich, with novel, globally derived assemblages of species that have no obvious analog in native ecosystems. This cultivated ecosystem is overall shadier, greener for longer periods of time, if not evergreen, and colorful.

Many questions about this macrosystem remain, including patch- to regional-scale shifts in ecosystem function as a result of almost complete species turnover. With respect to the role of decision-making in structuring cultivated urban biodiversity, the high species richness of these ecosystems is not fully understood, particularly of exotic noninvasive species. Studies of urban residents in Europe have shown that the perceived attractiveness of designed urban landscapes is correlated with perceived biodiversity and species richness as well as high flower cover and colorful plantings (Hoyle, Hitchmough, & Jorgensen, 2017; Lindemann-Matthies & Marty, 2013). The extent to which high-cultivated species richness is driven by individual preferences for visual or ecological variety, varying preferences and priorities among diverse residents and populations, and/or institutional, cultural, and economic drivers of horticultural and gardening practices, is not yet well understood. In addition, the role of environmental versus socioeconomic constraints on landscaping decisions, including the legacy effects of previous landowner decisions, is still fairly uncertain. Exploring resident desires for plants and their attributes, actual planting behaviors, and their interactions with socioeconomic and environmental drivers of urban plant composition, are ripe avenues for more research. Finally, another contributing factor to the landscapes of Los Angeles has been inexpensive and abundant water. Studies have shown that with higher water prices, drought messaging, and turf replacement rebate programs, residents reduce landscape water use and are willing to replace their lawns with plants that use less water (Pincetl et al., 2019).

In Los Angeles, we have demonstrated that residents have created a new unique urban plant biome. It is reasonable to assume that the particular traits of urban plants might affect the associated bird, insect, and other animal communities. Studies in other cities have found that non-native species affect biodiversity (Burghardt, Tallamy, & Gregory, 2009) and growth (Narango et al., 2018) of associated animal communities. Thus, the human-created biome might not facilitate the presence of other types of desired wildlife or may facilitate wildlife that has found refuge in novel urban ecosystems, such as parrots. Yet, losses of biodiversity in some cases can feedback to negatively affect humans, with current bee colony collapse, which might in part be caused by habitat loss (Naug, 2009), as a particularly troubling example. Ultimately, urban communities will need to decide which types of ecosystems they want to create in urban environments to facilitate the well-being of human and nonhuman inhabitants.

5 | CONCLUSIONS

Regardless of whether species are growing spontaneously or are cultivated, all urban plants interact with the environment and contribute to benefits and hazards. Here we show that throughout the city of Los Angeles people have greatly increased plant diversity by planting many cultivated exotics. Further, urbanization has shifted the functional types of local plants by increasing the number of woody and succulent species and decreasing the number of grass species. Such a turnover of functional types will most likely affect ecosystem services, such as storage of carbon and water use. Our findings demonstrate that urban residents have planted a high diversity of exotic perennial woody (mainly trees) and forb flowering species. A large majority of these exotic plants were introduced intentionally through the nursery industry, demonstrating the need for more knowledge of the factors that drive decision-making in the regional to global horticultural trade. Ultimately, better understanding which plants people in cities select, and why, is necessary to fully understand the urban "macrosystem" that has been created through cultivation in Los Angeles and elsewhere.

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AUTHOR CONTRIBUTIONS

MLA wrote the paper along with DEP and GDJ. LWC, HRM, TT, MLA, GDJ, TWG, DEP, and SP collected the data. DEP, SP, and GDJ designed the tree collection methodology and social surveys. GDJ and LWC designed the community garden data collection methods. TWF, JC-B, SEH, and KLL contributed to data collection methodology for the residential yards and social surveys. All the co-authors edited the manuscript.

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