Horticultural availability and homeowner preferences drive plant diversity and composition in urban yards

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Abstract

Understanding the factors that influence biodiversity in urban areas is important for informing management efforts aimed at enhancing the ecosystem services in urban settings and curbing the spread of invasive introduced species. We determined the ecological and socioeconomic factors that influence patterns of plant richness, phylogenetic diversity and composition in 133 private household yards in the Minneapolis-Saint Paul Metropolitan area, Minnesota, USA. We compared the composition of spontaneously occurring plant species and those planted by homeowners with composition in natural areas (at the Cedar Creek Ecosystem Science Reserve) and in the horticulture pool of species available from commercial growers. Yard area and fertilizer frequency influenced species richness of the spontaneous species but expressed homeowner values did not. In contrast, the criteria that homeowners articulated as important in their management decisions—including aesthetics, wildlife, neatness and food provision—significantly predicted cultivated species richness. Strikingly, the composition of plant species that people cultivated in their yards resembled the taxonomic and phylogenetic composition of species available commercially. In contrast, the taxonomic and phylogenetic composition of spontaneous species showed high similarity to natural areas. The large fraction of introduced species that homeowners planted was a likely consequence of what was available for them to purchase. The study links the composition and diversity of yard flora to their natural and anthropogenic sources and sheds light on the human factors and values that influence the plant diversity in residential areas of a major urban system. Enhanced understanding of the influences of the sources of plants—both native and introduced—that enter urban systems and the human factors and values that influence their diversity is critical to identifying the levers to manage urban biodiversity and ecosystem services.

Keywords: Horticulture, urban domestic yards, introduced species, urban biodiversity, attitudes, preferences

Introduction

Within cities, homeowners shape urban landscapes, but the consequences for biodiversity and ecosystem functions are poorly understood. The urban footprint extends far beyond city boundaries: urbanization and suburban development alter the pool of species that occur in regional and continental floras and faunas (Antrop 2004, Kowarik 2011) and may reduce representation of native species diversity at both of these scales (e.g., Hansen et al. 2005, Grimm et al. 2008). As the world's human population becomes concentrated in cities, and the natural environment becomes increasingly fragmented, understanding the consequences of urbanization for biodiversity is more and more important (Cavender-Bares et al. 2018).

In many countries private residential yards are a major component of urban green space, comprising up to one-third of the total urban area and often containing a majority of the vegetation present (Kendal et al. 2012b). Urban yards thus have the potential to provide considerable habitat for many organisms (Goddard et al. 2010, Bolund and Hunhammar 1999, Fissore et al. 2011, 2012). Through dispersal, species that are promoted in urban yards and escape cultivation also have the potential to influence the regional and ultimately continental flora (Reichard et al. 2001; Dehnen-Schmutz et al. 2007).

The composition and biodiversity of urban yards are ultimately determined by a suite of biophysical, cultural and socioeconomic factors that drive the assembly of urban plant communities (Fig. 1) (Aronson et al. 2016, Groffman et al. 2017, Pearse et al. 2018, Padullés Cubino et al. 2019). These include the composition and diversity of source pools as well as the socio-ecological drivers that influence yard choices, including the attitudes, motivations, and practices of yard owners (Clayton 2007, Cameron et al. 2012, van Heezik et al. 2013, Padullés Cubino et al. 2015, Avolio et al. 2018) as well as their ecosystem conceptualizations and diverse nature discourses (Kurz and Baudains 2012, Dahmus and Nelson 2014a, 2014b). Convergence of such drivers across regions may lead to the ecological homogenization of urban yards compared to natural areas (Groffman et al. 2014, Pearse et al. 2018), although we understand comparatively little about how these drivers affect phylogenetic diversity at local scales (but see Pearse et al. 2018, Padullés Cubino et al. 2019). The goals of this study were to decipher the socio-ecological drivers of plant richness and phylogenetic diversity in

household yards in the Minneapolis-Saint Paul (U.S.) metropolitan area, and to identify the plant species pools, including commercially available and naturally occurring plant populations, as well as their introduced and native components, from which yard flora are assembled.

Drivers of diversity are different for spontaneous and cultivated species

Urbanization has resulted in entire landscapes that are now occupied by plant communities wholly or partially created and managed by humans, in which diversity may reflect social, economic, and cultural influences in addition to those recognized by traditional ecological theory (Hope et al. 2003, Swan et al. 2011, Aronson et al. 2016). Humans cultivate gardens, plant trees, manage lawns and maintain green spaces for a variety of social, economic and logistical reasons. They are likely to intentionally cultivate specific species or suites of species according to their values and management priorities but their options will be heavily influenced and limited by the availability of propagules. At the same time, many urban plant species grow spontaneously, without human cultivation, via dispersal from nearby managed or unmanaged areas. Birds are critical dispersal agents of many spontaneously occurring plants, enabling species from horticultural sources to escape cultivation (Reichard et al. 2001). Many spontaneous species are cosmopolitan plants or "weeds," which have attributes that make them well suited to carrying out their life-cycle in the urban environment (Lososová et al. 2006, 2011, Knapp et al. 2012).

The composition, diversity and distribution of plants in urban environments are heavily influenced by human activities, but the human activities and ecological processes that promote spontaneously occurring species are likely to be different from those that promote cultivated species. While spontaneous species are subject to environmental filtering and species interactions (Ricotta et al. 2012), management often protects cultivated species from stress and competitive exclusion. Homeowner's conceptualizations of ecosystems can influence the role and function they assign to distinct species as well as how aggressively they create barriers to prevent spread or spend time to facilitate growth (Dahmus and Nelson 2014a). In addition, given distinct human discourses of nature, the same species can be seen as pest or pleasure by different urban residents (Dahmus and Nelson 2014b). Even indirectly, yard management practices, including watering, lawn care and pesticide use,

may influence ecological processes (Harris et al. 2012) with consequences for both the cultivated species diversity as well as the spontaneously occurring yard species.

Gardening behavior is known to be heavily influenced by household-level factors such as gender, age, cultural background and personal attitudes towards gardening effort (Kendal et al. 2010). In Phoenix (USA), neighborhood vegetation richness increased across a gradient of low to high socioeconomic status, interpreted as a "luxury" effect (Hope et al. 2003, Martin et al. 2004). Likewise, in Potchefstroom (South Africa), socioeconomic and cultural factors influenced plant diversity patterns, showing higher species richness in more affluent suburbs. However, much of the plant diversity of affluent suburbs was made up of introduced species, whereas utilitarian (and often native) plants were associated with lower socio-economic status suburbs (Lubbe et al. 2010). In contrast, Padullés Cubino et al. (2019) found that biophysical factors, rather than socioeconomic factors, drove species richness in yards across 6 cities in the US. This same pattern has also been reported at local scales, including in Ballarat, Australia (Kendal et al. 2012b). Also, the size of the vegetated area was most critical in driving plant diversity in Dunedin, New Zealand, although socioeconomic status and ability of homeowners to discriminate between native and introduced species were important factors associated with introduced species plant diversity; older people with smaller properties of lower value harbored more introduced plant species in their yards (van Heezik et al. 2013). The differences in drivers of plant diversity among locations may be related to the ratio of cultivated to spontaneously occurring species as well as an array of socioeconomic and biophysical factors.

Introduced species in urban areas

Cities often show higher species richness than their surroundings because the number of introductions of introduced species outweighs the number of local or regional extinctions (Hobbs and Mooney 1998, Rosenzweig 2001, Sax and Gaines 2003, Marco et al. 2008, Bigirimana et al. 2012), and more populated cities often have greater proportions of introduced species (Gaston et al. 2005). High biodiversity in cities, however, is not solely due to introductions of exotics. For example, cities in Germany tend to be found in areas that are naturally high in biodiversity due to natural features that

provide life-supporting energy and resources for many organisms including humans (Kühn et al. 2004); likewise in sub-Saharan Africa, high human population density coincides with high species richness of birds, mammals, snakes and amphibians (Balmford et al. 2001).

Cities are epicenters for intentional and unintentional introduction of exotic species. In the urban domestic yard flora of five United Kingdom cities, 70% were introduced (Loram et al. 2008). On the one hand, exotic plant species are sought for attributes that make them appealing to humans and easy to cultivate; they are provided as stock or seed through the nursery trade and commercial vendors to landscapers and home owners who cultivate them locally (Avolio et al. 2018). On the other hand, exotic introduced species occur spontaneously in the urban flora after escaping cultivation or other means of introduction, and successfully reproducing, dispersing and persisting in the urban environment (Knapp et al. 2012). Such spontaneous introduced species are often good dispersers. On islands in Boston Harbor, for example, introduced species were better at overcoming dispersal barriers and thus populating distant islands than native species (Long et al. 2009). Cultivated introduced plant species that occur in Switzerland were found to germinate faster and more abundantly than closely related native species (Chrobock et al. 2011). Introduced species in the urban flora may thus be biased towards success in the highly disturbed and fragmented urban environment.

Taxonomic versus phylogenetic diversity

Species richness—or taxonomic diversity—and phylogenetic diversity are alternative measures of biodiversity that encompass different aspects of variation in plants. Species richness provides information on how many species are present, while phylogenetic diversity, calculated in a manner that is independent of species richness, provides information about the degree to which species in a community are related to one another evolutionarily. Phylogenetic diversity indicates the breadth of the tree of life that is encompassed in a yard or region and has been argued to be important to consider in management decisions aimed at conservation of biodiversity (Winter et al. 2013, Faith 2018). Knapp et al. (2008) found that in Germany, urban areas had higher species richness, but lower phylogenetic diversity, than non-urban areas, because urban plant communities included closely related species that are functionally similar and able to deal with urbanization. Ricotta et al. (2009)

found that urban environments filtered out functional and phylogenetic diversity of the plant flora, including a reduction in the phylogenetic diversity of introduced species in urban floras in the US and Europe. Similarly, a general pattern of reduced phylogenetic diversity relative to expectation was found for a suite of different urban habitats in 32 cities across Europe (Ceplová et al. 2015). In the Minneapolis-Saint Paul metropolitan area (Twin Cities), Minnesota, phylogenetic diversity of spontaneously occurring species in urban areas was lower than in surrounding natural areas (Knapp et al. 2012). Thus, evolutionary information was lost in the urban spontaneous flora relative to more pristine environments with likely consequences for ecosystem resilience and ecosystem services.

