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California's native trees and their use in the urban forest

Camille C. Pawlak[a,b,*,1], Natalie L.R. Love[a,b,1], Jennifer M. Yost[a,b], G. Andrew Fricker[b,c], Jacqueline M. Doremus[b,d], Matt K. Ritter[a,b]

[a] Biological Sciences Department, California Polytechnic State University, San Luis Obispo, CA 93407, USA
[b] Urban Forest Ecosystems Institute, California Polytechnic State University, San Luis Obispo, CA 93407, USA
[c] Social Sciences Department, California Polytechnic University, San Luis Obispo, CA 93407, USA
[d] Department of Economics, California Polytechnic State University, San Luis Obispo, CA 93407, USA

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ABSTRACT

California's urban forest is composed of both native and non-native species. These trees improve the quality of life of urban residents and mitigate the effects of climate change by buffering local microclimates. A species' native status is often defined at the scale of the state's political boundaries, which doesn't reflect its actual native range. Here we define the list of 95 tree species native to California, create digital range maps for each species, provide native species lists for every city in California, and analyze trends in native tree species in the state's urban areas. We found that California's urban areas have relatively few tree species that are native within a given city's boundaries. Even though non-natives outnumber natives in all California cities, opportunities for more native tree diversity are slim as most cities have less than four native species that aren't already growing as urban trees. California's cities face a hotter and drier future, threatening existing urban forests and the benefits they provide residents. We explore different options for tree selection based on the goal of growing healthy and resilient urban forests into the future.

1. Introduction

Urban environments are novel ecosystems where a majority of the human population lives alongside native and non-native plants and animals (Uchida et al., 2021; Marris, 2013). Given climate change predictions, these environments will become more challenging for humans with increased temperatures, frequent extreme weather events, increased drought, higher intensity winds, and associated risks like fire, air pollution, and disease (Ordóñez and Duinker, 2014). Urban forests can help mitigate these environmental challenges by providing a suite of ecosystem services such as controlling microclimate, contributing to resident energy-savings, reducing hard-surface runoff and water quality, creating habitat for biodiversity, reducing particulate pollution, and sequestering carbon (Livesley et al., 2016; McPherson and Simpson, 2002). Although urban forests can mitigate some effects of climate change, they are also vulnerable to the stressors associated with climate change (Esperon-Rodriguez et al., 2022;Ordóñez and Duinker, 2014). Urban forests are designed environments and if planned with climate resiliency as a guiding factor can continue to provide sustained benefits to future urban residents (Livesley et al. 2016).

Planting climate resilient urban forests is a goal in many urban forestry management plans. Stressors associated with climate change such as increased temperatures and drier conditions will create challenging conditions for urban trees (Ordóñez and Duinker, 2015; San Francisco Planning Department, 2014; Dudek, 2018; Abeyta et al., 2013; Juzwik et al., 2011; Lesk et al., 2017; Restaino et al. 2016; Jagemann et al., 2018; Cavender-Bares et al., 2022). Selecting tree species that can survive such stressors is essential for planning resilient urban forests. Many factors are considered in species selection including site conditions such as soil and available space, as well as conditions related to the species of the tree including its native status, pest susceptibility and the overall species diversity of the area (Conway and Vander Vecht, 2015). Two common goals cited in urban forest management related to species selection are to increase the diversity of trees in the urban forest, and to select species that are considered native to the urban forest (Ordóñez and Duinker, 2013; Conway and Vander Vecht, 2015; Dudek, 2018; Abeyta et al., 2013; City of Los Angeles, 2018; City of Davis, 2002; San Francisco Planning Department, 2014; City of El Monte, 2010; Maryland

* Correspondence to: 1 Grand Ave, Building 33, San Luis Obispo, CA 93407, USA.
E-mail address: cpawlak@calpoly.edu (C.C. Pawlak).
[1] Indicates first authors.

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Department of Environment, 2022). Planting a high diversity of tree species increases urban forest resiliency by minimizing tree loss to individual threats like high or low temperatures, specific pests, or storms (Huff et al., 2020; Nitschke et al., 2017; Paquette et al., 2021; Raupp et al., 2006; Wood and Dupras, 2021). Native species are selected for planting in urban forests because they are believed to create better habitat for wildlife, are culturally significant, and are thought to be better adapted to the environment of the city they are native to because they have evolved in that climate and therefore might be more resilient than non-native trees (Ordóñez and Duinker, 2013; Conway and Vander Vecht, 2015; City of Los Angeles, 2018; Abeyta et al., 2013; Spotswood et al., 2017; Tallamay and Darke, 2009a). The strategy of increasing diversity has been shown to promote resiliency in many previous studies (Dymond et al., 2014; Huff et al., 2020; Nitschke et al., 2017; Paquette et al., 2021; Raupp et al., 2006; Wood and Dupras, 2021). However, it is unclear if planting native tree species results in urban forests that are better adapted for local climates and create better wildlife habitat, as there are competing literature and claims about the advantages of selecting species based on native status (Ordóñez and Duinker, 2013; Dickie et al., 2014; Boshier et al., 2015; Tallamay and Darke, 2009a; Spotswood et al., 2017; Frankie et al., 2019; Tallamy and Shropshire, 2009a,b; Abeyta et al., 2013; Suzi Katz Garden Design, 2022; Carper et. al, 2014; Sax, 2002; Wood and Esaian, 2020; Lockwood and Gilroy, 2004; Wood and Dupras, 2021; Mckinney, 2002). Species selection for urban forests is influenced not just by scientific literature, but also often by preferences of urban residents, the nursery industry, landscape architects, and non-profit organizations including government and institutional organizations (Avolio et al., 2018; Avolio et al., 2015b; Conway and Vander Vecht (2015)). Species selection policies are outlined in urban management plans, which are often collaborative efforts that synthesize expert opinion and community member input.

California boasts rich species diversity in both its urban forests and natural spaces. California has over 1400 species of trees growing in the urban forest and is a biodiversity hotspot with more than 5000 native plant species and 95 native tree species (Love et al., 2022; Burge et al., 2016; Jepson Flora Project, 2022; Myers et al., 2000; SelecTree, 2022). California's native tree species live in a wide range of climates from hot, dry deserts to cool, wet, montane environments (Sawyer and Stuart, 2001). They are some of the most impressive trees in the world, being the oldest, tallest, and most massive trees on earth. Nearly 30 % of the state is covered in forests, mostly dominated by conifer species in the mountainous regions. The topographic diversity leads to many high elevation tree-dominated plant communities. California has a Mediterranean climate in which trees must endure hot dry summers (Ritter, 2018). Many of the state's trees are found along rivers and waterways where they have access to year-round water. Additionally, California has high soil diversity and some of the native trees are soil specialists and grow, for example, on serpentine soils (Ritter, 2018). Tree species in California are considered "native" if they occurred within the political boundary of the state naturally, not as a consequence of human activity (Jepson Flora Project, 2022). Because California is topographically, edaphically, and climatically diverse, not all trees native within the political boundary of California will be suitable urban trees for every city in the state. Many of California's major cities are in arid or semi-arid climates where expansive forests and woodlands are not naturally found, and large trees that are dependent on ample water may suffer in urban environments (Avolio et al., 2015a). For example, the state's official tree, *Sequoia sempervirens*, the coast redwood, currently only occurs in the moist, coastal fog belts of central and northern California (Griffin and Critchfield, 1976). When planted outside of this range in more arid climates, it may suffer from drought stress if not supplementally irrigated.

Here, we sought to assess the role of California's native trees within the state's urban forests and to better understand the geographic patterns of California's native trees. To answer questions about these native trees, we first created digital range maps for each species. We then used these maps to examine the geographic patterns of native tree diversity throughout the state. We address which tree species are native to each city in California, what proportion of California native trees are used in the urban forest, and finally, what proportion of California's urban forests are comprised of native species. This work contributes to our understanding of native tree diversity in California and improves the ability of urban foresters to select appropriate species for tree planting in their cities.

