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Environmental attitudes predict native plant abundance in residential yards

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HIGHLIGHTS

- Phoenix, Arizona residents hold positive attitudes toward native plants.
- However, few native woody plants were found in Phoenix front yards.
- Knowledge about native plants was low, but did not predict native woody plant abundance.
- Residents who prioritized low water use had fewer native woody plants in their yards.
- Native plant abundance could be increased by marketing toward low water use priorities.

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ABSTRACT

Native plant landscaping can provide unique support for native wildlife in urban settings, but the drivers of native plant inclusion in private residential yards are not well characterized. As with other pro-environmental behaviors, native plant landscaping is likely driven by a combination of resident and landscape attributes. We ask, how do resident attitudes, knowledge, plant choice priorities, demographics, and parcel structure predict existing native plant abundance? To address this question, we compared resident characteristics with front yard woody vegetation in 105 parcels in Phoenix, Arizona. Although many residents had positive attitudes toward native plants, less than a third of woody plants in most yards were native. Native woody plant abundance was higher in xeric rock-covered yards where residents believed native plants belonged in the city, prioritized choosing native plants, and had higher household income. Reported knowledge about native plants was low, but did not predict native woody plant abundance. Although native plants in the arid environment of Phoenix are adapted to low water conditions, residents who prioritized low water use plant selection had fewer native plants, highlighting an opportunity for native plant marketing. These results suggest that educational campaigns to increase resident knowledge of native plant identification and care are unlikely to result in greater native plant abundance in the residential landscape. Marketing native plants to highlight qualities such as low water needs and addressing barriers such as horticultural availability and expense should be further investigated as potential methods of increasing native plant resources in urban environments.

1. Introduction

Residential yards are a dominant feature of cities, with 92% of new U.S. homes including some outdoor space (U.S. Census Bureau, 2019). These urban spaces can support diverse wildlife communities, depending on land management practices (Goddard, Dougill, & Benton, 2010). Landscaping with native species can support biodiversity by providing resources for wildlife that are unmatched by horticultural non-natives (Berthon, Thomas, & Bekessy, 2021; Burghardt, Tallamy, & Shriver, 2009; Narango, Tallamy, & Marra, 2018; Pardee & Philpott, 2014). For example, in Phoenix, Arizona, residential yards with desert-style native landscaping provide higher quality habitat for native Sonoran bird species (Lerman, Warren, Gan, & Shochat, 2012). Native vegetation can also create locally distinct urban landscapes, reducing urban homogenization while supporting connection to the environment and local sense of place (Groffman et al., 2014; Hooper, Endter-Wada, & Johnson,

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2008).

In yards, individual residents make choices about management actions, which are guided by personal motivations as well as the social and physical environment (Cook, Hall, & Larson, 2012). These choices can have important outcomes for urban biodiversity (Belaire, Westphal, & Minor, 2016). Environmental attitudes sometimes predict behavior and thus environmental outcomes, but social, financial, and other constraints often prevent direct correspondence between attitudes and behavior (Heberlein, 2012). Few studies have investigated how resident attitudes relate to native plant outcomes, despite the ecological benefits of native plants. Here, we use a case study in the arid city of Phoenix, Arizona, to ask, how do resident attitudes, priorities, and demographic characteristics together with physical yard characteristics predict native plant abundance in residential front yards?

1.1. Native plants in urban landscapes

The term "native plants" is often used in both gardening and ecology, but its definition can vary in practice (Berthon et al., 2021). Ecologically, native species are defined as organisms that have a long evolutionary history in a particular location, likely with coevolved species and adaptations suitable to local environmental conditions. However, nativity is not a trait that can be measured, so classifications of individual species are typically based on judgements of how long a species has been in a location and how it arrived (Kendle & Rose, 2000). Further, nativity classifications are regularly made following political rather than geographic boundaries, resulting in different statuses across ecologically meaningless divisions.

While ecologists use geopolitical and historical nativity classifications to describe whether a species is appropriate in a given location, non-ecologists may think of species with cultural connections to a city or with large urban populations as belonging there, regardless of ecological nativity (Head & Muir, 2006). Thus, plants seen as belonging, and sometimes colloquially considered native, could include those with a long history in the local urban environment, adaptations that make it well suited to the local environment, or historic representations in the local culture (Head & Muir, 2006). While ecologists and horticultural professionals may attach importance to native species due to their roles in healthy ecosystems, members of the general public may take a more pragmatic, functional, or cultural approach to landscaping without regard to a plant's status as native or not.

Native plants have long been a subject of interest in horticulture and urban landscape design, though they are often perceived as a relatively small niche market (Hooper et al., 2008; Kauth & Pérez, 2011; Potts, Roll, & Wallner, 2002). Horticultural industry professionals have identified several motivations driving native plant sales in urban landscapes, including reduced yard maintenance requirements, limited water use, and habitat provision for wildlife (Brzuszek & Harkess, 2009; Hooper et al., 2008; Potts et al., 2002). Similarly, participants in the U.S. Master Gardener program reportedly selected native plants due to their adaptations to the local environment (Brzuszek, Harkess, & Kelly, 2010). Landscape designers in the southwestern U.S. reported increasing the use of native plants in their work, though very few considered themselves to be expert native plant users (Hooper et al., 2008). Moreover, designers perceive a lack of public support and enthusiasm for native landscaping (Crewe, 2013).

Although native plants are adapted to the local environment, they may be poorly suited to urban heat, pollution, and disturbance, and so may not always be an appropriate choice for landscaping (Kendle & Rose, 2000). Native plants can also be difficult for nurseries and landscapers to source and propagate, and only about a quarter of native vascular plant species in the U.S. are available commercially (Potts et al., 2002; White, Fant, Havens, Skinner, & Kramer, 2018). Thus, finding appropriate native species at local nurseries and big box stores can be a challenge for consumers. Further, horticultural professionals suggest that consumer education is necessary for proper maintenance and to manage expectations for native plants (Brzuszek & Harkess, 2009; Brzuszek, Harkess, & Mulley, 2007; Crewe, 2013; Hooper et al., 2008; Kauth & Pérez, 2011; Potts et al., 2002). While native plants can provide benefits for biodiversity and place attachment, they may present important functional challenges for residents and landscapers.

1.2. Environmental attitudes, knowledge, and native plants

Environmental attitudes can influence pro-environmental behaviors, such as the decision to landscape with native plants (Heberlein, 2012; Kollmuss & Agyeman, 2002; Schultz, 2011). Simply defined, attitudes are positive and negative judgements about some object or phenomenon such as native plants (Heberlein, 2012; Larson, 2010). While attitudes do not always predict behavior, they can reveal motivations and constraints around actions and thus are important to promote public support and desirable behaviors (e.g., planting natives). Changing people's attitudes is rarely an effective way to increase pro-environmental behaviors, but understanding attitudes and working with existing motivations is an effective strategy to promote conservation goals (Heberlein, 2012; Schultz, 2011).