Here we examined the drivers of plant species richness and phylogenetic diversity in 133 household yards in a single metropolitan region, where we had survey information on homeowner preferences and management practices. We hypothesized that the composition of species that homeowners cultivated would strongly reflect the horticultural options available for planting, which could be approximated by the local commercially available horticultural source pool. Moreover, we expected that cultivated species would contain a larger proportion of introduced species than spontaneously occurring species, reflecting a bias in the horticultural species pool towards exotic species. We further hypothesized that the diversity (species richness or phylogenetic diversity) of cultivated plants would be driven by homeowner attitudes about vegetation choices, with greater diversity following preferences for wildlife and beauty and lower diversity following preferences for orderliness and easy maintenance. In contrast, we expected that the composition of spontaneously occurring species, those that occur without human cultivation, would strongly overlap those species and lineages occurring in the regional species pool, including those found in outlying natural areas, as well as species that had escaped cultivation. We expected diversity to be driven largely by parcel area and factors limiting dispersal and survival rather than by homeowner attitudes.

To test these hypotheses we compared the composition of native and introduced floras that occurred (1) in natural areas near the metropolitan area (i.e., flora from Cedar Creek Science Reserve), (2) spontaneously in urban yards, (3) cultivated in urban yards, and (5) in nursery stocks. We then examined the drivers of species richness and phylogenetic diversity of yard plant assemblages focusing on 1) structural attributes, such as housing density and yard size, 2) socioeconomic factors, including education level, income, and property value, 3) management

activities, including fertilizing and watering practices, and 4) homeowner attitudes that drive management priorities. We specifically compared drivers of species richness and plant phylogenetic diversity in household yards for the plant species cultivated by homeowners and those that occurred spontaneously (i.e., those not planted by homeowners) as well as the factors that drove native and exotic species diversity in yards. Our goal was to gain insight into the factors that influence composition and diversity in urban residential landscapes, which represent a major component of the urban species pool, taking an in-depth view of a single metropolitan region as an important case study.

Methods

Study site

The occurrence of cultivated and spontaneously growing vascular plant species was recorded in 133 private household yards in the Minneapolis-Saint Paul Metropolitan area, Minnesota, USA, in the summer of 2008. Through the Twin Cities Household Ecosystem Project (TCHEP), surveys were sent to 15,000 randomly selected single-family households (Fissore et al. 2011) in Ramsey and Anoka counties, spanning an urban to exurban gradient. Of the 3,100 households that responded to the survey, 1,517 gave us permission to visit the property to conduct the vegetation survey. These households were previously demonstrated to be only slightly higher with respect to socioeconomic factors (e.g. income, age, education) than the general single-family homeowner population in the study area. We subsampled the 1,517 household yards of homeowners who granted permission in a stratified random design as follows: households were binned into four housing density categories and random subsamples were drawn in equal proportions from each category, giving a total of 157 yards. Of these, 24 were excluded due to incomplete data, for a total final sample size of 133 yards.

Vegetation surveys

In each household yard, we recorded presence/absence of all species growing in lawns, perennial gardens, woodlots, gardens, and annual beds. Species were assigned a Latin binomial based on published flora (Lorenzi and Jeffrey 1987, Steiner 2005, Kershner et al. 2008, McCarty et al. 2008) and standardized using the R package *Taxonstand* (Cayuela et al. 2017) to The Plant List (theplantlist.org) version 1.1. Photographs were taken in cases where on-site identification was difficult. In some cases, physical specimens were collected for subsequent identification. Individual species were recorded as intentionally cultivated or spontaneously occurring in each yard. Species were recorded as cultivated if there was evidence that they were directly planted, or it appeared likely that they were, and recorded as spontaneous if they were not likely to have been planted or sown in lawns. Yard location, prevalence and identity were used in the categorization process. Most spontaneous species were weeds that grew in places such as lawns, along edges of driveways, and sporadically in garden beds (Knapp et al. 2012) or were growing in woodlots or unmanaged areas and appeared to have established on their own. The same species was recorded as both cultivated and spontaneous in a particular yard if it was clearly planted in one location and occurred spontaneously in another location in the same yard. For example, planted trees often produce propagules that result in the emergence of saplings of the same species and in other parts of the yard.

Species were classified as native or introduced based on the USDA Plants database (plants.usda.gov) and The Encyclopedia of Life (EOL; eol.org). If only the genus was recorded, and the genus was present in the native flora, it was classified as native. These classifications may have created a slight bias towards overestimating the proportion of native species.

The species list for the Cedar Creek Ecosystem Science Reserve (CCESR) was used to represent the flora of an adjacent natural area, and hence the natural areas species pool, similar to a previous analysis of the spontaneous plant diversity in the Twin Cities (Knapp et al. 2012). CCESR is located approximately 70 km north of the Twin Cities and includes a diversity of upland and wetland habitats with both southern boreal and temperate forest and prairie species: tallgrass prairie, oak savanna, mixed deciduous forest, successional old fields, and various wetlands. The horticultural species pool was determined from the species list in the 2008 catalog of a local commercial plant vendor, Bachmann's, which had the most exhaustive and taxonomically best documented list of the

commercial horticulture plant vendors in the area and provided a good representation of nursery plants species available to homeowners in the Twin Cities.

Socioeconomic, yard management, attitudinal and structural data

Socioeconomic data (household income, highest education level), information regarding landscape management (fertilizer and irrigation practices) and household criteria used in making yard management decisions were gathered using a 40-question mail survey (Fissore et al. 2011, 2012)(Table 1). Specifically, one survey question was posed to gain insight into the homeowner's criteria for vegetation choices, such as beauty, orderliness, wildlife, or native species. There was also the possibility to write in additional criteria. Throughout the text, we use the more general term "preferences" to refer to these criteria. In addition, we included several survey questions related to yard management, specifically the frequency of fertilizing and watering as well as whether a lawn service company was hired (Table 1). We also obtained property market value for each household for the year 2011 from the Metropolitan Council MetroGIS Regional Parcel Dataset (gisdata.mn.gov/dataset/us-mn-state-metrogis-plan-regonal-parcels-2011).

We used high-resolution aerial photographs to calculate parcel size of each yard, excluding the house and driveway (Fissore et al. 2011). We calculated housing density as the number of houses per hectare in the Census block (2000 U.S. Census data; census.gov/main/www/cen2000.html) where each house was located.

Phylogenetic analysis

We used an updated version of the Zanne et al. (2013) phylogeny produced by Qian and Jin (2016) for all phylogenetic metrics. Species missing from this phylogeny were added at the genus level using the 'congeneric.merge' function in the R package *pez* (Pearse et al. 2015). Species for which there were no phylogenetic data (~0.7%) were excluded from the analysis.

Mean Phylogenetic Distance (MPD) (Webb 2000) was calculated for each household yard. MPD provides a measure of phylogenetic diversity represented in a given yard and is calculated as the

total phylogenetic distance between all pairs of species normalized by the distance between species in randomized null communities of the same species richness. MPD was calculated using the R package *Picante* (Kembel et al. 2010). Other metrics of phylogenetic diversity and species relatedness that are independent of species richness were also calculated, including phylogenetic species variance (PSV) (Helmus et al. 2007) and average phylogenetic distinctiveness (adapted from Clarke and Warwick 1994), but results were nearly identical and are not shown. In addition, Mean Nearest Taxon Distance (MNTD) was calculated but it was significantly negatively associated with species richness in the data set, such that all yards with higher species richness had lower MNTD and vice versa, and could not be interpreted separately from species richness.

Similarity of species pools

To compare the phylogenetic similarity of the species lists from the spontaneous, cultivated, horticultural and CCESR species pools described above, we computed the phylogenetic Sørensen's and PhyloSor's indices (Bryant et al. 2008) in packages *vegan* (Oksanen et al. 2017) and *picante* (Kembel et al. 2010), respectively. We also calculated Sørensen's index to examine the extent to which the species and phylogenetic composition of the pools differed. To see whether each species list represented a phylogenetically random subset of the study species, the phylogenetic dispersion of each list was calculated using D (Fritz and Purvis 2010). We use D, and not SES_{MPD} (which is more directly linked to MPD in our analysis above; Kembel 2009), because comparing SES_{MPD} across varying source pools is statistically problematic (Pearse et al. 2013). All phylogenetic analyses were additionally repeated using only native and introduced species.

Statistical analysis

We used a multiple regression analysis to assess the effects of structural attributes (yard area, housing density), socioeconomic variables (education level, household income, property value), criteria for landscape vegetation management, and yard management practices (fertilization, lawn care and

irrigation) on species richness and phylogenetic diversity for both cultivated and spontaneous plant species in household yards.

Models were developed for each dependent variable (metrics of plant diversity per yard) by performing a bidirectional stepwise regression using the 'step' function in R (Venables and Ripley 2002). This forward-selection method is appropriate for variable selection in cases such as this, where we have too many explanatory variables for alternative methods (e.g., Burnham and Anderson 1998). Models were chosen based upon Akaike's Information Criterion (AIC), which aims to find a compromise between model fit, usually gauged by residual mean or sum of squares and model 'complexity', which is a function of the number of model terms (MacNally 2002). In each case, we chose the model provided by bidirectional stepwise regression that was within 2 AIC points of the most conservative model, thus maintaining complexity and not overlooking potentially important trends with predictor variables, while at the same time maintaining a statistically conservative method of model selection. The 'plot(model)' function in R was used to test model residuals for normality of distribution, influential observations, and multicollinearity.