2. Methods

2.1. Defining a tree

To create a complete list of California's native trees, we started with a list of 249 large woody plants present in CalFlora, a database of information on species native to California, and all tree species classified as native to the state by SelecTree (CalFlora, 2022; SelecTree, 2022). Then, we excluded all hybrids, varieties, and subspecies. We also excluded large woody plants that grow primarily as shrubs (Appendix 3). For a large, woody plant species to be defined as a tree, over 90 % of the total known or surveyed individuals in the species must mature to a height of are over 20 feet (6.1 meters) tall and have a single, dominant trunk more than 15 centimeters in diameter at 1.5 m above the ground. Shrubs are smaller and shorter than trees and often have many small, bark-covered stems rising from near ground level. There are many California plants (e.g. *Ceanothus* and *Arctostaphylos*) where individuals occasionally, satisfy the definition of a tree, including large, iconic shrubs like toyon (*Heteromeles arbutifolia*), islay (*Prunus ilicifolia*), smoke tree (*Psorothamnus spinosus*), and elderberry (*Sambucus mexicana*). We excluded these species from our list (Appendix 3). Our final list has 95 species of trees native within California (Appendix 1).

2.2. Species range determination and digitization

For each species on our list, we created new hand digitized range maps using the following sources: Griffin and Critchfield's "Distribution of Forest Trees in California" (1970), Kauffmann (2013), Rundel's "California Desert Plants" (2022), and Little's "Atlas of United States' Trees" (1971, 1976). We also examined red oak range maps produced in recent academic research, as well as records from the Geographic Biodiversity Information Facility (GBIF) and iNaturalist research-grade points to help determine range boundaries for each of the 95 species (Appendix 1) (Hauser et al., 2017; GBIF, 2022; iNaturalist, 2022). After assessing discontinuity between sources, we selected the source with the most detailed range map available and modified the map where needed based on new additional data. For example, the Little range map for *Washingtonia filifera* does not include many populations in southeastern California that are well documented with GBIF and iNaturalist records. We added populations indicated by those sources into our range maps. For some species which have restricted ranges within the state (e.g. *Populus angustifolia)*, we visited populations and validated our range maps.

To digitize each range map, a Portable Networks Graphic (PNG) file of each range map was copied from a pre-existing map, if one existed and completed all operations in ArcGIS Pro (ESRI, 2022). Where spatial files didn't exist, we georeferenced each PNG using and manually digitized the boundary of each range by creating a shapefile. Georeferencing was done using latitude and longitude coordinates given on the maps, or state and county boundaries where no coordinates were listed. Populations from GBIF or iNaturalist were manually drawn in. The sources for each of the range maps are available in Appendix 4. After initial digitizing, each shapefile polygon was given a value of 1 and was smoothed by 0.1 degrees using the Smooth Polygon tool (ESRI, 2022). Shapefiles were converted to rasters with a resolution of 50 m^2. For each species, we calculated the area of the range using the "Area" function within "Calculate Field" (ESRI, 2022).

2.3. Species diversity heat maps

To identify diversity hotspots in California, we created tree species heat maps by combining sets of rasters together using the "Mosaic to New Raster" (ESRI, 2022). We set the mosaic operator to sum, meaning our heat maps were created by summing each range map together. We created heat maps of 1) all 95 tree species in California, 2) all species of *Pinus* (18 species), 3) all species of *Quercus* (10 species), 4) and all endemic tree species (24 species) (Appendix 1). These genera were selected because of their significance to the state. The genus *Pinus* represents the genus with the highest number of native tree species in California. Oak woodlands dominated by species in the genus *Quercus* are an iconic part of California's environment, and cover about 10 % of the state (Ritter, 2018). We defined endemic status using the Jepson eFlora and Little's range maps (Little, 1976; Little, 1971, Jepson Flora Project, 2022). A tree is endemic to California if its native range is entirely within the state boundary. This resulted in a gridded map where each grid contained the number of native tree species present in that 50 m^2 area. 50 m^2 was chosen for visual purposes, the individual range files are intended to be used as shapefiles.

2.4. Creating native species lists for California cities

In this study we defined the boundaries of 1173 urban areas in California using two sources: TIGER Line Census boundaries and a 2014 CDFW land classification map (U.S. Census Bureau, 2010; LandIQ, 2017). We started with the TIGER Line Census shapefiles for all census-defined places in California. Many census-defined places have boundaries that extend outside of urban areas and include agricultural or natural areas (e.g., the Angeles National Forest, which is a natural area close to the urban areas in Los Angeles County). To focus our study on urban areas rather than surrounding more rural areas, we refined the boundaries for each census-defined place by restricting them to areas classified as urban reserves in the 2014 CDFW land classification map (LandIQ, 2017). We did this by cropping the TIGER place file to the urban reserves using "Clip" (U.S. Census Bureau, 2010; ESRI, 2022). In this paper, when we refer to cities, we are referring to the urban-restricted census-defined place boundary as defined above.

Next, we used our tree species maps to identify the number of species native to each city. In this study, our working definition for a species to be considered native to a city is if the native range for that species overlaps the city boundary. We overlaid our city boundaries with the tree species maps to identify native species. Within each city boundary, we counted the number of ranges that intersected the boundary. We calculated the mean number of tree species native across all of California's cities. Finally, for all cities in California, we created lists of trees native to each city.

2.5. Assessing the current native tree species composition in California cities

We assessed the current proportion of native trees in California cities with tree inventories using data from the California Urban Forest (CUF) Inventory (Urban Forest Ecosystem Institute, 2022; Love et al., 2022) https://datastudio.google.com/u/0/reporting/880d448d-de26-48d3-b563-0c6317e456e4/page/jWHKB). The CUF Inventory is a database of over 7 million individual tree records (including species, size, and location) for publicly managed trees in California and is the most comprehensive inventory of California's street trees (Love et al., 2022). Trees in the inventory are primarily street trees, although some trees planted in urban public parks are included (Love et al., 2022). Although uncommon, some arborists include large shrubs in urban forest inventories, such as *Heteromeles arbutifolia.* Before conducting data analysis, we removed all shrubs listed in Appendix 1 that were present in the CUF Inventory. This removed 18,155 observations from the dataset, leaving 7,073,463 trees in the database. We also removed all observations where the specific epithet of the tree was not specified, this removed 680,719 observations, leaving the final 6,392,744 trees that we assessed as native or non-native. For cities with at least 100 trees in their inventories (n = 512 cities), we summarized the number of species present in each city (species richness) using a spatial join of the tree inventory points to our modified cities file. To assess the contribution of native species to overall city species diversity, we also used CUF Inventory data to calculate the Shannon Diversity Index for each city both with and without native species. The Shannon Index (H') is a metric that accounts for species richness and evenness. and is calculated using the equation:

$$H' = -\sum_{i=1}^{S} p_i \quad \ln p_i \tag{1}$$

where S is the number of species and p_i is the proportion of total trees in each city within species *i.* We calculated the Shannon Diversity Index using the vegan package in R (Oskanen et al., 2022, R Core Team, 2022). Because our data was not normally distributed, we compared the two independent groups (diversity calculated with and without native species) to see if their distributions were significantly different using a Wilcoxon rank sum test (W) using the "stats" package in R (R Core Team, 2023).

We also calculated what proportion of the trees and species present in each city's inventory were native based on the species lists we generated for that city. Species are considered native if their native range overlaps that city, otherwise, they are considered non-native. A species can be native to the state of California, but not native to the city within California where it is planted. Using the native species lists we generated for each city, and the number of native species currently in that city, we calculated how many species were native to but not planted within each city in California. Using water use rankings from SelecTree, we assessed the water use rankings of trees planted in California's urban forests that are native to the state (SelecTree. (2022)). These analyses were done in R using the sf, dplyr, and data.table packages (Pebesma, 2018; Wickham et al., 2022; Dowle and Srinivasan (2021); R Core Team, 2022).

3. Results

3.1. Trends in native tree species diversity

The final species list identifies 95 tree species as native to California (Appendix 1). Across the state, there are more species native to higher elevation, mountainous areas compared to valleys and deserts (Fig. 1A). The highest density of native tree species in California occurs in northern California, in Siskiyou County (Fig. 1A), where the ranges of 24 native tree species overlap. The highest density of endemic tree species native to one area is eight species, occurring north of Santa Rosa, in Robert Luis Stevenson State Park, California (Fig. 1B). The highest density of co-occurring oak species, *Quercus* spp., is seven species. This occurs in several places throughout the state including west of Pieta (Mendocino County), east of Cloverdale (Sonoma County), and northwest of Santa Margarita (San Luis Obispo) (Fig. 1C). The highest number of co-occurring pines, *Pinus* spp., is also seven. This occurs in several locations across California including north of Whitney Portal (Inyo County), south of Aspendell (Inyo County), in the Klamath National Forest and just east of Mount Shasta in Siskiyou County (Fig. 1D).

The species with the smallest native range within the state is *Hesperocyparis stephensonii*, occurring in only 0.4 km^2 east of San Diego (Appendix 1). The species with the largest native range in the state is *Salix lasiandra*, with an area of 183,385 km^2 covering most of the northwest of the state and all coastal areas (Appendix 1).

