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Research article

Municipal regulation of residential landscapes across US cities: Patterns and implications for landscape sustainability

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ABSTRACT

Local regulations on residential landscapes (yards and gardens) can facilitate or constrain ecosystem services and disservices in cities. To our knowledge, no studies have undertaken a comprehensive look at how municipalities regulate residential landscapes to achieve particular goals and to control management practices. Across six U.S. cities, we analyzed 156 municipal ordinances to examine regional patterns in local landscape regulations and their implications for sustainability. Specifically, we conducted content analysis to capture regulations aimed at: 1) goals pertaining to conservation and environmental management, aesthetics and nuisance avoidance, and health and wellbeing, and 2) management actions including vegetation maintenance, water and waste management, food production, and chemical inputs. Our results reveal significant variation in local and regional regulations. While regulatory goals stress stormwater management and nuisance avoidance, relatively few municipalities explicitly regulate residential yards to maintain property values, mitigate heat, or avoid allergens. Meanwhile, biological conservation and water quality protection are common goals, yet regulations on yard management practices (e.g., non-native plants or chemical inputs) sometimes contradict these purposes. In addition, regulations emphasizing aesthetics and the maintenance of vegetation, mowing of grass and weeds, as well as the removal of dead wood, may inhibit wildlife-friendly yards. As a whole, landscaping ordinances largely ignore tradeoffs between interacting goals and outcomes, thereby limiting their potential to support landscape sustainability. Recommendations therefore include coordinated, multiobjective planning through partnerships among planners, developers, researchers, and non-government entities at multiple scales.

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1. Introduction

Governance of residential landscapes is essential because yards and gardens affect landscape sustainability across urban social-ecological systems (Lin and Egerer, 2020). An important element of landscape sustainability is the ecosystem services they provide (Raudsepp-Hearne et al., 2010). The extent of ecosystem services (or disservices) delivered to local residents depends partly on how homeowners manage their private landscapes, which is influenced by broader-scale forces including local regulations (Cook et al., 2012; Lin and Egerer, 2020). We, therefore, ask: how are urban landscapes governed through municipal ordinances, and how do these local laws influence residential yard management and associated environmental and social outcomes in the U.S.?

One view of landscape sustainability is, "the capacity of a landscape to consistently provide long-term, landscape-specific ecosystem services essential for maintaining and improving human well-being" (Wu, 2013: 999). From this perspective, a primary goal is enhancing multiple services while minimizing disservices. Enhancing services entails increasing the multifunctionality of landscapes, which necessitates managing social-ecological interactions that can result in tradeoffs and synergistic outcomes (Fagerholm et al., 2019). One example of tradeoffs in urban landscapes is between water conservation and heat mitigation, since vegetation often requires irrigation but provides cooling benefits (Middel et al., 2012). Another interchange is between biodiversity outcomes and aesthetic benefits, since the vegetation structure that provides wildlife habitat can often be perceived as messy and disorderly (Nassauer, 1995).

Globally, researchers have examined the outcomes of residential landscapes, often called gardens or yards (e.g., see Larson et al., 2016; Camps-Calvet et al., 2016; Mohri et al., 2013; Cilliers et al., 2018). These outcomes include ecosystem services such as enhanced biodiversity and human well-being in cities (Goddard et al., 2013; Cilliers et al., 2018; Langemeyer et al., 2018). Scholars have also identified which ecosystem services are most important in driving peoples' landscaping decisions, which typically comprise cultural services such as aesthetics and recreation (Camps-Calvet et al., 2016; Larson et al., 2016; Barnes et al., 2020).

Camps-Calvet et al. (2016) argue that incorporating the multiple ecosystem services provided by urban gardens into local policies can enhance quality of life. In Berlin, research has examined how city planning increasingly incorporates ecosystem services for urban greening (Kabisch 2015). Other studies have examined how local governments regulate residential landscapes, thereby affecting ecosystem services; conducted in particular cities, research has focused on pesticide (Cole et al., 2011) and fertilizer (Souto et al., 2019) restrictions, as well as those on water use (Hester and Larson, 2016) and weed heights (Sisser et al., 2017). However, limited studies have broadly examined how and why local governments are regulating residential landscapes through legal ordinances (Sisser et al., 2017), thereby affecting ecosystem services and tradeoffs. In this paper, we answer calls for research on how formal institutions (i.e., codified laws) influence landscape practices and the potential for residential landscapes to provide multiple ecosystem services (Cook et al., 2012; Lin and Egerer, 2020).

Specifically, we examine residential landscape ordinances (i.e., laws) across 156 municipalities in a range of climatic regions of the U.S. (Table 1): Los Angeles, CA; Phoenix, AZ; Miami, FL; Baltimore, MD; Boston, MA; and Minneapolis-St. Paul, MN. Evaluating local landscaping laws across diverse regions of the U.S. facilitates examination of how these formal institutions aggregate, or not, to large metropolitan areas at the continental scale. Our comparative study informs the scale at which local governance influences ecosystem services and disservices across the "residential macrosystem" broadly, as compared to particular locales or regions (Groffman et al., 2017). Specifically, we: 1) evaluate the extent to which municipalities regulate residential landscapes for particular goals and management strategies, and 2) compare the prevalence of these regulations across diverse regions. We then discuss the implications of these regulations on the ability of residential landscapes to provide multiple ecosystem services in diverse regions.