Species richness and MPD per yard for the total, native and introduced flora, together with the proportion of native species, were used as response variables in the models. Parcel size, excluding the area of impervious surfaces, was always included as a predictor to account for the area dependence of species richness. All statistical procedures were performed in R version 3.4.1 (R Core Team 2017).

Results

Species pool compositions

The cultivated and horticultural species pools were the most similar, showing both higher phylogenetic similarity in species composition (Table 2a) as well as the greatest proportion of shared species (Table 2b). The cultivated and the CCESR species pools were the next most similar in terms of phylogenetic similarity (Table 2a), but not in terms of shared species (Table 2b). This phylogenetic similarity appears to be driven by native species (Tables 2c). The reasonably high similarity between

the spontaneous and CCESR floras, in contrast, is driven more by the shared introduced species than by shared native species (Table 2c-d).

The top four families with the highest numbers of shared species between the cultivated and horticultural pools included Rosaceae, Pinaceae, Asteraceae and Cupressaceae. Between the cultivated and CCESR pools, these included Asteraceae, Pinaceae, Poaceae and Rosaceae (Fig. 2). For the shared species between the spontaneous and the CCESR pools, the top families included Asteraceae, Poaceae, Rosaceae and Fabaceae (Fig. 2).

The D values indicate that species pools were phylogenetically non-random subsets of the total species pool (Appendix S1: Fig. S1). In particular, although native species from the different pools of species had similar dispersion values, native species from CCESR were the most phylogenetically clustered group of species. In the case of introduced species, the spontaneous pool was the most phylogenetically clustered, possibly indicating that species came from a phylogenetically clustered subset (Appendix S1: Fig. S1). This also concurs with the idea that introduced cultivated and horticultural species come from different parts of the tree of life.

Diversity of pools

Within household yards in the Minneapolis-Saint Paul Metropolitan area, we found a total of 756 different species encompassing a total of 110 families, and 63.8% of these were introduced (36.2% were native) (Fig. 2; Appendix S1: Table S1). Out of the 548 cultivated species found in yards, 66.4% were introduced. Within the spontaneous pool, 54.3% species of the 230 total species were introduced. The horticultural pool had the largest proportion of introduced species (76.7% out of 387), and the CCESR pool the lowest (16.6% out of 512). The highest MPD was found for the horticultural pool (371.69), followed by the CCESR (337.35), and then by the cultivated (321.69) pool, which had somewhat higher MPD than the spontaneous pool (295.78). The combined MPD of both yard pools (309.53) was still lower than CCESR.

Yard plant diversity and structural factors

Among the study households, the richness of spontaneously occurring species was highly dependent on yard area, while cultivated species richness was only weakly influenced by yard area (Figure 3), regardless of whether we considered the total flora, native species or introduced species (Table 3a). Phylogenetic diversity of native spontaneous species also increased with yard area (Table 3a), as did the proportion of cultivated species that were native (Table 3b).

Higher housing density was not associated with species richness, phylogenetic diversity or the proportion of native species for either the spontaneous or cultivated flora (Table 3a-b).

Yard plant diversity and management criteria

Homeowners who added fertilizer cultivated a higher number of total species as well as more native species (Table 3b). However, higher frequency of fertilizer application was associated with lower total, introduced and native spontaneous plant species richness (Table 3a), even though yard species richness within the individual categories of fertilizer frequency did not differ significantly (Figure 3). Greater fertilizer frequency was also associated with lower phylogenetic diversity for total and native cultivated species. Homeowners who hired lawn services had a lower richness of total and native cultivated species. Interestingly, the proportion of spontaneous native species relative to the total spontaneous pool was positively affected by lawn care services. Watering frequency did not significantly affect plant diversity.

Yard plant diversity and socioeconomic factors

Property market value was positively associated with total and native plant richness of the cultivated flora, but not with any of the spontaneous species groups (total, native nor introduced) (Table 3b). Property value also positively predicted phylogenetic diversity for the total spontaneous pool and the native species within it (Table 3a). In contrast, household income was negatively associated with native species richness in the cultivated flora and the proportion of native species within the cultivated flora (Table 3b) but did not predict total cultivated richness. Phylogenetic diversity of introduced

spontaneous species also decreased with increasing household income. Education did not significantly affect yard plant diversity.

Yard plant diversity and homeowner attitudes/choices

Homeowner vegetation management criteria were strongly associated with cultivated species diversity (Table 3b), but were not significantly associated with any measure of spontaneous species diversity (Table 3a). People who stated that they managed the vegetation in their yards to enhance beauty, wildlife, or for food production, cultivated more species (total, native and introduced) (Figure 4), while homeowners who managed their yards for orderliness cultivated significantly fewer species in all groups (Table 3b).

People who preferred ease of maintenance cultivated plants from a phylogenetically restricted pool of total and native species, while orderliness and native species priorities were associated with increased total phylogenetic diversity of the cultivated flora (Table 3b). Moreover, the orderliness criterion was associated with increased proportion of cultivated native species. Preference for privacy did not affect cultivated diversity at all.

Discussion

Urbanites cultivated a high number of species, the composition of which strongly resembled the pool of horticultural species that were commercially available to homeowners. A large fraction of these horticultural species were introduced. As a consequence, a large fraction of the species people planted in their yards were introduced, a finding that has been reported frequently in other urban areas (e.g., Loram et al. 2008, Bigirimana et al. 2012, Padullés Cubino et al. 2015). Spontaneously occurring species partially resembled the natural areas pool (here defined as the CCESR flora) but also included other species, supporting the idea that they were assembled from the regional flora that included both the native flora and the group of cosmopolitan introduced species that have found their way into the urban spontaneous pool. However, phylogenetic diversity of both cultivated and spontaneously occurring species was lower in urban yards than in natural areas, probably resulting from a complex

interplay of factors including environmental sorting processes associated with species functional traits (Knapp et al. 2012).

Cultivated and spontaneous species richness in household yards were associated with different household-specific factors. Yard size was the primary factor driving spontaneous species richness, with greater richness associated with larger yards (see also Knapp et al. 2012). Total cultivated species richness did not correlate with parcel area, a pattern that has been observed in urban yards in other cities (Loram et al. 2008, Marco et al. 2008, van Heezik et al. 2013). This likely indicates that cultivated species are uncoupled from environmental filters that limit dispersal, competitive ability and persistence. This finding highlights the importance of distinguishing between cultivated and spontaneous species to allow for more nuanced and mechanistic understanding of the drivers of biodiversity in urban yard flora. Moreover, despite results from previous studies showing that urban land use decreases phylogenetic diversity (Knapp et al. 2012, Ceplová et al. 2015), housing density, which could be considered as a proxy for degree of urbanization, did not influence any measure of diversity of either cultivated or spontaneous species pools.

Our results reveal that different yard management practices influence cultivated and spontaneous species richness in the Minneapolis-St. Paul metropolitan area. For example, greater frequency of fertilizer use reduced the richness of total, native and introduced spontaneous species. High fertilization frequency may promote grass species that out-compete spontaneously occurring species. Moreover, although the use of herbicides was not assessed in our study, fertilizers and herbicides are sometimes used simultaneously, which may further explain why fertilizer frequency was negatively associated with total and native cultivated phylogenetic diversity.

Socioeconomic factors influenced the diversity of both the cultivated and spontaneous pools. In particular, properties with higher market value had higher total and native cultivated species richness, supporting the "luxury effect" pattern (Hope et al. 2003). However, this pattern did not hold for the phylogenetic diversity of the cultivated pool, even though it did for the spontaneous pool. Thus, while households with higher market value accumulated more cultivated species than those of lower market value, these species came from a more limited set of lineages. In contrast with market value patterns, households with higher income had lower cultivated native species richness. This contradictory pattern between household income and property market value (which were correlated,

but not strongly so, in this study [r = 0.57, $P < 0.001$]) stresses the importance of using measures that capture the variability of the whole socioeconomic gradient. Furthermore, properties with higher market value also had higher phylogenetic diversity of total and native spontaneous species, perhaps as a consequence of phylogenetically diverse remnant native vegetation in woodlots. There was no association between yard size and market value in our study (r = 0.09, $P = 0.43$), so this result was not simply a consequence of an area effect on spontaneous plant diversity. In terms of education, although other studies have reported positive associations between this variable and yard species diversity (Luck et al. 2009, van Heezik et al. 2013, Padullés Cubino et al. 2017), we did not find a relationship in our study.

Interestingly, the criteria homeowners expressed as important in managing their yards were predictive of species richness and phylogenetic diversity of the cultivated but not the spontaneous pool. This finding again highlights the relevance of discriminating between these two pools of species. Although cultivated species diversity was more influenced by management criteria associated with cultural ecosystem services (i.e., beauty, orderliness, ease of maintenance or food production), those associated with habitat and supporting services (i.e., wildlife, native species priority) also influenced cultivated diversity. For example, attitudes expressed towards wildlife were positively associated with total cultivated species richness, including both native and introduced cultivated richness. Although preferences for wildlife consistently predicted cultivated species richness, this does not necessarily mean that homeowners share similar values concerning wildlife, native biodiversity or supporting ecosystem services. A study from Goddard et al. (2013) in Leeds (UK) revealed that motivations for wildlife-friendly gardening are largely centered on personal well-being and moral responsibility to nature, rather than any consideration of the role of biodiversity in supporting ecosystem services.

Household yards represent an important component of the urban species pool. Homeowners thus have an important role in creating the composition of species that colonize regions and ultimately contribute to continental floras. However, homeowners who indicated that they want to manage their yards for native species did not cultivate more native species nor support more spontaneous native species. This finding discords with other studies that have shown that conservation attitudes are related to the presence of native plants in homeowners' yards (Head and Muir 2006, Kendal et al.