3.2. Native tree species in urban areas

Of the 95 trees species recognized here, only 76 of them have ranges

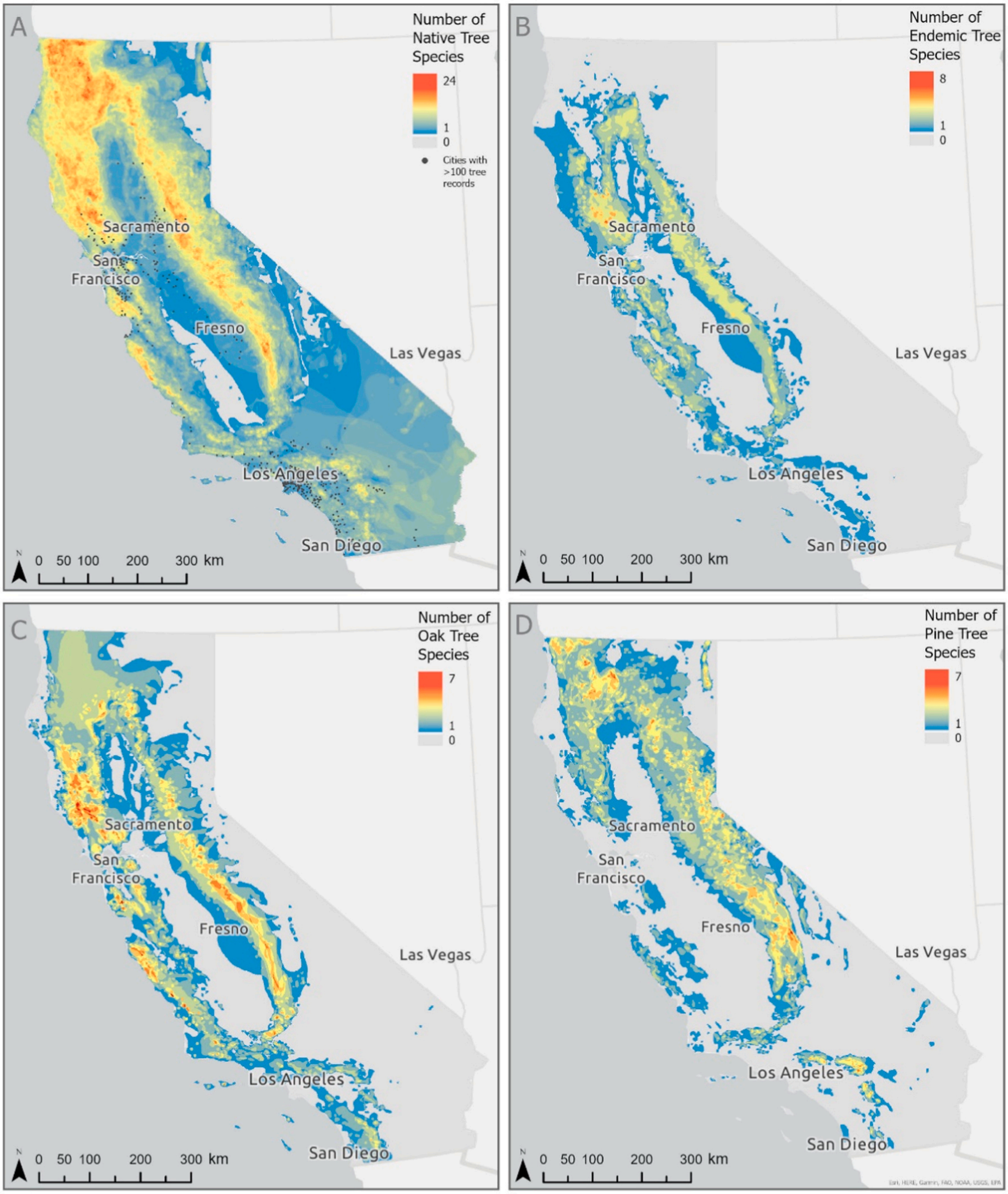

Fig. 1. Heat maps representing the number of species of trees native across the state, including (A) all 95 native tree species and cities with tree inventories containing over 100 records, (B) California's 24 endemic species, (C) the 10 tree oak species (*Quercus* spp.) and (D) the 18 pine species (*Pinus* spp.). Areas with warmer tones have higher numbers of species, while cooler tones have fewer. Areas within California with no native trees are light gray.

that overlap with California's cities. The remaining 19 species occur at high elevations, such as the bristle cone pine (*Pinus longaeva)*, or outside the population centers of the state, like numerous rare cypress species (*Hesperocyparis* spp.). The 76 native species are not evenly distributed throughout California. Generally, most large urban centers are in lowland valleys and flat areas, and fewer native tree species occur in these areas relative to the surrounding mountainous areas (Fig. 1A, Fig. 2). In the Bay Area, Sacramento, and Greater Los Angeles Area, the surrounding mountains have higher numbers of native tree species than urbanized areas (Fig. 2). Across California's cities, the mean number of tree species native to a city's geographic area is 6.9 species with a standard deviation of 4.9 species (Fig. 3 A). The highest number of native trees in urban areas is 23 and occurs in two cities, Cobb (Lake County) and Woodside (San Mateo County), California (Fig. 2 A). 18 cities have zero trees native to their area, and 67 cities have only one species of native tree, for 50 out of those 67 cities that species is black willow (*Salix gooddingii)*.

In general California's urban forests are comprised of fewer native than non-native species (Fig. 3C, Fig. 4B). While 95 species are native to the state, over 1307 non-native trees have been inventoried in the state. Of the 76 native species found within the geographic range of California's cities, 75 have been planted in the urban forest. In total, 78.9 % (75/95) are found within the urban forest. When we look at all cities with at least 100 inventoried trees (516 cities total), we find that on

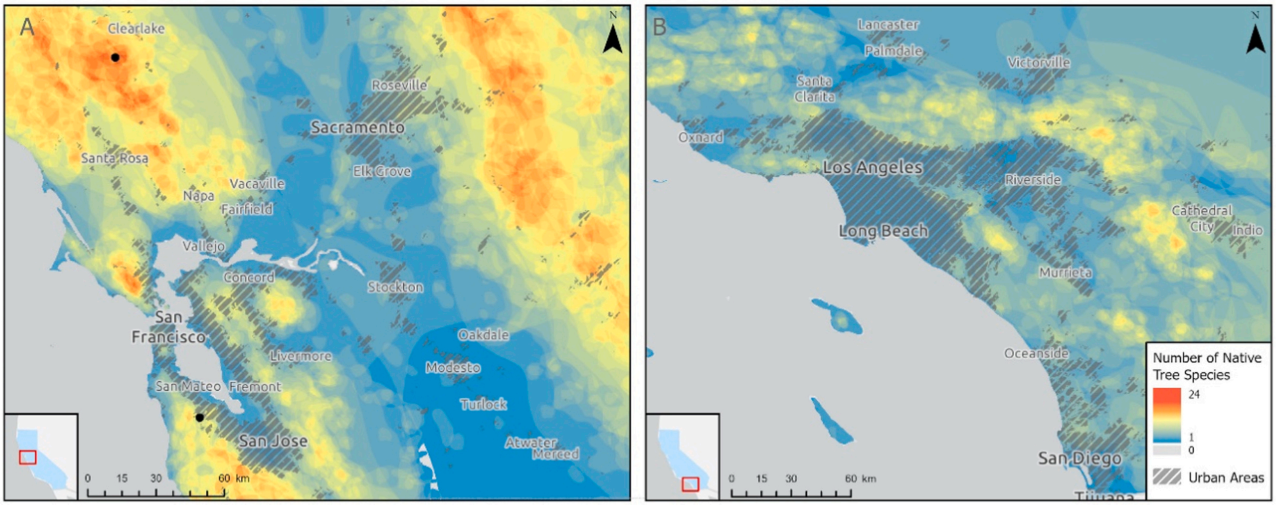

Fig. 2. Number of native species of trees in California's major urban areas. (A) The Bay Area and Sacramento. (B) Southern California. The grey hash marks depict the urban centers. In these areas, there are more native tree species outside of the urban centers. The cities with the highest number of native trees, Cobb and Woodside, CA are marked with black points (A).