Knowledge has sometimes been linked with environmental behavior, including yard management (Frick, Kaiser, & Wilson, 2004; Martini & Nelson, 2015; van Heezik, Dickinson, & Freeman, 2012). Lack of knowledge about native plants has been specifically implicated as a major barrier to their use in residential landscaping (Brzuszek & Harkess, 2009; Hooper et al., 2008; Kauth & Pérez, 2011; Potts et al., 2002). For example, customer unfamiliarity and confusion over what native wildflowers are have been identified as two major limitations to their adoption (Kauth & Pérez, 2011). A study of Australian residents who converted their yards from typical English-style gardens to native themes identified knowledge of environmental issues as a key driver of the choice to convert yards (Uren, Dzidic, & Bishop, 2015). These results suggest that knowledge of native plants may influence choices to include native vegetation in yard landscaping.

Typically, more specific attitudes and those with greater relevance to a particular attitude object are more predictive of behavior than are more general attitudes (Kim & Hunter, 1993). In residential yards, specific attitudes toward particular plant features can drive management decisions (Kendal, Williams, & Williams, 2012). For example, we would expect specific attitudes toward low water use plants to be more predictive of succulent abundance than general environmental attitudes would be. However, more general attitudes toward the environment may also be relevant (Head & Muir, 2006). Therefore, we consider both more specific attitudes toward native plants and more general attitudes toward the regional desert environment as potential predictors of native plant landscaping.

Previous research in the U.S. has identified consistent key priorities for residential yard management, including low maintenance requirements, neat and orderly appearances, and aesthetic beauty (Cook et al., 2012; Larson, Casagrande, Harlan, & Yabiku, 2009; Nassauer, Wang, & Dayrell, 2009). In accordance with these priorities, choices to purchase and install native plants in landscaping may be linked to plant traits (Kendal et al., 2012). In the arid southwestern U.S., residents reported positive attitudes toward desert plants, including natives, mostly agreeing that they look attractive and provide sufficient variety (Spinti, St. Hilaire, & VanLeeuwen, 2004; St. Hilaire, VanLeeuwen, & Torres, 2010). Additionally, residents reported that they would use native plants if they conserved water and were attractive (Lockett, Montague, McKenney, & Auld, 2002). However, residents have also expressed concerns about the presence of thorns on plants in yards where pets and children may play (Larson et al., 2009). Although informative, these studies have not tested whether prioritizing particular traits align with actual native plant cultivation in residential yards.

A recent survey of U.S. residents found a positive relationship between attitudes toward native plants and intentions to use them in yard landscaping (Gillis & Swim, 2020). In this study, attitudes about the

aesthetic appeal of native plants and their importance to local ecosystems predicted intentions to plant native species and reported yard native plant composition, while attitudes toward maintenance requirements were weakly predictive. However, the accuracy of reported behavior depends on the assumption that respondents are able to correctly classify the nativity of their yard landscaping, and comparison with actual yard plant composition is needed to fully align attitudes with ecological outcomes.

1.3. Beyond attitudes: Resident characteristics and urban structure

Attitudes alone cannot predict behavior, and the gap between attitudes and behavior can sometimes be explained by social characteristics and urban structure (Kollmuss & Agyeman, 2002). For residential yards, studies have shown more abundant and diverse vegetation in higher income neighborhoods (Avolio, Pataki, Trammell, & Endter-Wada, 2018; Cook et al., 2012; Hope et al., 2003). One proposed mechanism for this so-called "luxury effect" is financial resources (Hope et al., 2003), which can impact native plants because they are often more expensive than non-natives (Avolio et al., 2018; Brzuszek et al., 2007). Education level can also predict yard vegetation outcomes, such as tree planting rates and cultivated plant composition (Padullés Cubino et al., 2018; Roman, Battles, & McBride, 2014). The local specificity of native plants suggests that acculturation to a particular region might affect attitudes toward native plants, and thus related behaviors. For example, in Phoenix, Arizona, newer residents tend to prefer naturalistic xeric landscaping while long-term residents prefer grass (Martin, Peterson, & Stabler, 2003; Wheeler, Larson, & Andrade, 2020). By extension, newcomers may also embrace native plants relative to long-term residents.

Urban structure, or parcel and neighborhood characteristics, also affects yard outcomes. Lot and garden size constrain the area available for planting and amount of vegetation present (Bigsby, McHale, & Hess, 2014; Ossola, Locke, Lin, & Minor, 2019). Vegetation management may also be driven by a desire to match home and yard aesthetics, such as an adobe-style house with a desert-like yard and desert species, or a brick colonial house with a manicured English-style garden (Ossola et al., 2019; Peterson et al., 2012; Uren et al., 2015). Native species may be perceived as not fitting in with a manicured yard aesthetic (e.g., turfgrass lawns), or may be seen as the most appropriate choice for a yard with a naturalistic design (e.g., gravel groundcover in desert regions).

1.4. Research aims and hypotheses

In this research, we evaluate how resident attitudes and priorities, demographic characteristics, and parcel structure are associated with the abundance of native plants in residential yards. Using a paired social and vegetation survey of residential yards in Phoenix, Arizona, we tested four hypotheses:

H1) Plant nativity is a recognizable and important trait for residents.

H2) Plant selection priorities will best predict native plant abundance, followed by attitudes toward native plants, more general attitudes toward the desert, and resident knowledge of native plants.

H3) Native plants are selected when residents prioritize low water use, low maintenance needs, and providing habitat for wildlife, but are avoided due to negative aesthetic perceptions, potential hazards (e.g., cactus spines), and lack of availability or expense of purchasing.

H4) Resident characteristics and parcel structure have more influence on native plant abundance than do resident attitudes and priorities.

To address these hypotheses, we explored variation in front yard native plant abundance using resident knowledge of native plants, attitudes toward native plants, attitudes toward the desert, plant selection priorities, resident characteristics, and parcel structure as predictors to determine their relative importance.

2. Methods

2.1. Study location

We conducted our study in the city of Phoenix, Arizona, which is located in the Sonoran Desert of the southwestern United States. Historically, Phoenix has been viewed and advertised as a desert oasis, in which the warm climate is celebrated but the desert is seen as separate from the city and as a challenge to be conquered by urban planning and design (Zube, Simcox, & Law, 1986). To fit this vision, residential landscaping has traditionally been lush and grassy (Zube et al., 1986). However, new developments are more often landscaped with desert-like xeric designs reminiscent of the local context, particularly as developers are required to plan for future water security (Frost, 2016). Xeric yards are typically a mix of rock groundcover with some drought-adapted plants and trees, but no turfgrass (Fig. 1). Landscape architects in Phoenix have increasingly incorporated native plants into their designs and have made advances in identifying suitable species, but they have faced a lack of public support (Crewe, 2013).