Since the analysis focuses on ordinances 'on the books', we cannot speak to matters of enforcement 'on the ground', or the effectiveness of regulations leading to particular outcomes. Nonetheless, we address how current landscaping ordinances might foster or thwart landscape change while also highlighting potential ecosystem services and tradeoffs that should be anticipated and addressed for landscape sustainability.

2. Methods

2.1. The study regions

The study regions (Supplementary Table A) were selected due to variations in hydroclimate conditions, which may influence landscaping regulations. Four regions are located in the central or eastern U.S., where the climate is humid compared to the two other regions in the arid southwestern U.S. (Table 1). Meanwhile, the Sunbelt cities of Los Angeles, Phoenix, and Miami have hotter temperatures compared to the colder regions to the north. Miami, Baltimore, Boston, and Los Angeles are coastal areas. Meanwhile, water abounds in the "Land of 10,000 Lakes" in Minneapolis-St. Paul and even the semi-arid Phoenix region that encompasses more than 650 lakes (Larson et al., 2005).

2.2. Sampling strategy

We defined the six metropolitan boundaries based on federally designated Metropolitan Planning Organizations (MPOs, see details in Supplementary Table A). MPOs encompass all urbanized areas of 50,000 people or more, for which U.S. policy requires regional planning for transportation and other services (The Transportation Planning Capacity Building Program, 2017). The six MPOs encompass 436 municipalities across 22 counties. In our analysis, we included urban, suburban, and exurban towns and cities.

Due to limited time and resources, we limited our analysis to 30

Table 1
The Frequency of Diverse Landscape Ordinance Goals (n = 156 municipalities). The results of the T-test determine if a goal is referenced more or less often than others.

Codes/Themes	Total No. of References	Percent of Municipalities	χ^2	p value	Result[a]
Stormwater/ Flood Mitigation	116	74%	23.73	<0.001	More
Biological Conservation	112	72%	19.00	<0.001	More
Water Quality Protection	111	71%	17.90	<0.001	More
Pest Control	110	71%	16.83	<0.001	More
Aesthetic Maintenance	104	67%	11.11	<0.01	More
Safety	103	66%	10.27	<0.01	More
Encroachment Avoidance	99	63%	7.25	<0.01	More
Land Conservation	93	60%	3.70	0.054	NS
Water Conservation	91	58%	2.78	0.096	NS
Disease Avoidance	71	46%	0.81	0.379	NS
Property Values	64	41%	3.22	0.073	NS
Heat Mitigation	46	29%	16.83	<0.001	Less
Allergen Avoidance	15	10%	65.24	<0.001	Less

[a] "More" refers to regulatory goals referenced in significantly more than 50% of the municipalities and "less" denotes those referenced less often.

municipalities in each metro region. The Phoenix, Miami, and Baltimore areas had fewer than 30 municipalities (Table A); thus, all were included in our sample. For the other three regions, we randomly sampled 30 municipalities (for additional details, see [citation omitted for anonymous review]. The three sets of sampled municipalities include the central cities of Los Angles, Boston, as well as Minneapolis and St Paul, but otherwise are distributed across urban, suburban, and exurban municipalities. Our final sample was 156 municipalities, which vary in their year of incorporation (from 1630 to 2005; average of 1901). They also vary in size, with an average population of 93,197 residents (range was 2677 to 3,900,794).

2.3. Collecting municipal landscaping ordinances

To identify landscaping regulations, we collected the "city codes" (a single document) for each municipality online. City codes are policy documents in the U.S. that include all adopted ordinances, or laws, within local governments. These documents are distinct from local comprehensive plans but include visions statement and specific laws that have been adopted by a municipality. As such, they sometimes reference regional (e.g., county/district), state, and/or federal government policies with which they must comply, as well as influential information sources (e.g., landscaping guidelines or suggested plant lists).

The municipal ordinance documents are lengthy and can be found online (Larson et al., 2020). For our sample, the average length was 668 pages, with a range of 25 to 3370. Although originally adopted and then amended at specific moments in time, city codes are living documents in that specific ordinances may be added or modified by municipalities. While we gathered the latest documents available online (in 2017), the most recent amendments (as specified within documents) ranged from 2003 to 2017 (average was 2016). Hereafter, we avoid the phrase "city codes", and instead use "ordinances" or "regulations" to circumvent confusion between "city codes" and our technique of qualitative *coding* (i.e., content analysis) of ordinances, as explained next.

To determine how municipalities regulate residential landscaping, we employed content analysis (Krippendorff, 2012) of the ordinance documents using NVivo version 10. To identify all relevant text addressing residential landscaping laws, we searched for terms including landscaping, yards, gardens, and lawns within each document. We did not specify "residential" in our searches since many ordinances apply to landscapes across land uses. Our coding of text, however, captured regulations that apply to residential landscapes.