2012a). An information and education gap thus seems apparent. How this kind of education might be undertaken to assist residents in achieving their landscaping goals remains unclear. Coupling landscape designs that offer aesthetic benefits with those that promote native biodiversity and wildlife for personal enjoyment and social desirability may provide an avenue for shaping the urban flora in a manner that contributes to multiple ecosystem service benefits and ultimately to greater maintenance of native species in the regional flora. Limited availability of native plants through horticultural sources surely also contributes to this result. In our analysis, only 23.3% of the horticultural species were native. Limited options and information are both factors that could be addressed to increase the proportion of native species that are cultivated in urban yards.

Homeowners who managed yards for beauty planted a higher number of cultivated species, confirming the importance of aesthetic values for yard diversity (Kendal et al. 2012a, Goodness et al. 2016). Yards with greater variety of plant species likely encompass a wider range of plant sizes, morphologies, growth forms and colors. Vegetation scenes that display different heights, variation in structure and higher complexity have been shown to be preferred in a number of studies (Ulrich 1986). Likewise, homeowners who expressed interest in planting species for food also had greater total and native species richness, a pattern reported in other areas of the globe (Padullés Cubino et al. 2015, Davoren et al. 2016). This finding suggests strong linkages between the time people spend in gardening, the benefits they obtain from it and environmentally sensitive behaviors.

In contrast, surveyed homeowners who preferred more neat and orderly yards cultivated fewer total, native and introduced cultivated species. These neat and orderly plantings are usually associated with weed-free, monocultures and lush-green lawn landscaping that to many Americans are symbols of home ownership, private property and social status (Jenkins 1994) and deemed important for relaxation and exercise (Larson et al. 2009). In contrast with species richness, total cultivated phylogenetic diversity increased with preferences for neat and orderly landscapes. We argue that neat and orderly yards, despite having lower species richness, host more evolutionarily distinct species that are associated with intense yard planning and management, which selects for specific groups of distantly related species. This interpretation is supported by the finding that preference for ease of maintenance was negatively associated with total and native cultivated phylogenetic diversity. Previous studies have shown that factors related to environmental suitability of plant species for a

location (e.g., drought or shade tolerance), which permit low-maintenance, are among the most important reasons for choosing plants (Kendal et al. 2012a, Goodness 2018). Homeowners who preferred easier to maintain yards may have cultivated plants suited to local environmental stressors and climatic factors, resulting in more phylogenetically related species.

Overall, our findings support the idea that household cultivated vegetation is influenced by the household's socioeconomic factors, attitudes about management choices, and the horticultural stock available in the market.

Conclusions

Patterns of plant diversity and composition within the Minneapolis-St. Paul metropolitan area provide support for the hypothesis that the horticultural industry has a large influence on the plants people cultivate in their yards. The assertion is based on the high similarity of cultivated species to what is available commercially. In contrast, the composition of the spontaneous species more closely resembled that of natural areas. However, a large proportion of the spontaneous pool included species not present in any of the other pools, including many introduced cosmopolitan species. The significant influence of homeowner criteria and choices on plant richness and phylogenetic diversity of the cultivated flora – but not on the spontaneous pool – demonstrates the large influence of human values and decisions on the components of urban biodiversity under our direct control. Decisions about what people plant, in turn, have long-term consequences for the biodiversity maintained in urban systems and in regional species pools. These findings highlight the significant potential for human efforts to direct future management of biodiversity, ecosystem functions and ecosystem services in urban areas that can contribute to larger-scale regions. While this study examines a single urban area, comparisons with other areas and across spatial scales may contribute to a broader comparative understanding of social-ecological drivers of urban biodiversity and its consequences.

Acknowledgments

Literature Cited

Antrop, M. 2004. Landscape change and the urbanization process in Europe. Landscape and Urban Planning 67:9–26.

Aronson, M. F., C. H. Nilon, C. A. Lepczyk, T. S. Parker, P. S. Warren, S. S. Cilliers, M. A. Goddard, A. K. Hahs, C. Herzog, and M. Katti. 2016. Hierarchical filters determine community assembly of urban species pools. Ecology 97:2952–2963.

Avolio, M. L., D. E. Pataki, T. L. E. Trammell, and J. Endter-Wada. 2018. Biodiverse cities: the nursery industry, homeowners, and neighborhood differences drive urban tree composition. Ecological Monographs 88:259–276.

Balmford, A., J. L. Moore, T. Brooks, N. Burgess, L. A. Hansen, P. Williams, and C. Rahbek. 2001. Conservation Conflicts Across Africa. Science 291:2616–2619.

Bigirimana, J., J. Bogaert, C. De Cannière, M.-J. Bigendako, and I. Parmentier. 2012. Domestic garden plant diversity in Bujumbura, Burundi: Role of the socio-economical status of the neighborhood and alien species invasion risk. Landscape and Urban Planning 107:118–126.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. Ecological Economics 29:293–301.

Bryant, J. A., C. Lamanna, H. Morlon, A. J. Kerkhoff, B. J. Enquist, and J. L. Green. 2008. Microbes on mountainsides: Contrasting elevational patterns of bacterial and plant diversity. Proceedings of the National Academy of Sciences 105:11505–11511.

Burnham, K. P., and D. R. Anderson. 1998. Practical use of the Information-Theoretic approach. Pages 75–117 Model selection and inference. Springer, New York, NY.

Cameron, R. W. F., T. Blanuša, J. E. Taylor, A. Salisbury, A. J. Halstead, B. Henricot, and K. Thompson. 2012. The domestic garden – Its contribution to urban green infrastructure. Urban Forestry & Urban Greening 11:129–137.

Cavender-Bares, J., M. T. K. Arroyo, R. Abell, D. Ackerly, D. Ackerman, M. Arim, J. Belnap, F. C. Moya, L. Dee, N. Estrada-Carmona, J. Gobin, F. Isbell, G. Köhler, M. Koops, N. Kraft, N. Macfarlane, A. Mora, G. Piñeiro, C. Martínez-Garza, J.-P. Metzger, M. Oatham, A. Paglia, P. L. Peri, R. Randall, and J. Weis. 2018. Status and trends of biodiversity and ecosystem

functions underpinning nature's benefit to people. Regional and subregional assessments of biodiversity and ecosystem services: regional and subregional assessment for the Americas. IPBES secretaria, Bonn, Germany.

Cayuela, L., A. Stein, and J. Oksanen. 2017. Taxonstand: Taxonomic Standardization of Plant Species Names. R package version 2.0.

Ceplová, N., Z. Lososová, D. Zelený, M. Chytrý, J. Danihelka, K. Fajmon, D. Láníková, Z. Preislerová, Z. Řehořek, and L. Tichý. 2015. Phylogenetic diversity of Central European urban plant communities: effects of alien species and habitat types. Preslia 87:1–16.

Chrobock, T., A. Kempel, M. Fischer, and M. van Kleunen. 2011. Introduction bias: Cultivated alien plant species germinate faster and more abundantly than native species in Switzerland. Basic and Applied Ecology 12:244–250.

Clarke, K., and R. Warwick. 1994. Change in marine communities: an approach to statistical analysis and interpretation. National Environment Research Council, UK.

Clayton, S. 2007. Domesticated nature: Motivations for gardening and perceptions of environmental impact. Journal of Environmental Psychology 27:215–224.

Dahmus, M. E., and K. C. Nelson. 2014a. Yard stories: examining residents' conceptions of their yards as part of the urban ecosystem in Minnesota. Urban Ecosystems 17:173–194.

Dahmus, M. E., and K. C. Nelson. 2014b. Nature discourses in the residential yard in Minnesota. Landscape and Urban Planning 125:183–187.

Davoren, E., S. Siebert, S. Cilliers, and M. J. du Toit. 2016. Influence of socioeconomic status on design of Batswana home gardens and associated plant diversity patterns in northern South Africa. Landscape and Ecological Engineering 12:129–139.

Dehnen-Schmutz, K., J. Touza, C. Perrings, and M. Williamson. 2007. The Horticultural Trade and Ornamental Plant Invasions in Britain. Conservation Biology 21:224–231.

Faith, D. P. 2018. Phylogenetic Diversity and Conservation Evaluation: Perspectives on Multiple Values, Indices, and Scales of Application. Pages 1–26 Phylogenetic Diversity: Applications and Challenges in Biodiversity Science. Springer International Publishing, Cham.

Fissore, C., L. A. Baker, S. E. Hobbie, J. Y. King, J. P. McFadden, K. C. Nelson, and I. Jakobsdottir. 2011. Carbon, nitrogen, and phosphorus fluxes in household ecosystems in the Minneapolis-Saint Paul, Minnesota, urban region. Ecological Applications 21:619–639.

Fissore, C., S. E. Hobbie, J. Y. King, J. P. McFadden, K. C. Nelson, and L. A. Baker. 2012. The residential landscape: fluxes of elements and the role of household decisions. Urban Ecosystems 15:1–18.

Fritz, S. A., and A. Purvis. 2010. Selectivity in Mammalian Extinction Risk and Threat Types: a New Measure of Phylogenetic Signal Strength in Binary Traits: Selectivity in Extinction Risk. Conservation Biology 24:1042–1051.

Gaston, K. J., R. M. Smith, K. Thompson, and P. H. Warren. 2005. Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. Biodiversity and conservation 14:395–413.

Goddard, M. A., A. J. Dougill, and T. G. Benton. 2010. Scaling up from gardens: biodiversity conservation in urban environments. Trends in Ecology & Evolution 25:90–98.

Goddard, M. A., A. J. Dougill, and T. G. Benton. 2013. Why garden for wildlife? Social and ecological drivers, motivations and barriers for biodiversity management in residential landscapes. Ecological Economics 86:258–273.

Goodness, J. 2018. Urban landscaping choices and people's selection of plant traits in Cape Town, South Africa. Environmental Science & Policy 85:182–192.

Goodness, J., E. Andersson, P. M. L. Anderson, and T. Elmqvist. 2016. Exploring the links between functional traits and cultural ecosystem services to enhance urban ecosystem management. Ecological Indicators 70:597–605.