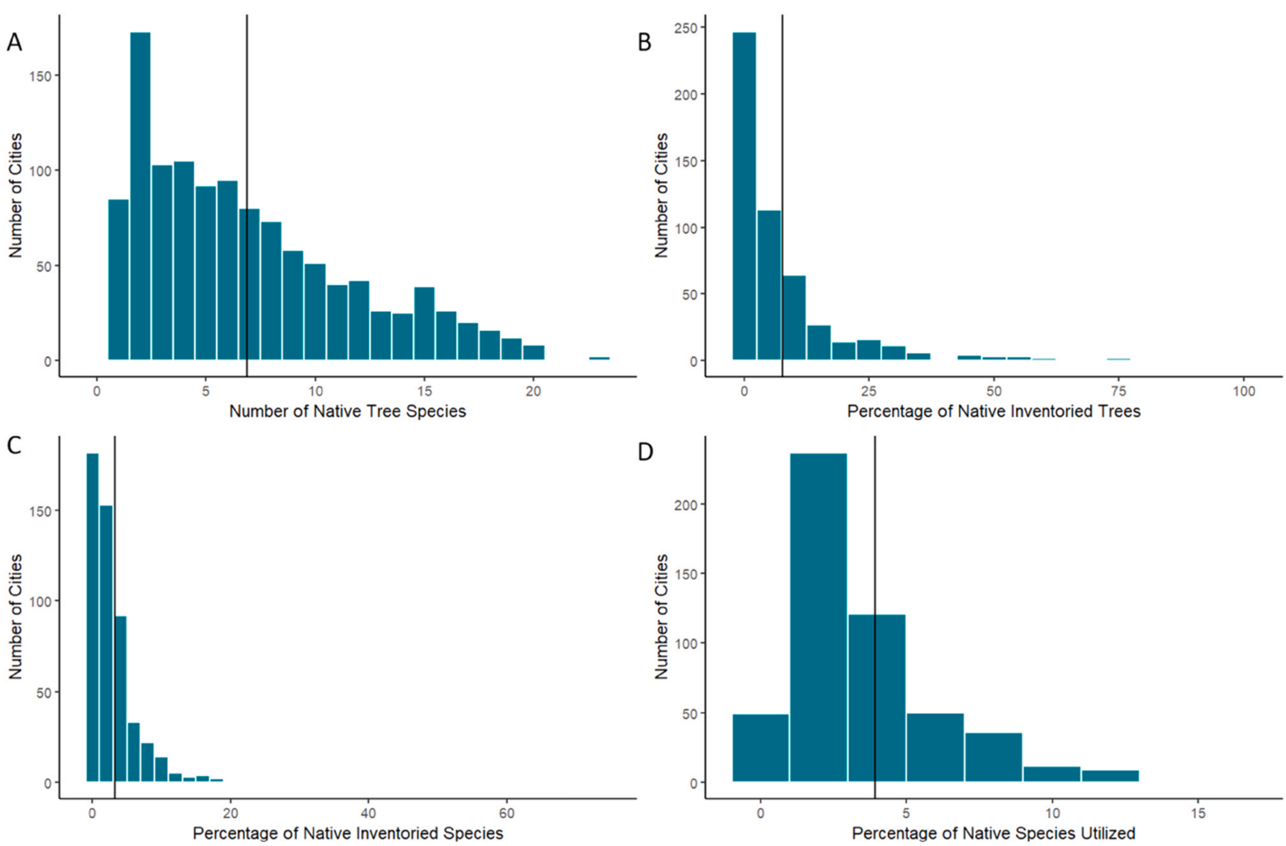

Fig. 3. (A) The distribution of the number of tree species native to California's cities (n = 1173 cities). The vertical line indicates the mean number of species native to cities (6.9 species) with a standard deviation of 4.9 species. (B) The distribution of the percentage of individual trees that are native to the city where they are planted (n = 6,372,744 trees in CUFI inventory, n = 516 cities). The vertical line indicates the mean of 7.7 % of trees in a city's inventory being native with a standard deviation of 12.6 %. (C) The distribution of the percentage of species that are native to the city where they are planted (n = 1377 species, n = 516 cities). The vertical line indicates the mean of 3.2 % of species in a city's inventory being native with a standard deviation of 4.7 %. (D) The distribution of the number of species native to a city that are not currently planted in that city's urban forest. The vertical line indicates the mean of 3.8 of species with a standard deviation of 2.6 (n = 516 cities). All inventory data comes from the CUF Inventory (Love et al., 2022).

average they were composed of 3.2 % of native species and 96.7 % non-native species with a standard deviation of 4.7 % native species (Fig. 3C). California's urban forests are also composed of fewer native individual trees than non-native trees (Fig. 3B, Fig. 4A). When assessing every individual tree in the CUF Inventory as native or non-native, as opposed to the species, we found 12.5 % of all inventoried trees are native to the state, but only 5.8 % were native to the city where they were planted. On average, at least 100 inventoried trees (516 cities

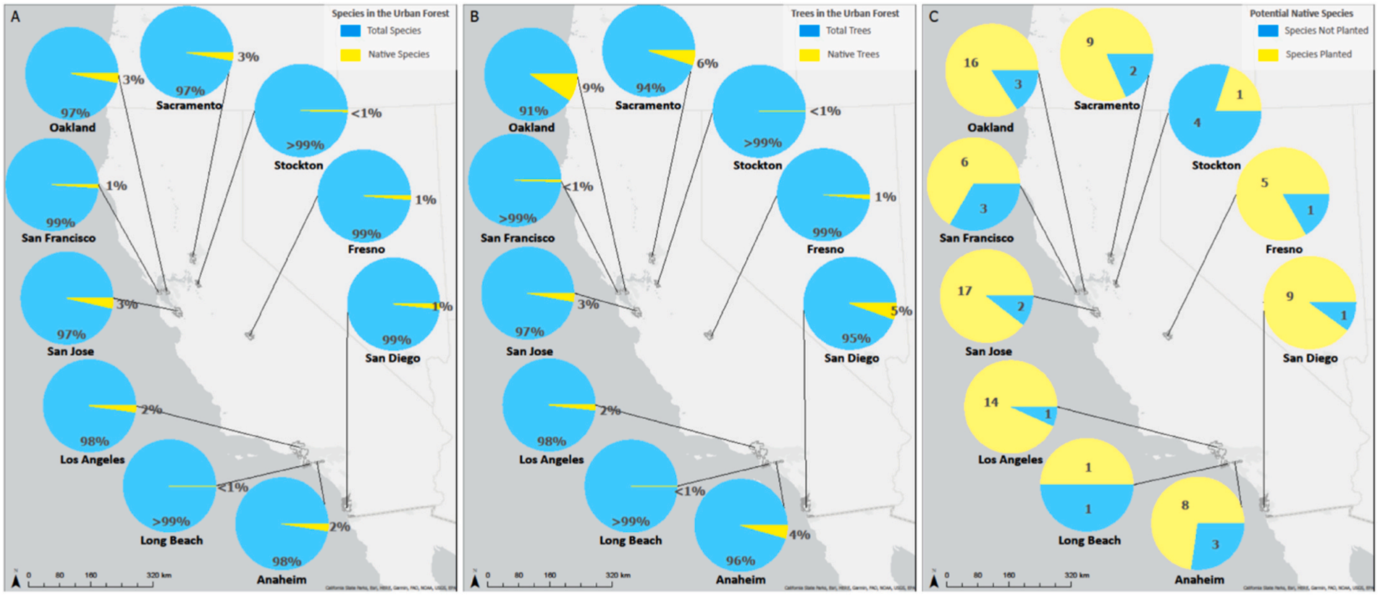

Fig. 4. (A) The number of species currently growing in California's most populous cities that are native to that city. (B) The number of individual trees currently growing in California's most populous cities that are native to that city. (C) Of the total number of species of trees native to a city, species represented by the CUF Inventory are shown in yellow. Blue areas represent the number of native species not planted in that city.

total), were composed of 7.7 % individual native trees and 92.3 % non-native individual trees with a standard deviation of 12.6 % (Fig. 3B). On average, cities in California have less than four species native to their city that are not already growing as urban trees with a standard deviation of 2.6 species (Fig. 3D). When comparing the Shannon Index scores for cities with and without native trees included using a Wilcoxon rank sum test, we found no significant difference between the distributions of the groups ($W = 134039$, $p\text{-value} = 0.8$).