2.4. Coding municipal landscaping ordinances

Following (MacQueen et al., 1998), we developed a set of qualitative themes, or codes, to capture 1) the *municipal goals* targeted in landscape regulations and 2) restrictions on specific landscape practices, or *actions*. The codes were deductively developed from the scholarly literature (e.g., Cole et al., 2011; Sisser et al., 2017; Souto et al., 2019), supplemented by knowledge among the research team about existing landscaping regulations in the U.S. and elsewhere. By *goals,* we mean stated objectives or purposes pertaining to water management, land/biological conservation, maintenance and property values, nuisance avoidance, and human health (Box 1). In contrast, regulated *actions* are legal stipulations that prohibit, require, or otherwise promote or discourage certain management practices, explicitly concerning water, vegetation, groundcover, waste, chemicals, and food (Box 2). During the development of the coding scheme, two researchers individually conducted a preliminary content analysis to refine the definitions (Boxes 1-2) and ensure uniformity in applying the codes. To reduce bias, we used regular peer-debriefing between the two coders over the duration of the coding process.

2.5. Analyzing trends in landscaping regulations

For each coded goal (Table 1) and action (Table 2), we report frequencies and percentages for how many municipalities have existing landscaping regulations across our sample. We then examined the extent to which local governments regulate landscapes for specific goals and actions (Tables 1 and 2) using a critical value approach involving a two-tailed test of proportion; this determined if each type of regulation (i.e., code) was mentioned in more or less than 50% of all municipalities analyzed. To understand the association between particular landscaping goals and regulated actions, we ran Pearson's correlation tests to identify how specific goals correlate with landscaping actions based on the overall number of references across municipalities.

In the next section, we present statistically significant correlations ($p < 0.05$) between the frequency of regulatory goals and regulated actions. As supplementary material, we present correlations between the various regulatory goals (Table B) and between the landscaping goals and actions regulated (Table C). To compare regulations across the study regions, we also present the percentages of municipalities within each region that regulate residential landscapes for specific goals and actions (Tables D and E).

Box 1

Code definitions for the *stated goals* guiding residential landscaping regulations

- **Water Quality Protection**: to reduce or control the movement of pollutants, such as fertilizer or nutrients, into water or the environment
- **Water Conservation**: to reduce water use or consumption
- **Stormwater and Flood Mitigation**: to reduce and manage water runoff, or otherwise mitigate risks associated with excessive water or flooding
- **Biological Conservation**: to protect wildlife and plant species, including supporting native species and preventing the spread of invasive species
- **Land Conservation**: to protect or preserve forests, agricultural lands, parks, or open space
- **Aesthetics**: to maintain the health and appearance of vegetation
- **Property Values**: to maintain or increase property values for the economic welfare of the area
- **Pest Control:** to prohibit or remove unwanted pests, such as insects or rodents, as well as noxious weeds or plants, such as poison oak
- **Encroachment Avoidance:** to prohibit or remove obstructions to nearby property/land
- **Disease Avoidance**: to avoid the spread of disease in vegetation
- **Heat Mitigation**: to reduce temperatures or heat
- **Safety**: to keep people safe by preventing and mitigating the occurrence of and exposure to hazards
- **Allergen Avoidance**: to prevent allergens or worsening of allergies that result from vegetation

3. Results

3.1. Prevalence of landscaping goals

3.1.1. Conservation and environmental management

The most common landscaping goals—adopted by more than 70% of the sampled municipalities—relate to managing stormwater and mitigating flooding, conserving biota, protecting water quality, and controlling pests (Table 1). Managing stormwater and protecting water quality are highly intertwined goals (rho = 0.43, $p < 0.0001$), as is stormwater management with impervious surface regulations (rho = 0.27, $p < 0.001$). Concerning stormwater, landscape ordinance goals often state how sites should be developed and managed to prevent erosion and flooding or to retain water on properties. An example (from Hopkinton, MA) reads, "stormwater management facilities shall be designed so that neighboring properties, public ways and public storm drainage systems will not be adversely impacted." Overall, stormwater management is a more prominent goal for wetter cities of the U.S. Specifically, 84% of municipalities in Minneapolis regulate for stormwater management, 78% in Baltimore, 77% in Boston, and 76% in Miami (Supplementary Table D). By comparison, 68% and 55% of municipalities in the southern regions of Phoenix and Los Angeles, respectively, explicitly address stormwater management in their landscaping ordinances.

A similar regional trend emerged for water quality goals. Protecting water quality is a dominant goal in the northern regions (Table 1), particularly in the Minneapolis–St. Paul area where 94% of municipalities sampled explicitly protect water quality. Boston-area municipalities (77%) also emphasize water quality goals (Table D). Phoenix municipalities (59%) had the lowest frequency of water quality objectives. In general, water quality ordinances aim to "prevent pollution," often during site development, or to "improve" or "protect" water quality. The focus tends to be on "receiving waters," with stormwater and wetlands receiving substantial attention.

Protecting water quality is highly correlated with regulations on trees (rho = 0.40, $p < 0.0001$) and other vegetation. In Annapolis, MD, the ordinances read: "Trees in the landscape provide a productive land use with significant water quality and wildlife habitat benefits…" Trees are also significantly associated with regulations on water catchment activities (rho = 0.29, $p < 0.002$). Regarding landscaping practices, the regulatory code in Afton, MN states:

> "The use of certain lawn care practices…will be regulated to preserve and enhance the water quality of the lakes, ponds, wetlands, creeks, and St. Croix River, prevent erosion into these water bodies, fix nutrients, preserve shoreland aesthetics, preserve historic values, prevent bank slumping, protect fish and wildlife habitat, and preserve the economic and natural environmental values of the surface waters and underground waters of the city to the best of its ability" (see below for more on yard care practices).