2.2. Residential yard sampling

We conducted paired vegetation and social surveys to characterize the plant composition of residential yards and motivations of residents. Our study neighborhoods were chosen from those studied by the Central Arizona-Phoenix Long-Term Ecological Research Project's Phoenix Area Social Survey (Larson et al., 2021), and have been previously described in other work (Larson & Brumand, 2014; Larson, Cook, Strawhacker, & Hall, 2010). The four focal neighborhoods used in this study were defined by 2000 U.S. Census block groups and are arranged roughly along a north-to-south transect in the city of Phoenix. The neighborhoods were chosen to represent a range of socioeconomic characteristics and include two older, primarily grassy (mesic) neighborhoods and two newer, primarily xeric neighborhoods (Table 1; Fig. 1). Approximately 100 parcels were randomly selected in each neighborhood when this study originated in 2008. We carried out paired vegetation and social surveys with a sample of 416 yards from these neighborhoods in the summer of 2018 (Table 1).

2.3. Front yard vegetation

To quantify yard vegetation, we conducted visual surveys from the front sidewalk and identified all woody vegetation in the front yards of 416 focal parcels. We identified plants to the lowest possible taxa using visible morphological traits and knowledge of the local horticulturally available species. We included only woody plants (trees, shrubs, succulents, and woody vines), as herbaceous and grass species could not be reliably identified from sidewalk surveys. In each yard, we recorded the number of individuals and growth form (tree, shrub, succulent, or vine) for each taxon. We then calculated the number of native woody individuals and native woody species richness in each front yard. We also estimated the proportion of the front yard covered by each growth form. On average, about 7% of a yard's ground area was occupied by woody plants (range: 0–42%), 18% was covered by turfgrass lawn (range: 0–86%), and <1% was covered by other herbaceous plantings (range: 0–14%). Thus, our analysis of woody plants considered most of the non-lawn vegetation found in these yards.

We classified all woody plant taxa by nativity in two ways: first, nativity to the Sonoran Desert, which included southern Arizona and parts of northern Mexico; and second, nativity to only the Arizona Sonoran Desert. We expected those species native to the Arizona Sonoran Desert would more closely match what Phoenix residents perceive as native to the local region, while the Sonoran Desert in its entirety more closely matches habitat suitability-based descriptions of nativity that would be more often used in ecological applications. Species with county-level native distributions in the Arizona Sonoran Desert

Fig. 1. Examples of surveyed front yards in the (A) Old Hispanic Core, (B) Historic Palms District, (C) New Xeric Tracts, and (D) Wealthy Mountain Oasis neighborhoods. A and B show examples of mesic, lawn-dominated yard types, while C and D show desert-like xeric landscaping.

Table 1
Neighborhood characteristics and sampling effort.

Neighborhood	Dominant landscape type	Home age (mean years ± std. dev.)[1]	Household median income ($)[2]	Plant surveys conducted	Resident survey responses	Response rate (%)
Old Hispanic Core	Mesic	65 ± 7	35,000	105	6	5.9
Historic Palms District	Mesic	80 ± 7	89,000	95	39	40.6
New Xeric Tracts	Xeric	24 ± 5	63,000	107	29[3]	27.4
Wealthy Mountain Oasis	Xeric	24 ± 2	150,000	109	30	28.6
Unknown[4]					1	
Total				416	105	25.7

[1] From tax assessor-reported year built, average age in 2018 for all parcels with plant surveys.
[2] As reported for most closely overlapping 2017 U.S. Census tract.
[3] Includes one respondent for whom no plant survey was conducted.
[4] Unique identifier removed from completed survey.

region were considered native to the Arizona Sonoran Desert and Sonoran Desert, and species native to Sonoran regions of Mexico but not Arizona were classified as native to the Sonoran Desert only (Fig. 2). Not all individuals could be identified to species (33% of individuals identified to genus only, 3% not identifiable to genus). These individuals were classified as native if all species recorded in the region were native, or if the most common species of the genus recorded in other Phoenix urban flora surveys was native (see Supplementary Material for complete classification methods).

We focus our results primarily on native woody plant abundance, with the assumption that a greater abundance of native plants would provide greater associated services. Previous studies in residential areas have supported the relationship between native plant abundance and native wildlife using native plant biomass (Narango et al., 2018) and native plant cover (Pardee & Philpott, 2014). In our sample of 416 yards, native plant abundance was correlated with native plant species richness (Pearson correlation = 0.84).

2.4. Resident attitudes, knowledge, and characteristics

During the summer of 2018, we mailed surveys to 425 Phoenix households, including the 416 for which we obtained vegetation data. Residents were initially contacted via postcard to alert them to the study, and then were mailed a printed survey with a stamped and addressed return envelope. A reminder postcard was sent thereafter, and 15 $25 Visa gift cards were raffled among respondents as an incentive for participation. All survey materials were available in Spanish by request. Survey methods were reviewed and classified as exempt by the ASU Institutional Review Board.

A total of 105 surveys were returned, yielding a response rate of 25.7% (Table 1). Responses were unevenly distributed by neighborhood, with few respondents in the Old Hispanic Core (6% response rate)

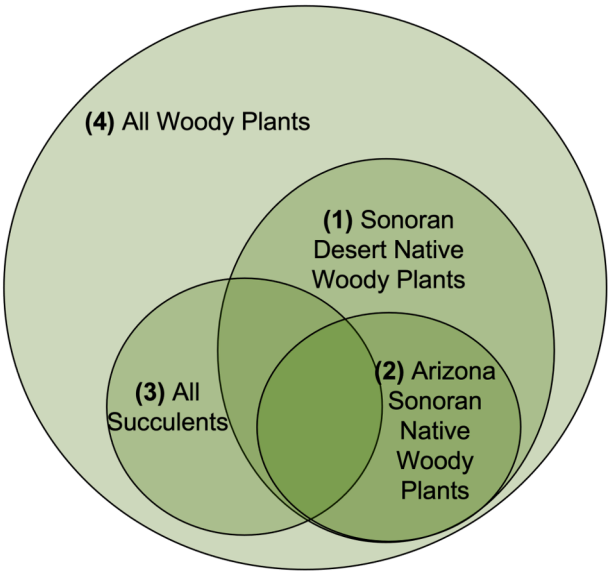

Fig. 2. Nested plant groupings. Numbers of individuals in each group were used as model response variables.

resulting in bias toward higher income, more educated, white homeowners. Previous research in this neighborhood has yielded similarly low engagement (Larson et al., 2017). The average respondent was 56 years of age (range 23–91) and had lived in their current home for 16 years (range 0–58 years). Nearly all respondents were homeowners (94%) and self-identified as white (94%). Most respondents were female (67%) and reported higher education (77% with bachelor's degree or higher) and income (median $120,000-$160,000, 38% over $200,000) than the neighborhood average based on U.S. Census data. Thus, our findings should be generalized with caution, and future research should endeavor to explore the perspectives and landscapes of diverse residents more fully.