Grimm, N. B., S. H. Faeth, N. E. Golubiewski, C. L. Redman, J. Wu, X. Bai, and J. M. Briggs. 2008. Global Change and the Ecology of Cities. Science 319:756–760.

Groffman, P. M., M. Avolio, J. Cavender-Bares, N. D. Bettez, J. M. Grove, S. J. Hall, S. E. Hobbie, K. L. Larson, S. B. Lerman, D. H. Locke, J. B. Heffernan, J. L. Morse, C. Neill, K. C. Nelson, J. O'Neil-Dunne, D. E. Pataki, C. Polsky, R. R. Chowdhury, and T. L. E. Trammell. 2017. Ecological homogenization of residential macrosystems. Nature Ecology & Evolution 1:0191.

Groffman, P. M., J. Cavender-Bares, N. D. Bettez, J. M. Grove, S. J. Hall, J. B. Heffernan, S. E. Hobbie, K. L. Larson, J. L. Morse, C. Neill, K. Nelson, J. O'Neil-Dunne, L. Ogden, D. E. Pataki, C. Polsky, R. R. Chowdhury, and M. K. Steele. 2014. Ecological homogenization of urban USA. Frontiers in Ecology and the Environment 12:74–81.

Hansen, A. J., R. L. Knight, J. M. Marzluff, S. Powell, K. Brown, P. H. Gude, and K. Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications 15:1893–1905.

Harris, E. M., C. Polsky, K. L. Larson, R. Garvoille, D. G. Martin, J. Brumand, and L. Ogden. 2012. Heterogeneity in Residential Yard Care: Evidence from Boston, Miami, and Phoenix. Human Ecology 40:735–749.

Head, L., and P. Muir. 2006. Suburban life and the boundaries of nature: resilience and rupture in Australian backyard gardens. Transactions of the Institute of British Geographers 31:505–524.

van Heezik, Y., C. Freeman, S. Porter, and K. J. M. Dickinson. 2013. Garden Size, Householder Knowledge, and Socio-Economic Status Influence Plant and Bird Diversity at the Scale of Individual Gardens. Ecosystems 16:1442–1454.

Helmus, M. R., T. J. Bland, C. K. Williams, and A. R. Ives. 2007. Phylogenetic Measures of Biodiversity. The American Naturalist 169:E68–E83.

Hobbs, R. J., and H. A. Mooney. 1998. Broadening the Extinction Debate: Population Deletions and Additions in California and Western Australia. Conservation Biology 12:13.

Hope, D., C. Gries, W. Zhu, W. F. Fagan, C. L. Redman, N. B. Grimm, A. L. Nelson, C. Martin, and A. Kinzig. 2003. Socioeconomics drive urban plant diversity. Proceedings of the national academy of sciences 100:8788–8792.

Jenkins, V. S. 1994. The lawn: A history of an American obsession. Smithsonian Institution Press, Washington D.C.

Kembel, S. W. 2009. Disentangling niche and neutral influences on community assembly: assessing the performance of community phylogenetic structure tests. Ecology Letters 12:949–960.

Kembel, S. W., D. D. Ackerly, S. P. Blomberg, W. K. Cornwell, P. D. Cowan, M. R. Helmus, H. Morlon, and C. O. Webb. 2010. Picante: R tools for integrating phylogenies and ecology. Bioinformatics:1463–1464.

Kendal, D., K. J. H. Williams, and N. S. G. Williams. 2012a. Plant traits link people's plant preferences to the composition of their gardens. Landscape and Urban Planning 105:34–42.

Kendal, D., N. S. G. Williams, and K. J. H. Williams. 2010. Harnessing diversity in gardens through individual decision makers. Trends in Ecology & Evolution 25:201–202.

Kendal, D., N. S. G. Williams, and K. J. H. Williams. 2012b. Drivers of diversity and tree cover in gardens, parks and streetscapes in an Australian city. Urban Forestry & Urban Greening 11:257–265.

Kershner, B., D. Mathews, G. Nelson, R. Spellenberg, and C. Tufts. 2008. National Wildlife Federation field guide to trees of North America. Sterling, New York, USA.

Knapp, S., L. Dinsmore, C. Fissore, S. E. Hobbie, I. Jakobsdottir, J. Kattge, J. Y. King, S. Klotz, J. P. McFadden, and J. Cavender-Bares. 2012. Phylogenetic and functional characteristics of household yard floras and their changes along an urbanization gradient. Ecology 93:S83–S98.

Knapp, S., I. Kühn, O. Schweiger, and S. Klotz. 2008. Challenging urban species diversity: contrasting phylogenetic patterns across plant functional groups in Germany. Ecology Letters 11:1054–1064.

Kowarik, I. 2011. Novel urban ecosystems, biodiversity, and conservation. Environmental Pollution 159:1974–1983.

Kühn, I., R. Brandl, and S. Klotz. 2004. The flora of German cities is naturally species rich. Evolutionary Ecology Research 6:749–764.

Kurz, T., and C. Baudains. 2012. Biodiversity in the Front Yard: An Investigation of Landscape Preference in a Domestic Urban Context. Environment and Behavior 44:166–196.

Larson, K. L., D. Casagrande, S. L. Harlan, and S. T. Yabiku. 2009. Residents' Yard Choices and Rationales in a Desert City: Social Priorities, Ecological Impacts, and Decision Tradeoffs. Environmental Management 44:921–937.

Long, J. D., G. C. Trussell, and T. Elliman. 2009. Linking invasions and biogeography: Isolation differentially affects exotic and native plant diversity. Ecology 90:863–868.

Loram, A., K. Thompson, P. H. Warren, and K. J. Gaston. 2008. Urban domestic gardens (XII): the richness and composition of the flora in five UK cities. Journal of Vegetation Science 19:321–330.

Lorenzi, H. J., and L. S. Jeffrey. 1987. Weeds of the United States and their control. Van Nostrand Reinhold. New York, USA.

Lososová, Z., M. Chytrý, I. Kühn, O. Hájek, V. Horáková, P. Pyšek, and L. Tichý. 2006. Patterns of plant traits in annual vegetation of man-made habitats in central Europe. Perspectives in Plant Ecology, Evolution, and Systematics 8:69–81.

Lososová, Z., M. Horsák, M. Chytrý, T. Čejka, J. Danihelka, K. Fajmon, O. Hájek, L. Juřičková, K. Kintrová, D. Láníková, Z. Otýpková, V. Řehořek, and L. Tichý. 2011. Diversity of Central European urban biota: effects of human-made habitat types on plants and land snails: Biodiversity of Central European cities. Journal of Biogeography 38:1152–1163.

Lubbe, C. S., S. J. Siebert, and S. S. Cilliers. 2010. Political legacy of South Africa affects the plant diversity patterns of urban domestic gardens along a socio-economic gradient. Scientific Research and Essays 5:2900–2910.

Luck, G. W., L. T. Smallbone, and R. O'Brien. 2009. Socio-Economics and Vegetation Change in Urban Ecosystems: Patterns in Space and Time. Ecosystems 12:604–620.

MacNally, R. 2002. Multiple regression and inference in ecology and conservation biology: further comments on identifying important predictor variables. Biodiversity and Conservation 11:1397–1401.

Marco, A., T. Dutoit, M. Deschamps-Cottin, J.-F. Mauffrey, M. Vennetier, and V. Bertaudière-Montes. 2008. Gardens in urbanizing rural areas reveal an unexpected floral diversity related to housing density. Comptes Rendus Biologies 331:452–465.

Martin, C. A., P. S. Warren, and A. P. Kinzig. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. Landscape and Urban Planning 69:355–368.

McCarty, L. B., J. W. Everest, D. W. Hall, T. R. Murphy, and F. Yelverton. 2008. Color atlas of turfgrass weeds: a guide to weed identification and control strategies. 2nd edition. John Wiley and Sons, Hoboken, New Jersey, USA.

Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, H. Wagner, and others. 2017. vegan: Community Ecology Package. R package version 2.4-4.

Padullés Cubino, J., J. Cavender-Bares, S. E. Hobbie, D. E. Pataki, M. L. Avolio, L. E. Darling, K. L. Larson, S. J. Hall, P. M. Groffman, T. L. E. Trammell, M. K. Steele, J. M. Grove, and C. Neill. 2019. Drivers of plant species richness and phylogenetic composition in urban yards at the continental scale. Landscape Ecology 34:63–77.

Padullés Cubino, J., J. B. Kirkpatrick, and J. Vila Subirós. 2017. Do water requirements of Mediterranean gardens relate to socio-economic and demographic factors? Urban Water Journal 14:401–408.

Padullés Cubino, J., J. Vila Subirós, and C. Barriocanal Lozano. 2015. Propagule pressure from invasive plant species in gardens in low-density suburban areas of the Costa Brava (Spain). Urban Forestry & Urban Greening 14:941–951.

Pearse, W. D., M. W. Cadotte, J. Cavender-Bares, A. R. Ives, C. M. Tucker, S. C. Walker, and M. R. Helmus. 2015. pez : phylogenetics for the environmental sciences. Bioinformatics 31:2888–2890.

Pearse, W. D., J. Cavender-Bares, S. E. Hobbie, M. L. Avolio, N. Bettez, R. Roy Chowdhury, L. E. Darling, P. M. Groffman, J. M. Grove, S. J. Hall, J. B. Heffernan, J. Learned, C. Neill, K. C. Nelson, D. E. Pataki, B. L. Ruddell, M. K. Steele, and T. L. E. Trammell. 2018. Homogenization of plant diversity, composition, and structure in North American urban yards. Ecosphere 9:e02105.

Pearse, W. D., F. A. Jones, and A. Purvis. 2013. Barro Colorado Island's phylogenetic assemblage structure across fine spatial scales and among clades of different ages. Ecology 94:2861–2872.