Adopted by 60% and 58% of municipalities overall, land and water conservation are moderately common goals (Table 1). To conserve water, municipalities commonly regulate irrigation practices (rho = 0.40, $p < 0.0001$), as further discussed below. Municipalities often recommend the use of drought-tolerant plants, sometimes referencing low water-use plant lists available through state or other organizations, especially in the Los Angeles and Phoenix regions. In the Los Angeles municipalities of Signal Hill and El Monte, ordinances stress: "It is the policy of the state to promote the conservation and efficient use of water and to prevent the waste of this valuable resource." Meanwhile, several municipalities in the Miami area emphasize xeriscaping principles—"by encouraging the use of drought-tolerant landscape materials, grouping of plant material by water requirements, and irrigation systems that conserve the use of potable water supplies"—as outlined by the South Florida Water Management District's Xeriscape Plant Guide. In the Los Angeles area, 87% of the municipalities stressed water conservation, followed by 68% and 62% in the Phoenix and Miami regions respectively (Table D). In comparison, about half of municipalities in Boston and fewer in Minneapolis-St. Paul and Baltimore underscore water conservation as a landscaping goal.

Land and water conservation goals also aim to protect natural features and "environmentally sensitive areas," with a focus on wetlands,

Box 2

Code definitions for *landscaping actions* regulated by municipalities

- **Irrigation Restrictions**: regulate how and when residents irrigate their yards based on weather events, time of day, time of week, or seasonal restrictions
- **Other Water Regulations**: require monitoring or reporting water use, or the installation of certain (i.e. climate-smart) devices
- **Water Catchment Activities**: regulate catchment projects, such as rain barrels or stormwater gardens, for water conservation and environmental management
- **Vegetation Minimums:** require a minimum amount of trees or plants in yards
- **Non/Native Requirements**: regulate the management of native or non-native plants, by requiring the presence of natives or the removal of non-native species
- **Tree Maintenance Rules:** specify how trees must be managed, including stipulations regarding height requirements, pruning, and acceptable species to be planted
- **Other Maintenance Requirements:** require vegetation to be maintained to create a well kept, aesthetically pleasing landscaping
- **Turfgrass Stipulations**: control the amount of grass, or lawns, in residential yards
- **Weed Limits**: dictate how "weeds" must be removed or managed, typically with height limits
- **Impervious Surface Rules**: limit the amount of impervious surface, such as rooftops or driveways, on lots
- **Disposal Requirements**: specify how to properly get rid of yard waste, including proper containment, and to prevent noxious smells or unsanitary waste containment
- **Composting Regulations**: specify how to properly manage composting systems (for recycling of organic waste) in homes and community gardens
- **Fertilizer Use Restrictions**: limit or control fertilizer applications
- **Pesticide Use Restrictions**: control the use of chemicals to eliminate or manage insects/pests
- **Food Gardening Restrictions:** regulate the maintenance of plants that produce food, including vegeTable Bnd herb gardens as well as fruit trees
- **Chicken Management Rules:** regulate poultry or fowl, or their maintenance in residential areas
- **Bee Keeping Rules:** regulate beekeeping, including number of bees and maintenance of hives

Table 2
The Frequency of Regulated Management Actions (n = 156 municipalities). The results of the proportions test determine if a type of action or management practice is being regulated more or less frequently than the others.

Code/Theme	Total No. of References	Percent of Municipalities	χ^2	p value	Result[a]
Tree Maintenance	122	78%	31.82	<0.001	More
Other Vegetation Maintenance	115	74%	22.50	<0.001	More
Impervious Surface Restrictions	112	72%	19.00	<0.001	More
Waste Disposal	111	71%	17.90	<0.001	More
Weed Maintenance	107	69%	13.82	<0.001	More
Turfgrass Maintenance	103	66%	10.27	<0.01	More
Chicken Management	101	65%	8.69	<0.01	More
Irrigation Restrictions	82	53%	0.26	0.61	NS
Vegetation Minimums	71	46%	0.81	0.37	NS
Other Water Regulations	53	34%	10.27	<0.01	Less
Non/Native Vegetation Requirements	50	32%	12.89	<0.001	Less
Fertilizer Usage	46	29%	16.83	<0.001	Less
Compost Management	45	29%	17.90	<0.001	Less
Bee Keeping	44	28%	19.00	<0.001	Less
Food Gardening	43	28%	20.13	<0.001	Less
Water Catchment	42	27%	21.30	<0.001	Less
Pesticide Usage	33	21%	33.28	<0.001	Less

[a] "More" refers to regulatory goals referenced in significantly more than 50% of the municipalities and "less" denotes those referenced less often.

floodplains, or buffer zones. Land conservation is most highly correlated with regulations on native or non-native plants (rho = 0.38, $p < 0.0001$), followed by regulations that specify vegetation minimums (rho = 0.31, $p < 0.0001$). Land conservation goals are especially prevalent among municipalities in the Minneapolis–St. Paul region (81%), followed by Boston (68%) and Miami (66%). Fewer than half of municipalities in the other regions stress land conservation (Table D).