To assess resident knowledge of and attitudes toward native plants, we prompted respondents to think of native plants as "trees or other plants that come from or grow naturally in the desert around Phoenix. Do not include plants that come from other regions or parts of the world." Self-reported knowledge of native plants was evaluated with two statements: "I know a lot about gardening with native plants," and "I know how to determine whether a plant is native." Participants responded on a five-point scale from strongly disagree (1) through neither agree nor disagree (3) to strongly agree (5). We averaged these two responses addressing different facets of knowledge about native plants into a single native plant knowledge scale (Pearson correlation = 0.62; Table 2). We also asked residents, "how many of the trees or other plants in your current front yard landscape are native to the Phoenix region?" with the options none, a few, most, or all of my front yard plants are native, and "not sure".

Attitudes toward the desert were measured with a previously-used scale for this region (Andrade, Larson, Hondula, & Franklin, 2019; Wheeler et al., 2020). Respondents were asked how strongly they agreed or disagreed with four statements: "the desert is an empty wasteland," "the desert is a very special place to me," "the desert is beautiful," and "the desert is a nice place to spend time." Responses were averaged with the first (negatively worded) statement reversed to give a unidirectional scale of attitudes toward the desert (Cronbach's alpha = 0.89; Table 2). For specific attitudes toward native plants, we asked how strongly respondents agreed or disagreed with two statements: "native plants do not belong in the city" and "native plants are beautiful." Respondents were again prompted to think of native plants as "trees or other plants that come from or grow naturally in the desert around Phoenix. Do not include plants that come from other regions or parts of the world." These

Table 2
Summary statistics for predictors used to model yard native plant abundance and diversity. The desert attitudinal scale was calculated with negative items reversed such that higher values indicate more positive attitudes. Total respondents = 105.

	Mean ± std. dev.	Median	Range	N
Knowledge[a]				
Native plant knowledge scale (corr = 0.62)	2.9 ± 1.1	3	1–5	104
Know about gardening with	2.7 ± 1.2	3	1–5	105
Know how to determine nativity	3.0 ± 1.2	3	1–5	104
Attitudes[a]				
Native plants do not belong in city	1.5 ± 0.9	1	1–5	105
Native plants are beautiful	4.3 ± 0.9	5	1–5	105
Desert scale (alpha = 0.89)	4.2 ± 0.9	4.5	1.5–5	104
Wasteland[b]	1.3 ± 0.7	1	1–4	104
Very special	3.9 ± 1.3	4	1–5	104
Beautiful	4.3 ± 1.0	5	1–5	104
Nice place to spend time	4.0 ± 1.2	4	1–5	104
Plant Choice Priorities[c]				
Low water use	3.3 ± 0.7	3	2–4	103
Beautiful	3.2 ± 0.6	3	2–4	102
Low maintenance	3.0 ± 0.8	3	1–4	103
Native	2.9 ± 0.9	3	1–4	102
Has spines	2.6 ± 1.0	3	1–4	103
Attracts wildlife	2.6 ± 0.9	3	1–4	103
Easy to get	2.5 ± 0.9	3	1–4	103
Resident Characteristics				
Percent of life in Phoenix	49 ± 29	45	0–100	101
Household income (ordinal)	7.5 ± 3.3	7.5	1–11	84
Education (ordinal)	4 ± 1	4	1–5	102
Parcel Structure				
Front yard area (m^2)	221 ± 155	185	62–1,165	104
Front yard rock cover (%)	27 ± 23	33	0–69	104

[a] Levels: strongly disagree (1), neither agree nor disagree (3), strongly agree (5).
[b] Negatively worded item, reversed in combined scale.
[c] Levels: not at all important (1) to very important (4).

items were not correlated (Pearson correlation = −0.07) and were both retained as independent attitudes toward native plants. Perception of native plants as beautiful was correlated with attitudes toward the desert (Pearson correlation = 0.56), but was unique enough that we included both in analyses.

Similar to previous work addressing value-based motivations for yard vegetation management (Kendal et al., 2012; Larson et al., 2016; Padullés Cubino et al., 2020), we asked residents to rank the importance of several priorities in their choice of new yard vegetation. Response options were on a four-point scale: (1) not at all important, (2) slightly important, (3) important, and (4) very important. We investigated seven priorities: whether the tree or other plant is *easy to get*, whether the tree or other plant is *native*, whether the tree or other plant needs a lot of *water*, whether the tree or other plant will *attract birds or other wildlife*, whether the tree or other plant is *beautiful*, whether the tree or other plant has spines or *thorns*, and whether the tree or other plant is *low maintenance* (does not require much trimming; Table 2).

To address personal characteristics that may affect native plant adoption, we asked respondents about income, education, and how long they had lived in Phoenix. For income, we asked about 2017 household income using response options in $20,000 increments up to $200,000. We also included an "over $200,000″ response and a "prefer not to say" response. Income was treated as an ordinal variable from 1 to 11, with prefer not to say responses omitted. For education, we asked, what is the highest level of school you have had a chance to complete? Responses were (1) less than high school, (2) high school, (3) community college, vocational school, or trade school, (4) bachelor's degree, and (5) graduate or professional school. Finally, we asked in what year the respondent was born and for how many years they had lived in the Phoenix

Valley. Following Larson et al. (2016), we divided the number of years lived in Phoenix by the respondent's age in 2018 to get the percentage of life lived in Phoenix as a measure of local acculturation.

2.5. Parcel structure

We considered two aspects of parcel physical structure: front yard area and rock cover. Front yard area was calculated in ArcGIS in 2008 by matching parcel boundary shapefiles from the Maricopa County tax assessor records with 2005 aerial photos (0.3 m resolution) and 2009 satellite images from Google Maps. Front yards were manually outlined to calculate yard area. Approximate percent rock cover was used as a metric for the "xeric-ness" of the landscape aesthetic, with the idea that more xeric landscaping may have more native plants. During vegetation surveys, we divided each front yard into quadrants and visually estimated the percent cover of rock in each quadrant. These estimates were averaged to get overall yard percent rock cover.

2.6. Models of native plant abundance

We ran generalized linear models to test the effects of resident knowledge, attitudes, characteristics, and parcel structure on front yard native plant abundance and species richness. A total of 80 parcels had data for vegetation and all drivers included in the models, out of 103 parcels with both returned social surveys and completed vegetation surveys. The 23 omitted parcels had returned social surveys with at least one question of interest left unanswered, with 19 of these choosing not to provide income information. All analyses were run in R version 3.6.1 (R Core Team, 2019). Data are available online (Wheeler, Cook, Larson, & Hall, 2022).