Quercus agrifolia is the native tree species most commonly found in urban environments within its native range (Table 1). California's native tree species mostly have medium water use rankings (Fig. 5A). Of the 95 native trees species, 17.9 % (17/95) are very low water use, 24.2 % (23/95) are low water use, 44.2 % (42/95) are medium water use, and 13.7 % (13/95) are high water use species (Fig. 5A). Of the individual trees in the CUF Inventory that are native to the state, 2.7 % are very low water use, 37.6 % are low water use, 22.1 % are medium water use, and 37.6 % are high water use (Fig. 5B).

Table 1
The top ten most commonly inventoried trees growing within their native range. Number of cities indicates the number of cities the tree occurs in within its native range.

Rank	Species	Number of Trees Inventoried	Number of Cities inventoried in
1	*Quercus agrifolia*	152,594	287
2	*Platanus racemosa*	87,871	180
3	*Quercus lobata*	48,212	161
4	*Sequoia sempervirens*	15,831	40
5	*Pinus torreyana*	8001	7
6	*Fraxinus velutina*	7602	29
7	*Populus fremontii*	7484	108
8	*Washingtonia filifera*	6946	10
9	*Quercus douglasii*	6091	64
10	*Alnus rhombifolia*	4928	59

4. Discussion

4.1. Summary

In this study, we compiled a list of the 95 species of trees native to California, created digital range maps, and examined trends in tree diversity across the state. Using our range maps, we created city-specific native tree species lists for cities in California. We found that the average number of native species for cities in California is 6.9 species, but ranges from a high of 23 to a low of zero native trees. There were 18 cities with no native trees in their geographic footprint. For cities with tree inventories present in the CUF Inventory, we determined what proportion of each city's current urban forest is composed of native or non-native species and found that while non-natives trees are more common in California's urban forests, and that there are few native species that are not already being used in urban plantings.

4.2. Patterns in California's native trees

California has 95 species of trees that grow natively throughout the state. Although California is a biodiversity hotspot with a high diversity of plants, it does not have a higher number of native tree species compared to other states like Texas (222 trees) or Florida (262 trees) (Myers et al., 2000; Simpson, 1999; Little, 1978). Some of these states' tree statistics include species we would classify as shrubs, which has inflated their species counts slightly.

4.3. Patterns of native trees in California's urban areas

Diverse urban forests are resilient urban forests because diversity minimizes the risk of tree loss to individual threats like pests, diseases, or climate change (Huff et al., 2020; Nitschke et al., 2017; Paquette et al., 2021; Raupp et al., 2006; Wood and Dupras, 2021). In California, urban areas have been developed in areas that naturally have low numbers of native tree species compared to surrounding mountainous areas (Fig. 1A). The average number of tree species native within a California city's boundaries is 6.9 species (Fig. 3A). When comparing the Shannon Index scores for cities with and without native trees, we found no significant difference between the two distributions. This suggests that the

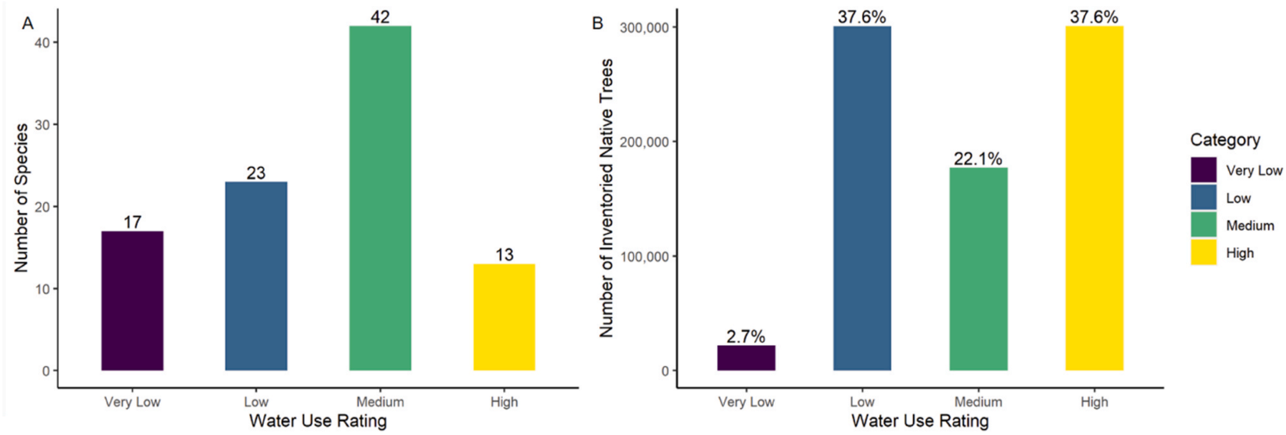

Fig. 5. (A) The water use ratings for the 95 trees native to California. Most native trees are rated medium water use. Water use ratings were obtained from SelecTree (SelecTree, 2022). (B) The water use ratings of the 800,752 inventoried trees native to California from the CUF Inventory. Most native street trees have high or low water use ratings.

native trees currently planted in cities do not significantly contribute to overall urban forest diversity. This is to be expected given the few native species found in each city (mean of 6.9 species per city). Of California's 95 native species, over half are medium or high-water use species. As water conservation continues to put urban forestry under pressure to conserve water, species with higher water use rankings will be inappropriate for future planting (Botkin and Beveridge, 1997). Of the native species we select for planting in California's urban forests, 37.6 % are high water use. Those species are less likely to be selected for future planting where water conservation is prioritized. Only 76 of the 95 possible tree species are native to urban centers in California. Major urban centers in California, like San Francisco, were built in areas that were not originally forested, but rather dominated by shrublands including coastal scrub and chapparal communities (Fig. 2) (San Francisco Planning Department, 2014).

Los Angeles is an example of a major city in California where trees and forests were not historically dominant across the broader landscape, but they are now because of the development of the urban forest. Los Angeles is built in part on a large salt marsh, remnants of which exist in Ballona Creek. The city of Los Angeles has a higher number of native tree species than many cities in California, with 15 native species (Appendix 2). Of those 15, seven are riparian trees (high water use), and many don't occur widely across the entire landscape of the city. For example, the California Bay Laurel, *Umbellularia californica*, only occurs at the very edge of the city boundary in the Santa Monica Mountains, and its distribution does not extend into the basin in which most of Los Angeles's urban environment lies. Currently, the city of Los Angeles has over 650 species represented in their public tree inventory (Urban Forest Ecosystem Institute, 2022). Of those species, 14 of the 15 native species are represented in Los Angeles's urban forest. Those 14 species represent only ~2 % of the total diversity found in Los Angeles (Fig. 4C). Increasing native tree plantings in Los Angeles could expand the planting of the seven riparian trees, although this might be unpopular for water restrictions, or could plant the one native tree not currently inventoried with the city, (*Pseudotsuga macrocarpa* – the big cone Douglas fir). The native tree palette for Los Angeles is very limited even though it has more native trees than most cities in the state.

Assessing what trees are native to the place of planting can help foresters plan for appropriate tree plantings rather than depending on a list of California natives. Knowing what trees are locally native is important since these are the species desired for their ability to tolerate and survive local conditions within a city, although local adaptation has limitations in the face of climate change (Bontrager et al., 2020). Here, we provide a list of all native species for each city so urban planners can be more targeted when native trees are appropriate for urban plantings.

Relatively few of the trees planted in California's urban forests are native. California's urban forest contains over 1400 species of trees, many more species than the 95 that are native (Urban Forest Ecosystem Institute, 2022). This is different from many parts of the U.S. For example, in the northeast, cities are often built in areas that are naturally forested. Across the U.S., 46.5 % of trees in urban forests are native to the state the tree is planted in (McCoy et al., 2022). The number of trees native to the state growing within urban forests varies from 0.5 % to 87.4 %, with cities in wetter, cooler climates having higher percentages of native trees (McCoy et al., 2022). Cities in the eastern U.S. tends to have higher percentages of native trees than in the western U.S., possibly due to being built in more heavily forested areas (McCoy et al., 2022; Little, 1977). California has lower percentages of individual trees that are native within cities than the average for the U.S., (11.3 % versus the 46.5 % country average) (McCoy et al., 2022), and only 4.6 % of individual urban trees are native to the city in which they are planted (Fig. 4, Appendix 2). This low number is partially explained by the low numbers of trees that occur natively within California cities. There is little opportunity in California to expand the number of native tree species planted within cities' urban forests; on average, cities only have 3.9 species that are native to their city, but not already planted in the urban forest (Fig. 3D). Those species may be further limited by nursery availability. To add a higher number of new species to California cities urban forests, non-native species must be considered.