Ordinances stress biological conservation to protect habitat and wildlife, especially during development and for sensitive or protected areas (e.g., wetlands or designated "conservation districts"). Some municipalities aim to protect "Significant Ecological Areas" that include "rare," "endangered," or "one of a kind" biotic resources, particularly in the Los Angeles area where they are emphasized in the County General Plan. Specific references to residents underscore the environmental and social value (e.g., historic, aesthetic; see quote above) of "natural" areas or resources broadly. Much emphasis is placed on the value of trees, with a high correlation (rho = 0.49, $p < 0.0001$) between biological conservation goals and regulations on trees. The regions varied substantially in their biological conservation goals. While the vast majority of municipalities (87%) in the Minneapolis–St. Paul and Boston areas stressed conservation, only about half of the municipalities in the Baltimore (56%) and Phoenix (47%) areas included these goals (Table D). Example excerpts from the ordinance documents include the following stated goals:

> "… to conserve natural, hydrological and wetlands resources, wildlife habitat, scenic corridors and views, agriculture, horticulture and forestry operations, cultural resources and other natural and man-made features of value to the community…" (Westwood, MA)

> "… to preserve and protect open spaces, park lands, wilderness areas, marshlands, watersheds and water recharge areas, scenic areas, beaches, and native flora and fauna… [in part] for residents and visitors to view wildlife in their natural habitat as a passive recreational opportunity…" (Cutler Bay, FL)

> "… to promote the public safety, health, and welfare, and to protect public and private property, wildlife, marine fisheries, and other ocean resources, and the natural environment, it is necessary to protect the ecological balance of the coastal zone and to prevent its deterioration and destruction…" (Los Angeles, CA)

3.1.2. *Nuisance avoidance, aesthetics, and safety*

Regulations on pest control are most widespread across the municipalities (71%; Table 1). These landscaping goals mostly aim to control insects and rodents, in addition to nuisance (e.g., "diseased" or "noxious") vegetation. Pest control is coupled with objectives concerning safety (rho = 0.40, $p < 0.0001$) in addition to maintaining property values (rho = 0.34, $p < 0.0001$) and avoiding property encroachments (rho = 0.35, $p < 0.0001$). Accordingly, pest control is most strongly associated with the proper disposal of waste (rho = 0.38, $p < 0.0001$), removal of weeds (rho = 0.45, $p < 0.0001$), and maintenance of turfgrass (rho = 0.35, $p < 0.0001$), followed by the maintenance of trees (e.g., to avoid encroachment; rho = 0.30, $p < 0.0001$) and chickens (rho = 0.23, $p < 0.003$). Pest control is slightly less common in Phoenix and Baltimore (Table D), and least common among municipalities in the Boston area (23%).

Emphasis on the aesthetic maintenance of landscapes is also prominent as a goal, appearing in 67% of the municipalities in our sample (Table 1). Aesthetic goals—emphasizing "attractive", "neat", "healthy," and/or "properly maintained" landscapes—are significantly associated with the goals of maintaining property values (rho = 0.32, $p < 0.0001$) and avoiding property encroachments (rho = 0.30, $p < 0.0001$). Aesthetic goals also emphasize maintaining landscapes in ways that avoid aesthetic nuisances (e.g., unsightly or deteriorated landscapes, including those with "uncontrolled growth"). Others uphold community appearances by, for instance, pruning or trimming plants and trees, removing dead vegetation and debris, or otherwise controlling vegetation. Interestingly, a larger portion of municipalities (>70%) in the southern metropolitan regions stress aesthetic maintenance compared to northern cities in this study (Table D). Moreover, aesthetics are among the most prevalent goals among municipalities in Phoenix and Miami.

Roughly two-thirds of municipalities specified objectives for ensuring safe landscapes and avoiding the encroachment of vegetation beyond an individual's property (Table 1). Goals relating to safety stress protecting public health and welfare, which commonly involves regulations on removing "dead," "dangerous," and "diseased" trees or other vegetation. Safety goals are highly correlated with pest control (rho = 0.40, $p < 0.0001$), property values (rho = 0.41, $p < 0.0001$), and properly disposing of waste (rho = 0.38, $p < 0.0001$). Meanwhile, regulations on avoiding encroachment emphasize keeping public rights-of-way (e.g., streets, sidewalks, and alleys), and to a lesser extent neighboring or adjacent structures, clear from vegetation and debris. The most strongly correlated actions with encroachment include maintaining vegetation broadly (rho = 0.30, $p < 0.0001$) and proper waste disposal (rho = 0.35, $p < 0.0001$). Both safety and encroachment avoidance are most common in Los Angeles (87% and 77% of municipalities, respectively) but are otherwise widespread across municipalities in all regions except the Boston area (only 32% of municipalities; Supplementary Table D).

Moderately common landscaping goals—adopted by less than half of the sampled municipalities (Table 1)—include avoiding diseases and maintaining property values. Disease avoidance predominantly involves removing "diseased," "dead," "dying," or "unhealthy" vegetation. This landscaping goal is most prevalent among municipalities (81%) in

Minneapolis–St. Paul, where ordinances often specifically reference managing Dutch Elm and Oak Wilt diseases. Avoiding diseased vegetation is also relatively common in Baltimore, Los Angeles, and Miami compared to Phoenix and Boston (see details in Table D). Unsurprisingly, disease avoidance is most highly correlated with the maintenance of trees (rho = 0.49, <0.0001).