We built four abundance models with the same set of predictors and different response variables to test for differences in the drivers of: (1) Sonoran Desert native woody plants, (2) Arizona Sonoran native woody plants, (3) all succulents, and (4) all woody plants (Fig. 2). We also modeled Arizona Sonoran Desert native woody species richness to compare the drivers of abundance with drivers of diversity. We considered abundance of all succulents to represent a group of species with similar adaptations to low-water environments but of varying nativities. The comparison with total woody plant abundance tested whether the drivers of native woody plant abundance could be explained more simply as drivers of overall abundance, where native plants increase as a constant proportion of total plants.

For each response variable, we built a generalized linear model with a Poisson distribution, which was run using R function glm. Pairwise correlations for all predictors were <0.6 and variance inflation factors were <4. To select the best models for each response variable, we conducted stepwise selection using AIC, starting with each global model and using the stepAIC function from package MASS version 7.3–51.4 (Ripley et al., 2019). Finally, we calculated standardized beta values to compare the relative importance of each predictor using the lm.beta function from package lm.beta version 1.5–1 (Behrendt, 2014).

3. Results

3.1. Native plant abundance and diversity

We observed 8,219 woody plants in 416 yards, of which 19% were native to the Arizona Sonoran Desert, 11% were native to the Sonoran Desert but not Arizona, 70% were non-native, and $<$ 1% could not be classified. On average, yards contained two woody plant species and four individuals that were native to the Arizona Sonoran Desert, and three woody plant species and six individuals native to the Sonoran Desert more broadly (Figs. 3, 4). Yards had 20% native individuals and 22% native species on average (out of all woody individuals and species, respectively) for native defined as the Arizona Sonoran Desert (31% native individuals and species for Sonoran Desert).

3.2. Importance and relevance of plant nativity (H1)

Survey respondents held positive attitudes toward native plants overall and rated nativity as an important consideration when selecting new plants (Table 2). Low water use was the top priority for

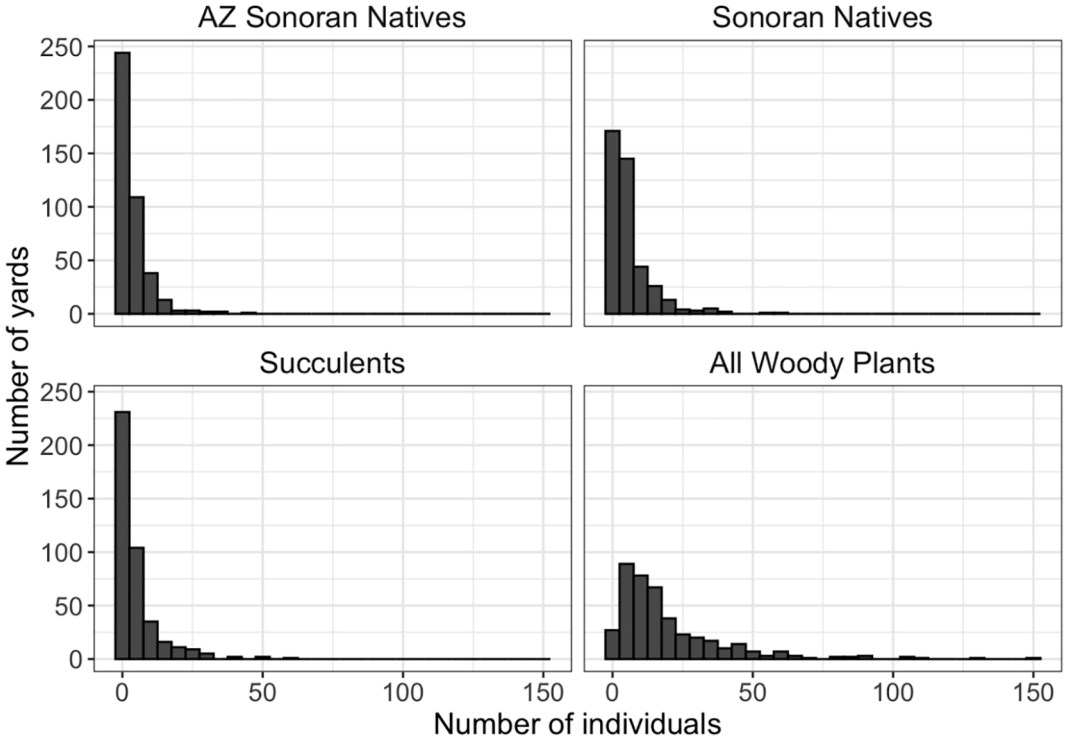

Fig. 3. Plant abundance in 416 surveyed yards.

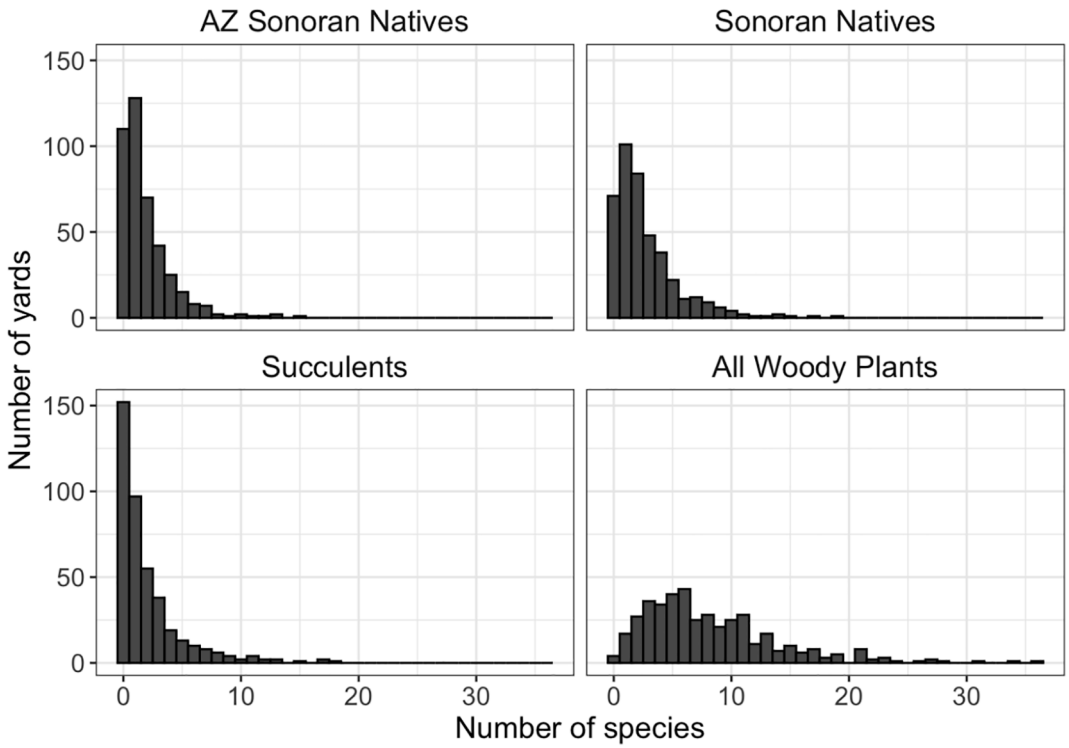

Fig. 4. Species richness in 416 surveyed yards.

respondents, and choosing beautiful and low maintenance plants were also more highly ranked priorities than nativity.