4.4. Urban forest species selection

In urban forestry in California, with fewer species of native trees to select from, the two strategies to increase urban forest resilience, either through diversification or through native-focused plantings, can unnecessarily come into conflict (Marris, 2013; Love et al., 2022; Dickie et al., 2014). California is a biodiversity hot spot full of rare plant species (Myers et al., 2000). Planting, promoting, and celebrating these native species in our cities is important. Our work helps to make that possible in a science driven way by directing communities to the species that are native to the local area. However, we caution about advocating for native-only planting since few native trees perform well in urban areas and doing so will decrease tree species diversity in cities so drastically as to be detrimental to most urban forestry goals.

Planting native trees is promoted because native trees are thought to support more wildlife biodiversity, functional diversity, are culturally significant and are thought to be more climate and drought resilient (Ordóñez and Duinker, 2013; Conway and Vander Vecht, 2015; City of Los Angeles, 2018; Abeyta et al., 2013; Spotswood et al., 2017; Tallamy and Darke, 2009a; Tallamy and Shropshire, 2009b; Suzi Katz Garden

Design, 2022). However, many of these reasons are specific to certain locations or species, and should not be applied as general rules. Although some studies have found native plants to support higher levels of wildlife in insect diversity, these studies were conducted in temperate ecosystems of the East Coast of the US, not California (Tallamy and Shropshire, 2009b; Burghardt et al., 2009). Other studies have found similar or higher wildlife biodiversity on non-native relative to native trees, and some wildlife utilizes non-native trees for habitat and foraging (Sax, 2002; Wood and Esaian, 2020; Carper et al., 2014; Shapiro, 2002; Lockwood and Gilroy, 2004). This suggests that the inclusion of non-native tree species creates and supports interactions that increase the ecological functional diversity of California urban forests, although our study does not test this directly (Carper et al., 2014; Sax, 2002; Wood and Esaian, 2020; Lockwood and Gilroy, 2004; Shapiro, 2002).

For an urban forest to provide ecosystem services to local communities, the trees need to be healthy (Livesley et al., 2016). Urban forests will experience stress as our climate gets warmer and drier, and native trees may or may not do well in urban forests as adaptational advantages they previously held weaken (Boshier et al., 2015; Bontrager et al., 2020; Esperon-Rodriguez et al., 2022). Of the trees native to the state planted as street trees in California's urban forest, 37.6 % represent high water use species (Fig. 5B) (SelecTree, 2022). Planting such a large proportion of high-water use species is ill advised in the face of the predicted future drier climate for most of California (Bedsworth et al., 2018) (Fig. 5A).

4.5. Caveats and limitations

This study focuses on the issue of nativity for trees in California's urban forest. California, which has many cities in arid or semi-arid climates, was not naturally forested in many large urban areas (Avolio et al., 2015a). In cities with similar climates, urbanization increases the number of trees overall (Avolio et al., 2015a). Other states also have higher numbers of native species of trees, like Texas (222 trees) or Florida (262 trees), meaning they have a broader and more diverse species palette of natives (Myers et al., (2000); Simpson, 1999; Little, 1978). In urban centers with few native species to select from, this study highlights that urban foresters and managers need to think critically about prioritizing native plantings when aiming to increase diversity and resilience.

As the climate changes, the native range of many species is expected to shift (Corlett and Westcott, 2013). Many plant species will not be able to migrate fast enough to maintain populations within the climates they can tolerate (Corlett and Westcott, 2013). In a species' native ecosystem, the advantages species had due to local adaptation are expected to decrease (Boshier et al., 2015; Bontrager et al., 2020). In the urban forest, both native and non-native species that tolerate the current climates may not be appropriate in the future (McBride and Laćan, 2018). Work that tests a species' ability to handle future climates, similar to work such as Climate Ready Trees at the University of California, Davis, will be an important factor in selecting species for future urban forests (McPherson et al., 2016).

Our research suggests that native trees do not represent a large proportion of the species diversity of California's urban forests; however, it is possible they contribute significantly to the structural functional diversity of the urban forest. Functional diversity measures how species traits contribute to their ecosystem. For example, a study done in Quebec City predicted that planting more conifers, due to differences in structure and traits from deciduous trees, would reduce pollution, reduce storm-water runoff and reduce heating needs for urban residents (Wood and Dupras, 2021). Increasing urban forests functional diversity can make them more resilient to change (Paquette et al., 2021). This study was designed to assess patterns in species diversity, not functional diversity, and whether native species increase functional diversity in California's urban forests is unknown. However, because cities in California are comprised of an average of 92.3 % non-native individual trees, it is unlikely that native species contribute significantly to increasing the functional diversity of urban forests in the state.

4.6. Accessing the data

This research created spatial files for each of California's 95 native tree ranges as well as city-specific native species lists for every city in California. These data can be accessed at https://calpoly.maps.arcgis.com/apps/webappviewer/index.html?id=3c4233d842a64e41ac9cf3713848a481. City-specific native species lists, though better than native lists at a state level, are still a broad level for defining a species as native. This tool allows urban foresters to access range maps and determine where within their city a species is native. Within the web application and in Appendix 2, users can also view the percent of the inventoried urban forest for their city that is currently native.

4.7. Conclusion

Urban forests can help make cities comfortable and livable by providing ecosystem services to residents. As the climate changes, urban forests are at risk. Future species selections must be resilient to drought and climate changes for urban forests to be healthy and continue to provide ecosystem services to residents. In California, our study found that native tree diversity hotspots occur outside of California's urban areas. Many of California's cities were built in areas that were originally non-forested. Across California's cities there is an average of 6.9 native tree species. California's urban forests are among the most diverse forests in the world. Our study found that California's urban tree species diversity is dominated by non-native trees, likely because of the limited options for native species compared to non-native species. The results from our analyses demonstrate that prioritizing native-only species selections could result in urban forests with lower species diversity because of the limited number of species to select from in each city. Consequently, this could impact the resilience of California's urban forests. Instead, urban forest managers should prioritize planting species with traits such as drought and heat tolerance that will ensure their survival as the climate changes, which may be native species or not.

CRediT authorship contribution statement

Camille C Pawlak: Methodology, Formal Analysis, Writing – original draft, writing – Review & Editing, Visualization. **Natalie L.R. Love:** Methodology, Supervision, writing – Review & Editing. **Jennifer M. Yost:** Conceptualization, Methodology, Resources, Supervision, writing – Review & Editing **G. Andrew Fricker:** Methodology, Supervision, writing – Review & Editing. **Jacqueline M. Doremus:** Methodology, Supervision **Matt K. Ritter:** Conceptualization, Methodology, Resources, Supervision, writing – Review & Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2023.128125.

References

Abeyta, D., Lanham, E., Hansen, R., Mize, R., Our City Forest. (2013). The City of San Jose Tree Policy Manual and Recommended Best Management Practices. ⟨https://www.sanjoseca.gov/home/showpublisheddocument/2520/636633198872030000⟩.

Avolio, M.L., Pataki, D.E., Gillespie, T.W., Jenerette, G.D., McCarthy, H.R., Pincetl, S., Weller Clarke, L., 2015a. Tree diversity in southern California's urban forest: the interacting roles of social and environmental variables. Front. Ecol. Evol. 3 https://doi.org/10.3389/fevo.2015.00073.

Avolio, M.L., Pataki, D.E., Pincetl, S., Gillespie, T.W., Jenerette, G.D., McCarthy, H.R., 2015b. Understanding preferences for tree attributes: the relative effects of socio-economic and local environmental factors. Urban Ecosyst. 18 (1), 73–86. https://doi.org/10.1007/s11252-014-0388-6.

Avolio, M.L., Pataki, D.E., Trammell, T.L.E., Endter-Wada, J., 2018. Biodiverse cities: the nursery industry, homeowners, and neighborhood differences drive urban tree composition. Ecol. Monogr. 88 (2), 259–276. https://doi.org/10.1002/ecm.1290.

Bedsworth, L., Cayan, D., Franco, G., Fisher, L., Ziaja, S. (2018). Statewide Summary Report. California's Fourth Climate Change Assessment. California Governor's Office of Planning and Research, Scripps Institution of oceanography, California Energy Commission, California Public Utilities Commission. ⟨https://www.energy.ca.gov/sites/default/files/2019–11/20180827_Summary_Brochure_ADA.pdf⟩.

Bontrager, M., Muir, C.D., Mahony, C., Gamble, D.E., Germain, R.M., Hargreaves, A.L., Kleynhans, E.J., Thompson, K.A., Angert, A.L., 2020. Climate warming weakens local adaptation [Preprint]. Evolut. Biol. https://doi.org/10.1101/2020.11.01.364349.