Beyond nuisance considerations, some municipalities also emphasize the preservation of trees and natural resources to protect the economic value of property. For example, some municipalities in the Miami area emphasize improving "the aesthetic appearance of…residential development through the use of plant material, thereby protecting and increasing property values within the community, and protecting designated historic landscapes" (quote from Palmetto Bay, FL). Across regions, protecting property values is emphasized most frequently among municipalities in Los Angles (65%), Minneapolis (55%), and Miami (52%) (Supplementary Table D).

3.1.3. Human health

Mitigating heat and managing allergens are the least commonly stated goals in landscape ordinances (Table 1). Heat mitigation (adopted by 29% of municipalities) is strongly correlated with the maintenance of vegetation (rho = 0.36, $p < 0.0001$), including trees (rho = 0.34, $p < 0.0001$), turfgrass (rho = 0.36, $p < 0.0001$), vegetation minimums (rho = 0.35, $p < 0.0001$), and native versus non-native plants (rho = 0.42, $p < 0.0001$). Heat mitigation goals are especially common among municipalities (Table D) in Miami (52%), similarly common between Minneapolis (36%) and Baltimore (33%), and oddly, given its hot climate, less common in Phoenix (28%). Specific language from Miami Gardens, FL, states, "Trees shall be planted so as to provide shade to residential structures that are of a height of 35 feet or less." Some municipalities also emphasize mitigating climate change, as well as related energy conservation benefits. For example, the city of Miami Beach promotes "the use of trees and shrubs for energy conservation, thereby helping to offset global warming and local heat island effects." Lastly, very few municipalities (10%) regulate landscapes to avoid allergies, though this percentage is highest in Phoenix (36%). These regulations largely aim to avoid allergenic or toxic plants or other materials. For example, in the Phoenix region, some municipalities specifically ban "pollen-producing" olive (*Olea europaea*) and mulberry (*Morus alba*) trees.

3.2. Regulated landscaping practices

3.2.1. Controlling vegetation

Municipalities in our study most commonly have regulations that involve maintaining vegetation (Table 2). Regarding trees, municipalities commonly require the removal of dead, diseased, or encroaching trees for safety reasons and nuisance avoidance, including maintaining the integrity of built structures. In some cases, this includes maintaining the health of trees through irrigation and fertilization. Some municipalities have tree preservation plans, notably (>80%) in the Miami, Minneapolis–St. Paul, and Los Angeles areas, where municipalities commonly require permits for removing trees (Supplementary Table E). Several municipalities in the Miami area reference adherence to a county-level (Miami-Dade) Tree Preservation and Protection Ordinance that prohibits certain tree species (e.g., *Ficus benjamina*/Weeping Fig), protects native species, and requires tree diversity. Overall, many of the tree ordinances (such as minimums, discussed further below) apply to the initial development of sites.

Weed-height maximums are also widespread, as are laws prohibiting the encroachment of trees onto other properties. Although not always clearly defined, "weeds" are commonly described as "noxious," "hazardous," or "dangerous" as well as "unsightly" or "unsanitary." Specific definitions of weeds vary, with some including specific plants and others referencing excessive growth at particular heights. Height limits range from 3 to 12 inches (8–30 cm), with limits of 6–8 inches (15–20 cm) most prevalent. Some municipalities specify several plants as weeds, many of which are invasive:

> "… alum (allium), Buckthorn, Bur Cucumber, Canada Thistle, Corncockle, Cressleaf Groundsel, Curly Dock, Dodder, Field Bindweed, French Weed, Hairy Whitetop, Hedge Bindweed, Hoary Cress, Horsenettle, Johnsongrass, Leafy Spurge, Mile-A- Minute Weed, Musk Thistle, Oxeye Daisy, Perennial Sow Thistle, Poison Hemlock, Purple Loosestrife, Quackgrass, Russian Knapweed, Russian Thistle, Serrated Onion, Wild Parsnip, Garlic Mustard, Common Tanzy, Japanese Knotweed, and any other weeds as defined or designated in…Minnesota Rules adopted pursuant thereto…" (from city codes of North Saint Paul)

Following this state statute, it is unsurprising that the vast majority of Minneapolis-St. Paul municipalities (90%) regulate weeds. Nearly all (97%) in Miami also have weed ordinances compared to two-thirds to three-fourths of municipalities in the other regions, except Boston, where only 16% regulate weeds (Table E).

Regarding turfgrass, municipal ordinances overwhelmingly involve height limits to avoid nuisance weeds. Some municipalities, especially in the Los Angeles and Miami areas, have regulations on artificial or synthetic turf that stress maintaining a "fadeless green" or "natural" appearance and ensuring the turf is securely attached to the property. Across regions, the vast majority of municipalities in Miami (93%) and Minneapolis-St. Paul (90%) regulate turfgrass, whereas relatively few (32%) regulate turfgrass in the Boston area (Supplementary Table E). In metro Miami, some municipalities specify the grass species (e.g., St. Augustine) or "other lawn species well adapted to localized growing conditions" (Aventura, FL). Very few regulations on lawns address environmental impacts, although select municipalities emphasize water conservation considerations. Examples follow:

> "Artificial or synthetic turf is an appropriate substitute for natural turf in some cases for the purposes of water conservation." (San Dimas, CA)