Qian, H., and Y. Jin. 2016. An updated megaphylogeny of plants, a tool for generating plant phylogenies and an analysis of phylogenetic community structure. Journal of Plant Ecology 9:233–239.

R Core Team. 2017. R: A language and environment for statistical computing. Foundation for Statistical Computing, Vi.

Reichard, S. H., L. Chaler-Scott, and S. Buchanan. 2001. Interactions among non-native plants and birds.*in* J. M. Marzluff, R. Bowman, and R. Donnelly, editors. Avian Ecology and Conservation in an Urbanizing World. Kluwer Academic Publishers, Bostonn.

Ricotta, C., F. A. La Sorte, P. Pyšek, G. L. Rapson, L. Celesti-Grapow, and K. Thompson. 2009. Phyloecology of urban alien floras. Journal of Ecology 97:1243–1251.

Ricotta, C., F. A. La Sorte, P. Pyšek, G. L. Rapson, L. Celesti-Grapow, and K. Thompson. 2012. Phylogenetic beta diversity of native and alien species in European urban floras: Phylogenetic beta diversity of urban aliens. Global Ecology and Biogeography 21:751–759.

Rosenzweig, M. L. 2001. The four questions: What does the introduction of exotic species do to diversity? Evolutionary Ecology Research 3:361–367.

Sax, D. F., and S. D. Gaines. 2003. Species diversity: from global decreases to local increases. Trends in Ecology & Evolution 18:561–566.

Steiner, L. M. 2005. Landscape with native plants of Minnesota. Voyageur Press, Saint Paul, MN, USA.

Swan, C. M., S. T. A. Pickett, K. Szlavecz, P. Warren, and K. T. Willey. 2011. Biodiversity and Community Composition in Urban Ecosystems: Coupled Human, Spatial, and Metacommunity Processes. Pages 179–186 *in* J. H. Breuste, T. Elmqvist, G. Guntenspergen, P. James, and N. E. McIntyre, editors. Urban Ecology. Oxford University Press.

Ulrich, R. S. 1986. Human responses to vegetation and landscapes. Landscape and Urban Planning 13:29–44.

Venables, W. N., and B. S. Ripley. 2002. Modern Applied Statistics. 4th edition. Springer, New York.

Webb, C. O. 2000. Exploring the Phylogenetic Structure of Ecological Communities: An Example for Rain Forest Trees. The American Naturalist 156:145–155.

Winter, M., V. Devictor, and O. Schweiger. 2013. Phylogenetic diversity and nature conservation: where are we? Trends in Ecology & Evolution 28:199–204.

Zanne, A. E., D. C. Tank, W. K. Cornwell, J. M. Eastman, S. A. Smith, R. G. FitzJohn, D. J. McGlinn, B. C. O'Meara, A. T. Moles, P. B. Reich, D. L. Royer, D. E. Soltis, P. F. Stevens, M. Westoby, I. J. Wright, L. Aarssen, R. I. Bertin, A. Calaminus, R. Govaerts, F. Hemmings, M. R. Leishman, J. Oleksyn, P. S. Soltis, N. G. Swenson, L. Warman, and J. M. Beaulieu. 2013. Three keys to the radiation of angiosperms into freezing environments. Nature 506:89–92.

Data Availability

Data are available from DRUM, the Data Repository of the University of Minnesota, at:
http://hdl.handle.net/11299/210002

Table 1. Summary of predictor variables used in the analysis, including the units they were measured in, categories or transformations used, and the mean ±SD of each variable.

Predictors	Units	Categories/Transformations	Mean ± SD
Structural factors			
Yard area	m^2	log(x)	-1.07 ± 0.36
Housing density	Number of houses per hectare	-	6.23 ± 4.27
Yard and lawn management			
Fertilizer addition	Dimensionless	0=No; 1=Yes	0.86 ± 0.35
Fertilizer frequency	Dimensionless	1=Never; 2=1 or 2 times/year; 3=3 or 4 times/year; 4= 5 or more times/year	2.20 ± 0.74
Lawn care service	Dimensionless	0=No; 1=Yes	0.24 ± 0.43
Watering frequency	Dimensionless	1=Rarely/never; 2=Occasionally (when grass is dry); 3=Regularly (once or more per week)	1.71 ± 0.70
Socioeconomic factors			
Education (max. in household)	Dimensionless	1=a few years of high school; 2=high school degree; 3=2 years degree; 4=4 years degree; 5=graduate degree, or higher	4.00 ± 0.98
Property market value	Thousands of $	-	271.86 ± 107.58
Household income	Thousands of $	1=less than 30; 2=between 30 and 49.9; 3=between 50 and 74.9; 4=between 75 and 99,9; 5=between 100 ad 149.9; 6=between 150 and 199.9; 7=between 200 and 249.9; 8=between 250 and 299.9; 9=More than 300	3.96 ± 1.87
Attitudes expressed in management criteria ("What criteria guide your landscape choices?")			
Supports wildlife	Dimensionless	0=disagree; 1=agree	0.31 ± 0.47
Creates a beautiful yard	Dimensionless	0=disagree; 1=agree	0.75 ± 0.44
Is easy to maintain	Dimensionless	0=disagree; 1=agree	0.73 ± 0.45
Is neat and orderly	Dimensionless	0=disagree; 1=agree	0.44 ± 0.50
Is native to Minnesota	Dimensionless	0=disagree; 1=agree	0.30 ± 0.46

Provides privacy/seclusion	Dimensionless	0=disagree; 1=agree	0.33 ± 0.47
Provides food	Dimensionless	0=disagree; 1=agree	0.06 ± 0.24

Table 2. Similarity among four species pools including commercially available plants (Horticultural), plants from household yards that were intentionally planted (Cultivated) or not (Spontaneous), and species found at the Cedar Creek Ecosystem Science Reserve (CCESR). Analyses of pool similarity were calculated as follows: 1) Phylogenetic similarity calculated using PhyloSor. All species are included in the analysis. Higher values indicate that species in the paired pools share a higher proportion of closely related species that come from the same regions of the phylogeny (1=identical). 2) Sørensen's similarity index giving proportional species similarity. The analysis include all species. Higher values indicate that the paired pools shared a higher proportion of the same species (1=identical). 3) Phylogenetic similarity for introduced (upper triangle, in bold) and native species (lower triangle). 4) Sørenson's species similarity index for introduced (upper triangle, in bold) and native species (lower triangle).

Species pools	Cultivated	Horticultural	Spontaneous	CCESR
Phylogenetic similarity (PhyloSor's index)				
Horticultural	0.71			
Spontaneous	0.40	0.33		
CCESR	0.55	0.47	0.50	
Sorensen's index (Sørenson's index)				
Horticultural	0.46			
Spontaneous	0.06	0.03		
CCESR	0.20	0.13	0.26	
Phylogenetic similarities (introduced/native) (PhyloSor's index)				
Cultivated		**0.69**	**0.32**	**0.37**

Horticultural	0.74		**0.28**	**0.33**
Spontaneous	0.42	0.33		**0.60**
CCESR	0.59	0.45	0.47	

Sorensen's index (introduced/native) (Sørenson's index)

Cultivated		**0.42**	**0.03**	**0.05**
Horticultural	0.55		**0.01**	**0.04**
Spontaneous	0.10	0.06		**0.34**
CCESR	0.30	0.19	0.23	

Table 3 Results of step-wise regression showing factors that were associated with diversity metrics for total, introduced, and native yard species that were either spontaneous (upper) or cultivated (lower). Metrics of diversity shown for total and introduced species include species richness and phylogenetic diversity using mean phylogenetic distance, MPD. Metrics of diversity shown for native species include species richness, MPD, and the proportion of species that were native. A suite of structural factors, yard and lawn management factors, socioeconomic factors, and attitudes expressed about management from homeowners were tested. Regression coefficients and t values (in brackets) are shown if the factor appeared in the model. If the factors were significant, they are shown in bold, and the significance level is indicated with asterisks as follows: $P < 0.05$ *, $P < 0.01$ **, $P < 0.001$ ***.

Predictors	Total species		Introduced species		Native species		
	Species richness	MPD	Species richness	MPD	Species richness	MPD	Proportion of total
Spontaneous Species							
Structural factors							
Yard area	**18.13*** (8.23)**	11.77 (1.68)	**10.92*** (7.52)**		**8.24*** (7.46)**	**38.79* (2.57)**	
Housing density						2.36 (1.77)	
Yard and lawn management							
Fertilizer addition				-14.89 (-1.65)			
Fertilizer frequency	**-3.06* (-2.84)**		**-2.26* (-3.24)**		**-1.34* (-2.35)**		
Lawn care service					1.43 (1.47)		**0.08* (2.94)**
Watering frequency		5.89 (1.69)					
Socioeconomic factors							
Education							
Property market value	**0.06* (2.31)**					**0.14* (2.82)**	
Household income	-3,00 (-		**-3.36* (-2.12)**		-4.20 (-		0.01 (1.84)

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
		1.92)			1.56)	
Attitudes expressed in management criteria						
Supports wildlife	-7.35 (1.40)	-9.49 (-1.44)				
Creates a beautiful yard		1.97 (1.66)				
Is easy to maintain						
Is neat and orderly						
Is native to Minnesota						0.04 (1.84)
Provides privacy/seclusion		-1.89 (-1.72)	9.41 (1.43)			
Provides food	-15.41 (-1.51)	-19.58 (-1.55)			-32.26 (-1.78)	-0.07 (-1.55)
Cultivated Species						
Structural factors						
Yard area						**0.09** (3.42)**
Housing density						
Yard and lawn management						
Fertilizer addition	**12.96* (2.05)**	6.94 (1.50)		**5.33* (2.55)**	56.03 (-1.54)	
Fertilizer frequency	**-20.96* (-2.70)**				**-46.15* (-2.64)**	
Lawn care service	**-10.92* (-2.42)**	-5.86 (1.70)		**-3.96* (-2.65)**		
Watering frequency	4.06 (1.39)			1.68 (1.76)		
Socioeconomic factors						
Education	4.27 (1.97)	3.08 (1.85)	10.52 (1.84)	1.32 (1.82)		
Property market value	**0.04* (2.13)**	0.03 (1.85)		**0.02* (3.23)**		
Household income				**-1.14* (-2.64)**		**-0.02** (-3.69)**
Attitudes expressed in management criteria						
Supports wildlife	**17.11*** (4.16)**	**11.86** (3.74)**	19.06 (1.68)	**4.72** (3.49)**		