Boshier, D., Broadhurst, L., Cornelius, J., Gallo, L., Koskela, J., Loo, J., Petrokofsky, G., St Clair, B., 2015. Is local best? Examining the evidence for local adaptation in trees and its scale. Environ. Evid. 4 (1), 20 https://doi.org/10.1186/s13750-015-0046-3.

Botkin, D.B., Beveridge, C.E. (1997). Cities as environments. Urban Ecosystems, 1.1 (3–19).

Burge, D.O., Thorne, J.H., Harrison, S.P., O'Brien, B.C., Rebman, J.P., Shevock, J.R., Alverson, E.R., Hardison, L.K., Rodríguez, J.D., Junak, S.A., Oberbauer, T.A., Riemann, H., Vanderplank, S.E., Barry, T., 2016. Plant diversity and endemism in the California Floristic province. Madroño 63 (2), 3–206. https://doi.org/10.3120/madr-63-02-3-206.1.

Burghardt, K.T., Tallamy, D.W., Gregory Shriver, W., 2009. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conserv. Biol. 23 (1), 219–224. https://doi.org/10.1111/j.1523-1739.2008.01076.x.

CalFlora. (n.d.). Calflora: Information on California plants for education, research and conservation, with data contributed by public and private institutions and individuals, including the Consortium of California Herbaria [Web Application]. The Calflora Database. Retrieved July 8, 2022, from ⟨https://www.calflora.org/⟩.

Carper, A.L., Adler, L.S., Warren, P.S., Irwin, R.E., 2014. Effects of suburbanization on forest bee communities. Environ. Entomol. 43 (2), 253–262. https://doi.org/10.1603/EN13078.

Cavender-Bares, J.M., Nelson, E., Meireles, J.E., Lasky, J.R., Miteva, D.A., Nowak, D.J., Pearse, W.D., Helmus, M.R., Zanne, A.E., Fagan, W.F., Mihiar, C., Muller, N.Z., Kraft, N.J.B., Polasky, S., 2022. The hidden value of trees: quantifying the ecosystem services of tree lineages and their major threats across the contiguous US. PLOS Sustain. Transform. 1 (4), e0000010 https://doi.org/10.1371/journal.pstr.0000010.

City of Davis. (2002). Community Forest Management Plan. City of Davis. ⟨https://www.cityofdavis.org/home/showpublisheddocument/5638/635992712147670000⟩.

City of El Monte. (2010). El Monte Urban and COmmunity Forestry Managment Plan. ⟨https://www.waterboards.ca.gov/losangeles/water_issues/programs/stormwater/municipal/lid_and_greenst/doc/greenst_poilcy/elmonte_ufmp_greenst.pdf⟩.

City of Los Angeles. (2018). 2018 Biodiversity Report, City of Los Angeles. Los Angeles Department of Sanitation. ⟨Https://www.lacitysan.org/cs/groups/⟩.

Conway, T.M., Vander Vecht, J., 2015. Growing a diverse urban forest: species selection decisions by practitioners planting and supplying trees. Landsc. Urban Plan. 138, 1–10. https://doi.org/10.1016/j.landurbplan.2015.01.007.

Corlett, R.T., Westcott, D.A., 2013. Will plant movements keep up with climate change? Trends Ecol. Evol. 28 (8), 482–488. https://doi.org/10.1016/j.tree.2013.04.003.

Dickie, I.A., Bennett, B.M., Burrows, L.E., Nuñez, M.A., Peltzer, D.A., Porté, A., Richardson, D.M., Rejmánek, M., Rundel, P.W., van Wilgen, B.W., 2014. Conflicting values: ecosystem services and invasive tree management. Biol. Invasions 16 (3), 705–719. https://doi.org/10.1007/s10530-013-0609-6.

Dowle, M., Srinivasan, A. (2021). *data.table: Extension of "data.frame"* [Computer software]. ⟨https://CRAN.R-project.org/package=data.table⟩.

Dudek. (2018). First Step: Developing an Urban Forest Management Plan for the City of Los Angeles. ⟨https://www.cityplants.org/wp-content/uploads/2018/12/10939_LA-City-Plants_FirstStep_Report_FINAL_rev12–7-18.pdf⟩.

Dymond, C.C., Tedder, S., Spittlehouse, D.L., Raymer, B., Hopkins, K., McCallion, K., Sandland, J., 2014. Diversifying managed forests to increase resilience. Can. J. For. Res. 44 (10), 1196–1205. https://doi.org/10.1139/cjfr-2014-0146.

Esperon-Rodriguez, M., Tjoelker, M.G., Lenoir, J., Baumgartner, J.B., Beaumont, L.J., Nipperess, D.A., Power, S.A., Richard, B., Rymer, P.D., Gallagher, R.V., 2022. Climate change increases global risk to urban forests. Nat. Clim. Change 12 (10), 950–955. https://doi.org/10.1038/s41558-022-01465-8.

ESRI. (2022). *ArcGIS Pro* (Version 10) [Computer software]. CA: Environmental Systems Research Institute.

Frankie, G., Feng, I., Thorp, R., Pawelek, J., Chase, M.H., Jadallah, C.C., Rizzardi, M., 2019. Native and non-native plants attract diverse bees to urban gardens in California. J. Pollinat. Ecol. 25 https://doi.org/10.26786/1920-7603(2019)505.

GBIF. (2022). GBIF: The Global Biodiversity Information Facility Occurence Download. ⟨https://www.gbif.org/occurrence/search⟩.

Griffin, J.R., Critchfield, W.B. (1976). The Distribution of Forest Trees in California. Pacific Southwest Forest and Range Experiment Station.

Hauser, D.A., Keuter, A., McVay, J.D., Hipp, A.L., Manos, P.S., 2017. The evolution and diversification of the red oaks of the California Floristic Province (*Quercus* section *Lobatae*, series *Agrifoliae*). Am. J. Bot. 104 (10), 1581–1595. https://doi.org/10.3732/ajb.1700291.

Huff, E., Johnson, M., Roman, L., Sonti, N., Pregitzer, C., Campbell, L., McMillen, H., 2020. A literature review of resilience in urban forestry. Arboric. Urban For. 46 (3), 185–196. https://doi.org/10.48044/jauf.2020.014.

iNaturalist. (2022). California's Native Trees. ⟨https://www.inaturalist.org/projects/california-s-native-trees⟩.

Jagemann, S.M., Juzwik, J., Tobin, P.C., Raffa, K.F., 2018. Seasonal and regional distributions, degree-day models, and phoresy rates of the major sap beetle (Coleoptera: Nitidulidae) vectors of the oak wilt fungus, Bretziella fagacearum, in Wisconsin. Environ. Entomol. 47 (5), 1152–1164. https://doi.org/10.1093/ee/nvy080.

Jepson Flora Project. (2022). Jepson eFlora [Computer software]. ⟨https://ucjeps.berkeley.edu/eflora/⟩.

Juzwik, J., Appel, D.N., MacDonald, W.L., Burks, S., 2011. Challenges and successes in managing oak wilt in the United States. Plant Dis. 95 (8), 888–900. https://doi.org/10.1094/PDIS-12-10-0944.

Kauffmann, M.E., 2013. Conifers of the Pacific Slope: California, Oregon, and Washington, First edition. Backcountry Press.

LandIQ. (2017). Land Use—2014—Land IQ [ds2677] [Computer software].

Lesk, C., Coffel, E., D'Amato, A.W., Dodds, K., Horton, R., 2017. Threats to North American forests from southern pine beetle with warming winters. Nat. Clim. Change 7, 713–717. https://doi.org/10.1038/nclimate3375.

Little, E.L., Jr. (1971). *Atlas of United States Trees* (Vol. 1). Department of Agrictulture, Forest Service.

Little, E.L., Jr. (1976). *Atlas of United States Trees* (Vol. 1). Department of Agrictulture, Forest Service.

Little, E.L., Jr. (1977). *Atlas of United States Trees* (Vol. 3). Department of Agrictulture, Forest Service.

Little, E.L., Jr. (1978). *Atlas of United States Trees* (Vol. 5). Department of Agrictulture, Forest Service.

Livesley, S.J., McPherson, E.G., Calfapietra, C., 2016. The urban forest and ecosystem services: impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. J. Environ. Qual. 45 (1), 119–124. https://doi.org/10.2134/jeq2015.11.0567.