> "In order to conserve water as required by the Department of Water Resources and the town regulations…grass (turf) use shall be restricted to 30% of the "gross" area of single-family and 2-family lots." (Florence, AZ)

> "Landscaping shall be comprised primarily of non-invasive, drought-resistant plantings that include trees, flowers, shrubs, succulents and ornamental grasses. High-water use turf shall not exceed twenty-five (25) percent of all landscaped areas or open space on the site." (Withrrop, MA)

3.2.2. Managing water and waste

Although municipal ordinances do not tend to regulate grass for water conservation purposes, about half of the sampled municipalities have restrictions on irrigating landscapes (Table 2). Typically, these ordinances specify when residents can water yards based on the time of day, days of the week (e.g., even/odd days), season (e.g., restrictions in summer), and/or weather events (e.g., drought). Municipalities in the Los Angeles and Minneapolis–St. Paul (68% each) regions most commonly restrict irrigation, followed by those in Phoenix (56%) and Miami (48%) (Table E). Less common water conservation regulations (adopted by 34% of municipalities overall) require water reporting or installation of specific technologies (e.g., climate-smart irrigation controls). However, water conservation regulations are fairly common in Los Angeles (71% of municipalities).

Regarding water catchment, relatively few municipalities (27%) regulate activities such as the maintenance of rain barrels or gardens (Table 2). Regulations on retaining water are most common in the Baltimore region (44% of municipalities; see Table E), with references to designing rain gardens, swales, and other best management practices

according to the state's Stormwater Design Manual. Some municipalities, especially in the Miami area, also explicitly allow or encourage cisterns or rain barrels for the purposes of water conservation.

The majority (71%) of the municipalities sampled have regulations on impervious surfaces such as driveways and roofs, primarily for stormwater management purposes. Some specify a maximum amount of impervious surface (e.g., concrete or built structures) that can cover a parcel (typically 25–50%) to reduce stormwater runoff and associated pollution. Other municipalities emphasize minimizing the amount of impervious surface. Some ordinances also caution residents to minimize runoff or the application of fertilizers to prevent pollutants from entering water bodies. Regulations on impervious surfaces are most common in the Los Angeles area (81% of municipalities), followed by Baltimore and Minneapolis–St. Paul (Table E). They are least common among municipalities (56%) in the Phoenix area.

Mainly to avoid nuisances, more than two-thirds of municipalities stipulate how residents must maintain or dispose of waste in residential areas (Table 2). The majority of municipalities in all regions—except for Boston (39%)—specify how waste should be handled (Table E). These ordinances include stipulations on properly preparing yard waste for pick-up, in some cases (especially in Minneapolis–St. Paul and Miami) for recycling or composting. Ordinances also limit the size of tree branches and the weight of yard-debris bags to facilitate pick-up and removal from homes. Also related to waste disposal, relatively few (29%) municipalities in our sample have regulations on composting except Minneapolis–St. Paul, where 71% of municipalities address composting of yard and food waste. These regulations focus on minimizing pests and other nuisances (such as odors), with some specifying setbacks of minimum distances from neighbors and/or sensitive areas such as wetlands and floodplains.

3.2.3. Regulating food production

Regarding food production, regulations on animal production—primarily to avoid nuisances—were more common than those for growing fruits, vegetables, or herbs (Table 2). In particular, regulations on chickens or other fowl were common among municipalities (65% of those sampled). Common restrictions include containment of animals, setbacks (commonly 20–100 feet) for coops from other properties, and the number of animals allowed relative to lot size (often 3–5 on residential plots). Some municipalities also require that residents obtain a permit to raise fowl, while others prohibit any fowl from being kept on residential property. Regulations on fowl are most common among municipalities (more than three-quarters) in the Miami and Los Angeles regions and least common (around one-third of municipalities) in the Boston and Baltimore areas (Table E).

Far fewer municipalities (slightly over one-quarter) had regulations on bees and food gardens or fruit trees (Table 2). Similar to regulations on chickens, restrictions on keeping bees often required permits and stipulated the number of bees or hives allowed. Some municipalities also have outright bans on beekeeping. Restrictions on beekeeping are most common among Los Angeles municipalities (58%), followed by Minneapolis–St. Paul (39%), while these regulations are nearly non-existent in the Boston and Baltimore regions (Table E). Meanwhile, regulations on food gardening exist among about one-quarter to one-third of municipalities across the study regions. These regulations tend to specify size and crop limits as well as irrigation requirements, such as prohibiting the use of wastewater. Others require residents to pick up dropped fruit from trees. Very few municipalities prohibit gardens overall, though setbacks of 10–20 feet (3–6 m) for gardens are common. A rare example states, "vegetable gardens are permitted in rear yards only" (Miami Shores, FL). In contrast, another municipality (in Mesa, AZ) specifies that in front and back yards, plant choices"…are left to the individual homeowners and their homeowners' association" (though plants from the "preferred desert uplands plant list" are encouraged).