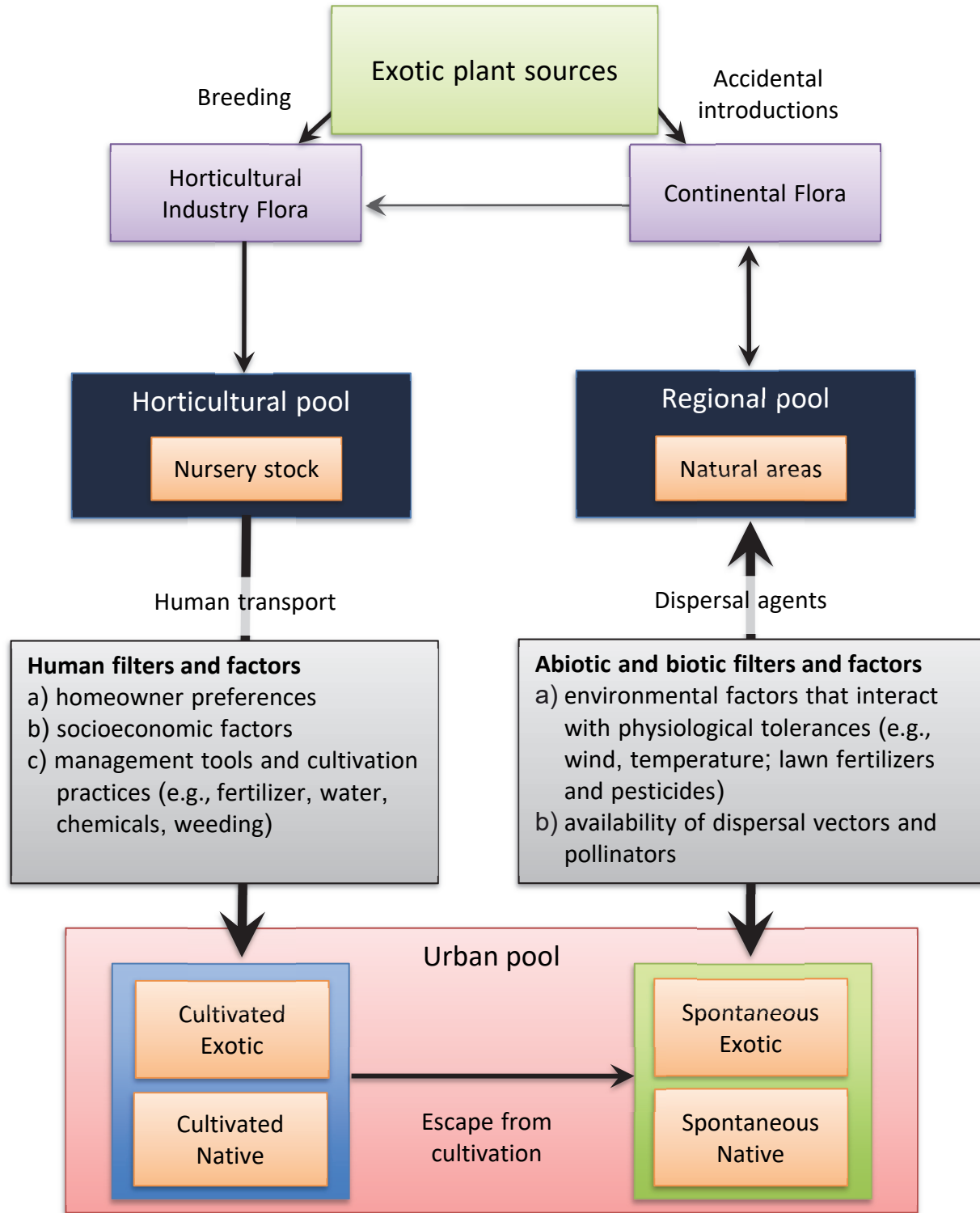|					
Creates a beautiful yard	**12.44* (2.64)**	**8.30* (2.29)**	-20.57 (-1.61)	**4.35* (2.82)**	40.00 (1.80)
Is easy to maintain		**-40.24* (-2.80)**			**-48.85* (-2.02)**
Is neat and orderly	**-11.62* (-2.91)**	**26.92* (2.39)**	**-8.39* (-2.75)**	**-3.09* (-2.37)**	**0.04* (2.02)**
Is native to Minnesota		**26.97* (2.18)**			
Provides privacy/seclusion					
Provides food	**18.11* (2.11)**	11.56 (1.76)	-30.86 (-1.39)	**6.67* (2.38)**	65.91 (1.55)

Figure Legends

Fig. 1. Conceptual overview of the hypothesized linkages between species pools, sources of exotic species, and the factors that influence composition and diversity within the urban household flora (cf. Groffman et al 2017, Pearse et al 2018). Human preferences including homeowner attitudes, socioeconomic factors, and management practices influence the species that are chosen for cultivation and promoted by human activities. These species are transported largely from commercial sources by humans to yards. In contrast, environmental characteristics of cities, such as temperature, wind speed, as well as lawn fertilizers and pesticides applied by humans and the availability of dispersal vectors and pollinators are important filters and factors that influence which species from the regional pool disperse into and persist in urban yards spontaneously.
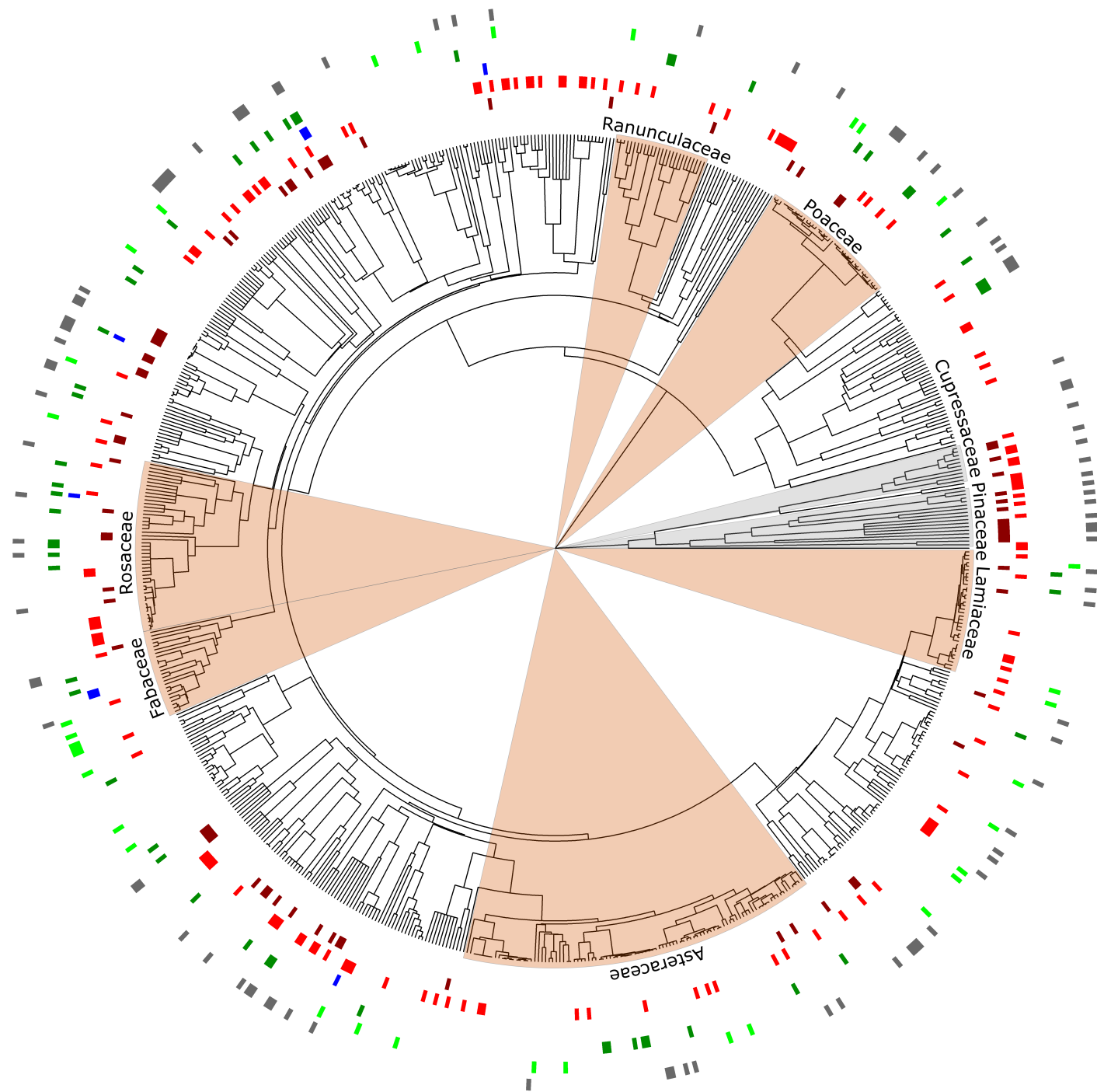
Fig. 2. Phylogeny of cultivated and spontaneous species found in yards in the Minneapolis-St. Paul metropolitan area. Species (phylogeny tips) are colored according to the intersection of the pools they belong to. CCESR = Cedar Creek Ecosystem Science Reserve. Brown shaded areas show the 6 plant families with higher numbers of plant species represented in yards: Asteraceae (108), Rosaceae (56), Poaceae (44), Lamiaceae (34), Ranunculaceae (27) and Fabaceae (24) (see Appendix S1: Table S1 for a complete list of plant family frequencies). Grey shaded areas show the other families referred in the main text (i.e., Cupressaceae, Pinaceae).