While a majority of respondents agreed that nativity was important, they were mostly neutral in their reported knowledge of native plants, neither agreeing nor disagreeing that they knew how to determine nativity or how to garden with native plants (Table 2). In addition, 25% of respondents reported that they were not sure what proportion of plants in their front yard was native. Where respondents did report how many of their front yard plants were native, their classifications did not closely match our definitions of nativity (Fig. 5). To better understand this lack of connection, we looked at the community composition of yards for which the resident reported having all native plants. In 12 of these 13 yards, our surveys found that less than half of woody plants were native (Fig. 5). We saw a range of plants represented in these 12 yards, including drought-tolerant, non-native shrubs that are commonly

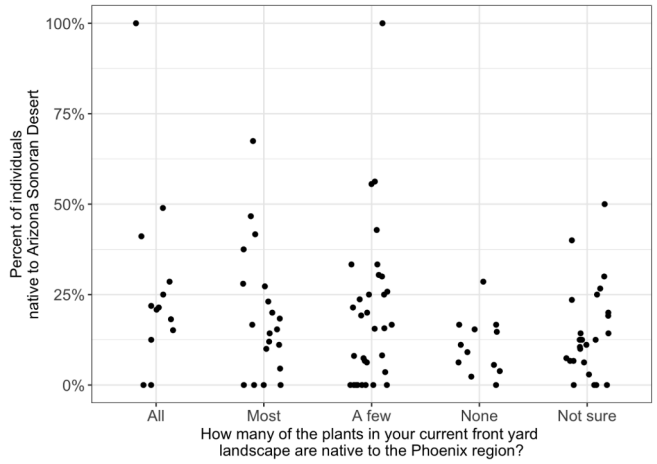

Fig. 5. Respondent classifications of the number of native plants in their front yard (x-axis) compared to vegetation survey results (y-axis). Each point represents one respondent/yard. Points are horizontally offset for clarity.

cultivated in the region (*Lantana* sp. in 7 yards, *Bougainvillea* sp. in 4 yards, *Nerium oleander* in 3 yards), commonly cultivated non-native succulents (*Echinocactus grusonii* in 5 yards, *Aloe* sp. in 3 yards), and species native to the Sonoran Desert broadly but not the Arizona Sonoran Desert (*Hesperaloe parviflora*, 6 yards, *Leucophyllum* sp., 5 yards). Several of these yards also contained an iconic native species, with six containing either *Carnegiea gigantea* (saguaro) or *Fouquieria splendens* (ocotillo).

3.3. Predictors of native plant landscaping (H2-H4)

Plant choice priorities, resident attitudes and characteristics, and parcel structure significantly predicted front yard native woody plant abundance (Table 3). Comparing standardized beta values, the drivers with the greatest influence on native woody plant abundance were beliefs that native plants are beautiful and belong in the city, priorities for choosing native and low water use plants, household income, and yard rock cover. As expected, respondents who prioritized choosing native plants and believed that they belong in the city had more in their yards. However, prioritizing natives did not predict greater native woody plant species richness (Table 4). Contrary to expectations, residents for whom water use was an important consideration had significantly fewer native plants and lower native plant species richness. Additionally, residents who agreed that native plants were beautiful actually had fewer individuals and species in their yards. Prioritizing plants that attract wildlife and choosing plants based on spines and thorns both predicted greater native plant abundance, though with smaller effects than other predictors. Knowledge of native plants did not predict native plant abundance or species richness. Attitudes toward the desert were positively associated with native plant abundance depending on the definition of nativity used (Table 3).

There were few differences in predictors between the two definitions of nativity. Attitudes toward the desert were significantly positively related to Sonoran native abundance, but not Arizona Sonoran native abundance. The model variables explained more variance in Arizona Sonoran native woody plants than in Sonoran native woody plants

Table 3
Predictors of woody plant, succulent, and native woody plant abundance in 80 Phoenix front yards. Predictors that are not included in the model for each response variable are left blank.

	Native to AZ Sonoran		Native to Sonoran		Succulents		All woody plants	
	Std Beta	P value	Std Beta	P value	Std Beta	P value	Std Beta	P value
Knowledge								
Knowledge of native plants	–	–	–	–	–	–	−0.004	0.01
Attitudes								
Native plants don't belong in the city	−0.06	0.0002	−0.02	0.003	−0.01	0.05	–	–
Native plants are beautiful	−0.07	<0.0001	−0.06	<0.0001	−0.08	<0.0001	−0.016	<0.0001
Attitudes toward the desert	–	–	0.03	0.0001	0.02	0.003	–	–
Plant Choice Priorities								
Low water use	−0.06	<0.0001	−0.03	<0.0001	–	–	0.004	0.02
Beautiful	–	–	–	–	0.01	0.01	0.009	<0.0001
Low maintenance	−0.02	0.13	–	–	−0.02	0.002	−0.006	0.0005
Native	0.07	<0.0001	0.03	<0.0001	–	–	–	–
Has spines	0.03	0.008	0.01	0.03	0.02	0.007	0.005	0.002
Attracts wildlife	0.04	0.001	0.02	0.01	0.05	<0.0001	0.010	<0.0001
Easy to get	−0.02	0.08	–	–	−0.01	0.03	−0.003	0.10
Resident Characteristics								
Percent of life in Phoenix	–	–	–	–	–	–	0.008	<0.0001
Household income	0.06	<0.0001	0.05	<0.0001	0.06	<0.0001	0.023	<0.0001
Education	0.02	0.07	–	–	–	–	–	–
Parcel Structure								
Front yard area	–	–	–	–	−0.02	0.003	0.006	<0.0001
Front yard rock cover	0.06	<0.0001	0.05	<0.0001	0.06	<0.0001	0.005	0.01
Model pseudo R squared	0.489		0.413		0.439		0.542	

Table 4
Predictors of Arizona Sonoran Desert native woody plant species richness in 80 Phoenix front yards. Predictors that are not included in the model are left blank.