Lockwood, J.L., Gilroy, J.J., 2004. The portability of foodweb dynamics: reassembling an Australian eucalypt-psyllid-bird association within California: foodweb reassembly. Glob. Ecol. Biogeogr. 13 (5), 445–450. https://doi.org/10.1111/j.1466-822X.2004.00116.x.

Love, N.L.R., Nguyen, V., Pawlak, C., Pineda, A., Reimer, J.L., Yost, J.M., Fricker, G.A., Ventura, J.D., Doremus, J.M., Crow, T., Ritter, M.K., 2022. Diversity and structure in California's urban forest: what over six million data points tell us about one of the world's largest urban forests. Urban For. Urban Green. 74, 127679 https://doi.org/10.1016/j.ufug.2022.127679.

Marris, E., 2013. Rambunctious garden: Saving nature in a post-wild world (Paperback ed). Bloomsbury.

Maryland Department of Environment, Maryland Department of Natural Resources, Maryland Department of Agriculture, Maryland Department of Transportation, & Chesapeake Bay Trust. (2022). Final Plan for Growing 5 Million Trees in Maryland. ⟨https://mde.maryland.gov/programs/air/ClimateChange/Documents/FINAL_Plan-for-Growing-5-Million-Trees-in-Maryland_10.28.22%20%281%29.pdf⟩.

McBride, J.R., Laćan, I., 2018. The impact of climate-change induced temperature increases on the suitability of street tree species in California (USA) cities. Urban For. Urban Green. 34, 348–356. https://doi.org/10.1016/j.ufug.2018.07.020.

McCoy, D.E., Goulet-Scott, B., Meng, W., Atahan, B.F., Kiros, H., Nishino, M., Kartesz, J., 2022. Species clustering, climate effects, and introduced species in 5 million city trees across 63 US cities. ELife 11, e77891. https://doi.org/10.7554/eLife.77891.

Mckinney, M.L., 2002. Urbanization, biodiversity, and conservation. BioScience 52 (10), 883. https://doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2.

McPherson, E.G., Simpson, J.R., 2002. A comparison of municipal forest benefits and costs in Modesto and Santa Monica, California, USA. Urban For. Urban Green. 1 (2), 61–74. https://doi.org/10.1078/1618-8667-00007.

McPherson, E.G., van Doorn, N., Berry, A., Downer, J., Hartin, J., Haver, D., Hodel, D. (2016). *Selecting Trees Fit for the Future*. Climate Ready Trees, U.C. Davis. ⟨https://climatereadytrees.ucdavis.edu/⟩.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403 (6772), 853–858. https://doi.org/10.1038/35002501.

Nitschke, C.R., Nichols, S., Allen, K., Dobbs, C., Livesley, S.J., Baker, P.J., Lynch, Y., 2017. The influence of climate and drought on urban tree growth in southeast Australia and the implications for future growth under climate change. Landsc. Urban Plan. 167, 275–287. https://doi.org/10.1016/j.landurbplan.2017.06.012.

Ordóñez, C., Duinker, P.N., 2013. An analysis of urban forest management plans in Canada: implications for urban forest management. Landsc. Urban Plan. 116, 36–47. https://doi.org/10.1016/j.landurbplan.2013.04.007.

Ordóñez, C., Duinker, P.N., 2014. Assessing the vulnerability of urban forests to climate change. Environ. Rev. 22 (3), 311–321. https://doi.org/10.1139/er-2013-0078.

Ordóñez, C., Duinker, P.N., 2015. Climate change vulnerability assessment of the urban forest in three Canadian cities. Clim. Change 131 (4), 531–543. https://doi.org/10.1007/s10584-015-1394-2.

Oskanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H. (2022). vegan: Community Ecology Package (2.5–7) [Computer software].

Paquette, A., Sousa-Silva, R., Maure, F., Cameron, E., Belluau, M., Messier, C., 2021. Praise for diversity: a functional approach to reduce risks in urban forests. Urban For. Urban Green. 62, 127157 https://doi.org/10.1016/j.ufug.2021.127157.

Pebesma, E., 2018. Simple features for R: standardized support for spatial vector data. R J. 10 (1), 439. https://doi.org/10.32614/RJ-2018-009.

R Core Team. (2022). R: A language and environment for statistical computing [Computer software]. R Foundation for Statistical Computing. ⟨https://www.R-project.org/⟩.

Raupp, M., Cumming, A., Raupp, E., 2006. Street tree diversity in eastern north america and its potential for tree loss to exotic borers. Arboric. Urban For. 32 (6), 297–304. https://doi.org/10.48044/jauf.2006.038.

Restaino, C.M., Peterson, D.L., Littell, J., 2016. Increased water deficit decreases Douglas fir growth throughout western US forests. Proc. Natl. Acad. Sci. USA 113 (34), 9557–9562. https://doi.org/10.1073/pnas.1602384113.

Ritter, M., 2018. California plants: A guide to our iconic flora, First edition. Pacific Street Publishing.

Rundel, P.W., Gustafson, B., Kauffmann, M.E., 2022. California desert plants (First). Backcountry Press.

R Core Team. (2023). Stats-package (4.3.0) [Computer software]. ⟨https://stat.ethz.ch/R-manual/R-devel/library/stats/html/stats-package.html⟩.

San Francisco Planning Department. (2014). *San Francisco Urban Forest Plan*. ⟨https://sfplanning.s3.amazonaws.com/default/files/plans-and-programs/planning-for-the-city/urban-forest-plan/Urban_Forest_Plan_Final-092314WEB.pdf⟩.

Sawyer, J.O., Stuart, J.D., 2001. Trees and Shrubs of California. University of California Press.

Sax, D.F., 2002. Equal diversity in disparate species assemblages: a comparison of native and exotic woodlands in California: Equal diversity in native and exotic woodlands. Glob. Ecol. Biogeogr. 11 (1), 49–57. https://doi.org/10.1046/j.1466-822X.2001.00262.x.

SelecTree (2022). *SelecTree: A Tree Selection Guide* [Web Application]. ⟨https://selectree.calpoly.edu/⟩.

Shapiro, A.M., 2002. The Californian urban butterfly fauna is dependent on alien plants. Divers. Distrib. 8 (1), 31–40. https://doi.org/10.1046/j.1366-9516.2001.00120.x.

Simpson, B.J., 1999. A Field Guide to Texas Trees. Taylor Trade Publishing.

Spotswood, E., Grossinger, R., Hagerty, S., Beller, E., Robinson, A., Letitia, G., Askevold, R. (2017). Re-Oaking Silicon Valley: Building Vibrant Cities with Nature. San Francsico Estuary Institure and the Aquatic Science Center. ⟨https://www.cityofdavis.org/home/showpublisheddocument/5638/635992712147670000⟩.

Suzi Katz Garden Design. (2022). California Native Plants Foster a Strong Sense of Place. ⟨https://www.suzikatzgardendesign.com/california-native-plants⟩.

Tallamy, D.W., Darke, R., 2009a. Bringing nature home: How you can sustain wildlife with native plants (Updated and expanded pbk. ed). Timber Press.

Tallamy, D.W., Shropshire, K.J., 2009b. Ranking lepidopteran use of native versus introduced plants. Conserv. Biol. 23 (4), 941–947. https://doi.org/10.1111/j.1523-1739.2009.01202.x.

Uchida, K., Blakey, R.V., Burger, J.R., Cooper, D.S., Niesner, C.A., Blumstein, D.T., 2021. Urban biodiversity and the importance of scale. Trends Ecol. Evol. 36 (2), 123–131. https://doi.org/10.1016/j.tree.2020.10.011.

Urban Forest Ecosystem Institute. (2022). California Urban Forest Inventory [Computer software]. Cal Poly State University. ⟨https://datastudio.google.com/u/0/reporting/880d448d-de26–48d3-b563–0c6317e456e4/page/jWHKB⟩.

U.S. Census Bureau. (2010). TIGER/Line and TIGER-related products electronic resource: Topologically Integrated Geographic Encoding and Referencing system [Computer software].

Wickham, H., Francois, R., Henry, L., Muller, K. (2022). Dplyr: A Grammar of Data Manipulation. [Computer software]. ⟨https://github.com/tidyverse/dplyr⟩.

Wood, E.M., Esaian, S., 2020. The importance of street trees to urban avifauna. Ecol. Appl. 30 (7) https://doi.org/10.1002/eap.2149.

Wood, S.L.R., Dupras, J., 2021. Increasing functional diversity of the urban canopy for climate resilience: potential tradeoffs with ecosystem services? Urban For. Urban Green. 58, 126972 https://doi.org/10.1016/j.ufug.2020.126972.