Fig. 3. Relationship between species richness and yard area (a-b), and boxplots (median and quartiles) of species richness according to fertilizer frequency (c-d) for the cultivated (blue) and spontaneous (yellow) pool. Both yard area and fertilizer frequency were the only 'structural' and 'yard and lawn management' variables, respectively, with a significant effect on total spontaneous species richness (Table 3a). Regression line, adjusted R^2 and *P*-value are shown for significant relationships. Significant differences in species richness were not found among categories of fertilizer frequency for any of the pools based on ANOVA. In a and b (adapted from Knapp et al 2012) yard area is log-transformed and species richness is square-root-transformed in order to achieve normally distributed residuals.
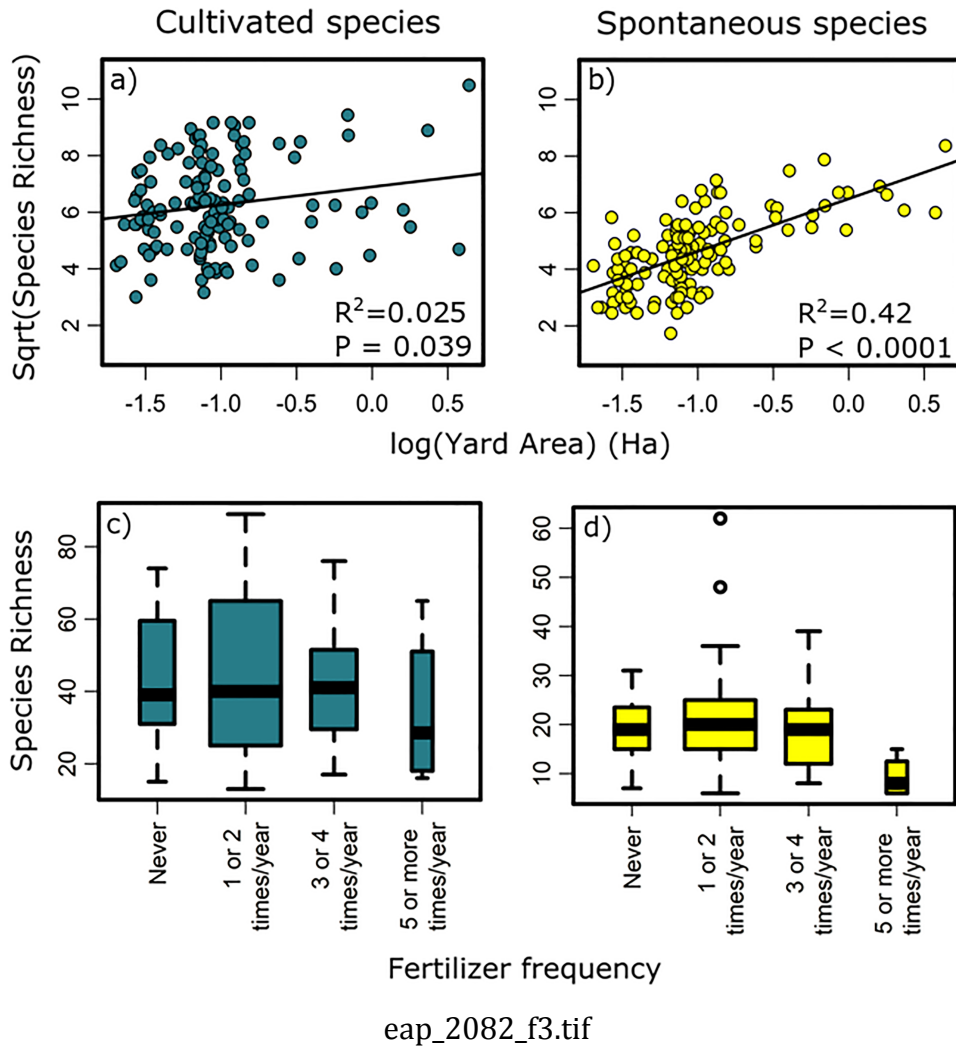
Fig. 4. Boxplots (median and quartiles) of species richness according to homeowners' attitudes expressed in management criteria that were included as significant factors in final models predicting total cultivated species richness (Table 3b): 'supports wildlife' (a-b), 'creates a beautiful yard' (c-d), and 'provides food' (e-f). Boxplots are presented for both the cultivated (blue) and spontaneous (yellow) pool. Boxplot widths are proportional to the square root of the sample size. Differences in mean values between groups were examined with *t*-tests and significant differences are indicated as follows: $P < 0.05$ *, $P < 0.01$ **.
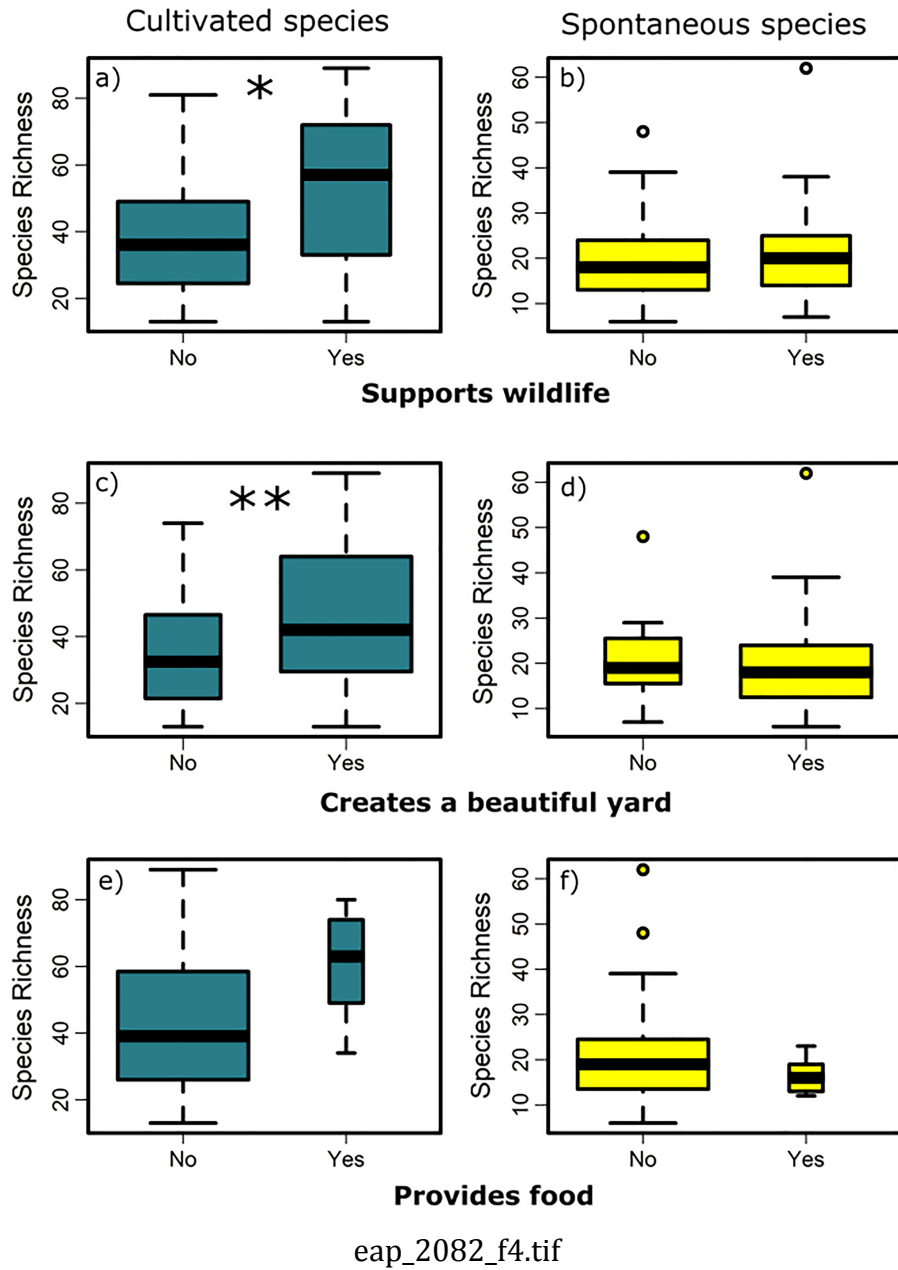
Figure 1

Exotic plant sources

Breeding

Accidental
introductions

**Horticultural
Industry Flora**

Continental Flora

Horticultural pool

Nursery stock

Regional pool

Natural areas

Human transport

Dispersal agents

Human filters and factors
a) homeowner preferences
b) socioeconomic factors
c) management tools and cultivation
   practices (e.g., fertilizer, water,
   chemicals, weeding)

Abiotic and biotic filters and factors
a) environmental factors that interact
   with physiological tolerances (e.g.,
   wind, temperature; lawn fertilizers
   and pesticides)
b) availability of dispersal vectors and
   pollinators

Urban pool

Cultivated
Exotic

Spontaneous
Exotic

Cultivated
Native

Escape from
cultivation

Spontaneous
Native

Ranunculaceae
Poaceae
Cupressaceae Pinaceae Lamiaceae
Asteraceae
Fabaceae
Rosaceae

	Horticultural ∩ Cultivated (native)		CCESR ∩ Spontaneous (native)
	Horticultural ∩ Cultivated (introduced)		CCESR ∩ Spontaneous (introduced)
	Horticultural ∩ Spontaneous (native + introduced)		CCESR ∩ Cultivated (native + introduced)

Cultivated species

Spontaneous species

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Cultivated species | Spontaneous species

a) * — b)

Supports wildlife

c) ** — d)

Creates a beautiful yard

e) — f)

Provides food

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