	Std beta	P value
Knowledge		
Knowledge of native plants	–	–
Attitudes		
Native plants don't belong in the city	−0.11	0.03
Native plants are beautiful	−0.23	0.000004
Attitudes toward the desert	0.08	0.10
Plant Choice Priorities		
Low water use	−0.12	0.01
Beautiful	−0.10	0.04
Low maintenance	–	–
Native	–	–
Has spines	–	–
Attracts wildlife	0.13	0.01
Easy to get	–	–
Resident Characteristics		
Percent of life in Phoenix	–	–
Household income	0.09	0.08
Education	–	–
Parcel Structure		
Front yard area	–	–
Front yard rock cover	0.16	0.002

Notes: Model pseudo $R^2 = 0.368$.

(Table 3), supporting the idea that Arizona Sonoran is the more appropriate definition of nativity.

Drivers differed for succulent abundance and total woody plant abundance. Respondents who prioritized low water requirements had slightly more woody plants overall. Residents who wanted low maintenance plants had fewer plants total, but also had fewer succulents. Similarly, those who prioritized plants that are easy to get had slightly fewer native woody plants, succulents, and total woody plants, although this effect was small and not always statistically significant. Spines and thorns did not appear to be a detractor for either native woody plants or succulents. As expected, residents who wanted to attract wildlife had significantly more native woody plants, succulents, and woody plants.

Prioritizing beautiful plants predicted more succulents and woody plants and did not negatively impact native plants as we might expect if residents believed native plants were not beautiful. The importance of choosing beautiful plants did predict decreased native woody plant species richness (Table 4).

Households with higher income had significantly more native woody plants, succulents, and total woody plants (Table 3). Income was the most important predictor of total woody plant abundance, but was equally weighted with other predictors for native woody plants and succulents. Duration of residence in the Phoenix Valley was positively associated with total woody plant abundance, but not significantly related to succulent or native woody plant abundance.

Front yard rock cover was positively associated with native woody, succulent, and total woody plant abundance and with native woody plant species richness. The effect of rock cover on total woody plant abundance was small relative to other drivers, while its effect on native woody and succulent abundance was greater. Larger yards contained more woody plants but slightly fewer succulents.

4. Discussion

4.1. Nativity is important, but knowledge is low (H1)

Phoenix residents recognized nativity as an important plant characteristic, but most reported a lack of knowledge about native plants and less than a third of woody plants in most front yards were native. Thus, we conclude that while nativity is a relevant concept for these residents, other factors are more important in structuring yard composition. As suspected by horticultural professionals, we found a knowledge gap surrounding the cultivation of native plants in yards (Brzuszek & Harkess, 2009; Kauth & Pérez, 2011; Potts et al., 2002). A quarter of respondents said they did not know whether their front yard plants were native, and of those who did, most assessments did not match our classifications based on ecological sources. Rather, some residents appeared to view drought tolerant or common urban species as native, suggesting a functional or cultural definition of nativity rather than a geographic or ecological definition (Head & Muir, 2006).

Although residents' self-reported understanding of native plants was low overall, this knowledge was not an important driver of native plant abundance in yards. Therefore, it is unlikely that knowledge of native plant landscaping and care was a major factor preventing native plant adoption. While other work has found that providing both technical and social knowledge to residents can provoke changes in gardening

behavior (van Heezik et al., 2012), we suggest that information about native species may not be essential for expanding native plant landscaping in residential spaces. Efforts to increase native planting must go beyond providing information about native plants, potentially by including normative motivations such as comparisons with other yards or by emphasizing valued characteristics of native species for landscaping.

Social norms have been shown to drive environmental behaviors in other contexts and are often acknowledged as important predictors of residential yard management choices (Heberlein, 2012; Nassauer et al., 2009). For example, most residents surveyed in Raleigh, North Carolina were accepting of native plant landscaping, but thought their neighbors were less likely to support native landscaping (Peterson et al., 2012). Thus, social pressures may have prevented them from including as much native vegetation as they would have liked. Alternatively, in settings where native landscaping is widely accepted, social norms can enforce the use of native plants (Uren et al., 2015). Normative impacts may be particularly influential in visible front yards while back yards may be more closely guided by personal preferences, leading to measurable differences in vegetation and overall biodiversity (Gillis & Swim, 2020; Ossola et al., 2019). Future work should explore the extent to which concerns about neighbor acceptance may limit adoption of native plant landscaping. Spreading awareness of high levels of social acceptance could address normative barriers and increase overall native landscaping in receptive communities (van Heezik et al., 2012).

4.2. Priorities and attitudes predict native plant abundance (H2, H3)

Respondents had positive attitudes toward native plants overall, similar to findings in New Mexico and for the U.S. broadly (Gillis & Swim, 2020; Spinti et al., 2004). However, low reported knowledge in combination with low prevalence of native plants suggest that positive attitudes may be weakly held and easily changed (Heberlein, 2012) due to little personal experience with native plants in a landscaping context. Further investigation on this topic could explore the strength of attitudes toward native plants and their relationships to core values, norms, and identities, which can also affect attitude stability, to determine the likelihood of current positive attitudes remaining with increased experience (Heberlein, 2012).

Other work has suggested that people would plant natives if they thought they were attractive enough (Lockett et al., 2002), and that finding native plants attractive is associated with greater intentions to plant them (Gillis & Swim, 2020). However, we saw that beliefs that native plants are beautiful was related to fewer native plants in front yards. Respondents who believed native plants were beautiful also held positive attitudes toward the desert, but did not necessarily believe that native plants belonged in the city. These differences suggest an appreciation of native species in their natural habitat but a sense that they do not belong in residential yards (Head & Muir, 2006). Additionally, prioritizing beautiful plants had no relationship with native plant abundance, but did predict reduced native diversity, suggesting that residents choose a subset of natives that they find most beautiful. Phoenix residential yard landscaping tends to have greater vegetation density than the natural desert (Larsen & Harlan, 2006), and thus desert- and native plant-loving residents may aim to create a more natural-looking yard landscape through lower density planting, resulting in reduced native plant abundance. Another possible explanation for this surprising relationship could be that residents with more experience with native plants in their yards think they are less beautiful due to the responses of native species to urban stresses and improper care. For example, some desert shrub species become very large and sparse under high water conditions (e.g., over-irrigation), which can lead to undesirable growth forms. Regardless of the mechanism, this result shows that efforts to improve people's attitudes toward native plants are unlikely to result in greater residential native plant cultivation.

Previous research has shown that drought tolerance is important to residents and that native plants in arid environments are chosen to reduce irrigation needs (Kendal et al., 2012; Martin et al., 2003; Potts et al., 2002; Uren et al., 2015). Our study supports the finding that residents place importance on water needs when selecting plants. However, we found that people who identified water use as more important had fewer native plants in their front yards. One explanation for this seemingly contradictory result is the low prevalence of native plants in the Arizona horticultural flora. For example, a prominent guide to low water use landscape plants for Arizona includes only 15% native species ("Landscape plants for the Arizona desert", 2006). Native plants sold at nurseries are often unlabeled and rarely marked as drought-tolerant (Brzuszek & Harkess, 2009). Given the lack of knowledge about which plants are native, residents may not be able to select native plants for drought-tolerant landscaping without marketing guidance.

The relationship between residents' reported plant selection priorities and vegetation outcomes reflects the gap between attitudes and behavior (Kollmuss & Agyeman, 2002). Other research has found that concern about conservation and intentions to use less water for landscaping often don't correspond with actual landscaping decisions, but instead follow social norms and personal preferences (Larson & Brumand, 2014). In this case, residents may feel that choosing low water use vegetation is important, but be unlikely to make changes to existing high water use vegetation or to select drought tolerant plants that conflict with other priorities. Our survey questions focused on plant purchasing decisions, but the observed yard vegetation is the result of accumulated plant addition, removal, and maintenance over time. Legacies of previous vegetation decisions made by developers and former residents also affect residential vegetation and therefore likely result in some disconnect between current resident priorities and yard composition (Grove et al., 2017; Larsen & Harlan, 2006).

A main benefit of native plant landscaping is resource and habitat provision for native wildlife (Burghardt et al., 2009; Narango et al., 2018). While attracting wildlife was not a top priority for our respondents, we found that those who chose plants to support wildlife had more native plants, as well as more woody plants overall. Similarly, a study of residential yards in Minnesota found greater native species richness in yards where residents prioritized supporting wildlife (Cavender-Bares et al., 2020). However, Cavender-Bares et al. found no relationship between reported importance of cultivating species native to the state and native plant diversity, while we found that residents who said they prioritized natives did have more native individuals, though not more species. This difference could reflect differing non-attitudinal barriers to native plant cultivation across regions, such as horticultural availability of native species, or could show that native-focused gardeners simply plant more of the same few species. Future research should explore drivers of native plant landscaping across climatic and social contexts to evaluate regional commonalities and differences.

Prioritizing low maintenance and easy-to-get plants had minimal correlations with native plant abundance. Previous research has suggested that gardeners choose native plants due in part to their low maintenance needs (Brzuszek et al., 2010; Gillis & Swim, 2020), but our respondents simply had fewer plants if they prioritized low maintenance needs. Similarly, prioritizing easy-to-get plants was also related to overall lower yard plant abundance. Residents who prioritize spending little time and effort on their yards may be unlikely to pursue management practices such as native plant landscaping, unless they are easy.

4.3. Resident characteristics and parcel structure (H4)

Resident characteristics and parcel structure were related to native plant abundance, but not more strongly than attitudes and plant choice priorities. As expected from the luxury effect, higher income predicted increased abundance of native, succulent, and all woody plants. However, belief that native plants are beautiful and belong in the city, prioritization of natives, and prioritization of low water use plants had larger effects, at least for nativity as defined by the Arizona Sonoran

Desert. Yard rock cover was also positively associated with native plant abundance, with a similar magnitude effect as income. Thus, increased xeric landscaping across the region may come with increased native plant abundance as native plants are seen as a better fit with this landscaping type. Overall woody vegetation increased with rock cover as well, suggesting that this effect may be due to an increase in woody planting (including natives) when turfgrass lawns are omitted.

4.4. Future directions for urban native plant landscaping

Our comparison of reported and observed plant nativity shows a lack of clarity among our respondents about what it means for a plant to be native. However, many respondents said that nativity is important to them when they choose a new plant. Other work has suggested that the designation of "native" is more of a value statement than a categorization related to particular functional benefits (Kendle & Rose, 2000). However, consumers asked whether they thought plant designation as "native" was primarily a marketing gimmick mostly disagreed, and agreed instead that native plants provided biodiversity and air pollution benefits (Yue, Hurley, & Anderson, 2012). We identify that marketing of native plants in arid environments as low water users could be one opportunity for emphasizing function-based benefits of native plants.

Enduring challenges to increasing native plant abundance in the urban environment include the selection of species to match urban needs and constraints (e.g., tolerant of urban air quality, low branch failure rates), ability of the horticultural industry to successfully propagate and distribute native species, and perceptions in the industry that such an effort will be worthwhile (Crewe, 2013). Considerations of these challenges and guidance from the horticultural industry will be important in any successful campaign to increase native plant landscaping through changes in marketing or other structural fixes, as the current positive resident attitudes toward these species may be weak and subject to change with negative experiences.

An important caveat to this study is the bias in survey respondents for whom we are able to draw conclusions about native plant attitudes and cultivation. Our survey respondents included few who were non-white, renters, or lower income; thus, we cannot claim to explain how attitudes, priorities, and structural considerations affect yard landscaping among these groups. Previous work shows differences in native plant preference by ethnicity (Peterson et al., 2012) and differences in yard management priorities for homeowners and renters (Larson et al., 2009). In Phoenix, Latino and lower-income residents have more negative attitudes toward the desert, which may also impact attitudes toward native plants (Andrade et al., 2019). Further, renters, low-income residents, and ethnic minorities may be more likely to reside in historically disadvantaged neighborhoods with less vegetation and reduced access to boutique horticultural sources that sell more native plants (Avolio et al., 2018; Grove et al., 2017). Much work in residential landscapes has focused primarily on higher income white homeowners, and thus, we suggest that it is particularly important for future work to systematically include historically understudied groups in order to develop a more inclusive and representative understanding of residential landscapes.

5. Conclusions

Native plants can provide important resources for urban native wildlife, but currently make up less than a third of front yard residential woody vegetation. We observed that both attitudinal and structural factors (but not knowledge) predicted native plant landscaping in an arid residential context. While one step toward integrating native plants into the urban landscape is increased education about their identification, value, and care, our results suggest that this approach is unlikely to change native plant adoption. Rather, structural barriers, such as native plant availability and cost, and opportunities, such as the current lack of labeling and marketing of drought-tolerant natives, should be addressed first. Positive attitudes should be monitored to ensure that increased experience with native plants does not change weakly held opinions, but attitudes are currently supportive of native plants in the urban landscape. However, further research is needed on how attitudes and native plant cultivation vary among residents of different socioeconomic status and ethnicity before applying generalized interventions. Where native plants are identified as uniquely valuable for wildlife, strategies can work with existing attitudes to support greater inclusion of native plants in the residential landscape.

CRediT authorship contribution statement

Megan M. Wheeler: Conceptualization, Investigation, Formal analysis, Writing – original draft. **Kelli L. Larson:** Conceptualization, Writing – review & editing. **Dena Bergman:** Conceptualization, Investigation, Data curation. **Sharon J. Hall:** Conceptualization, Writing – review & editing, Supervision.

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. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104443.

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