3.2.4. Maintaining landscapes and non-native species

Minimum vegetation or landscaping requirements were adopted by fewer than half of the municipalities (Table 2). These requirements often specify the percentage of a parcel (e.g., ranging from 5 to 50%) that must be vegetated or otherwise "landscaped," which in some cases can include non-vegetative materials including pools and tennis courts. These regulations typically apply to new developments, including single- and multi-family homes. Additional requirements include a minimum number of trees, shrubs, or native species (see below), and some municipalities require trees of minimum heights (especially 25 feet in the Miami area). Example language includes: "each [single-family] lot shall have a minimum of [two] non-ornamental trees (planted or preserved), in the front yard," with variations based on lot size (excerpt from Shakopee, MN). On single-family parcels, a minimum of one or two trees is common.

Other municipalities have requirements aimed at vegetation diversity, for instance: on multi-family residential plots, "diversity of required tree species" is required "to avoid a mono-species appearance and to circumvent significant tree loss due to disease to a specific tree species" (Miami Beach, FL). Although this particular regulation specifies goals, regulations on vegetation often state what is required or prohibited without such explicit ends. Across the metro regions, municipalities in Minneapolis–St. Paul (68%), Miami (55%), and Los Angeles (52%) tend to have vegetation minimums. They are least common among municipalities (about one-quarter only) in metropolitan Boston and Phoenix (Table E).

Among the less common regulations are those pertaining to non/native species (Table 2). Only about one-third of municipalities in our study have such ordinances, typically to encourage native plants instead of discouraging non-native or invasive ones. Native plants are especially protected during construction, for example, with stipulations to preserve or replace them—in some cases, "where feasible." Municipalities such as Miami, FL, require landscaping plans for development permits, which "shall include use of native plant species in order to reestablish an aesthetic regional quality and take advantage of the unique diversity and adaptability of native species to the environmental conditions of South Florida." In some municipalities, native plants are generally protected in designated areas such as wetlands, native desert areas (in Phoenix), and parks and open spaces.

Invasive plants are sometimes prohibited during new development or as replacement trees after construction. In other cases, the removal of invasive plants is explicitly allowed or required. For example:

> "Shrubs, brush, buckthorn and other invasive…trees may be removed by a property owner without submittal of a tree preservation plan" (Cottage Grove, MN).

> "Prior to construction on any site, all invasive exotic plants shall be removed, specifically melaleuca, casuarina, and Brazilian pepper." (Miami, FL)

In the Los Angeles area, some municipalities (e.g., Hermosa Beach) prohibit plants listed on the Invasive Plant Inventory of the California Invasive Plant Council "or equivalent authority." A similar rule applies in the Boston area (e.g., Scituate), where prohibited plants are specified in the Massachusetts Plant Advisory Group or banned on the Massachusetts Prohibited Plant List. Across regions, regulations on native and non-native species are most common in Minneapolis–St. Paul and Miami (48% of municipalities), followed by Boston and Phoenix (28–29%) (Table E).

3.2.5. Regulating chemicals

Adopted by only 21% and 29% of municipalities, fertilizer and pesticide use restrictions were among the least common regulations in our sample (Table 2). In order to protect water quality, fertilizer restrictions often restrict when and where fertilizer can be applied, mainly to avoid runoff from impervious surfaces (including frozen ground),

during storm events, or into water bodies. The latter includes bans in buffer zones near surface waters. Exceptions are sometimes made, particularly for newly established turfgrass. Some municipalities, especially in Minneapolis–St. Paul and Baltimore, require or suggest soil testing before applying fertilizers. Others limit the amount of fertilizer that can be applied, with references to standards established by the University of Minnesota Extension Service as well as the Maryland Department of Agriculture's Nutrient Management Manual. Phosphorous is commonly specified in restrictions, followed by nitrogen. The City of Minneapolis also restricts sales of fertilizers containing phosphorous. Moreover, the state of Minnesota has restricted lawn fertilizer phosphorus since 2002 Minnesota Department of Agriculture (MN DOA), (2020).

Although some strict regulations exist across municipalities, other ordinances instead use cautionary language or recommendations about fertilizer as well as pesticide use. Moreover, while most fertilizer regulations limit their use, some municipal ordinances encourage the use of fertilizer (or water) to maintain healthy landscapes. For example, Aventura, FL, directs people to "fertilize landscaping material, as needed, to maintain healthy, viable growth." The extent of fertilizer restrictions varies widely across metro regions, from a high of 71% in Minneapolis–St. Paul, to a low of 3% in Los Angeles. They are most common in the eastern U.S., with roughly one-fifth to one-third of municipalities regulating fertilizers in Miami, Boston, and Baltimore (Table E).

A similar pattern exists for pesticide use regulations, though they are most common among municipalities (approximately 40%) in the Baltimore and Minneapolis regions (Table E). Pesticide regulations often restrict or advise "extreme caution" when spraying on hard surfaces or near waterways. Municipalities also often specify that they should be used "… in accordance with manufacturer's specifications for application, storage, and disposal." In Bay Harbour Island, Florida, the use of fertilizers and pesticides is linked to "minimum landscaping standards", as follows:

> "A property owner is responsible for ensuring that landscaping…[is] maintained so as to represent a healthy, vigorous, and neat appearance, free from over growths, weeds, refuse and debris; [and] sufficiently fertilized and watered to maintain the plant material in a healthy condition, including appropriate use of pesticides as necessary."

Regulations on pesticide use also often apply to commercial users, including requirements for signs to warn people after spraying has occurred. Also, municipal ordinances on pesticides include recommendations to apply them in ways that minimize runoff or otherwise follow "all necessary precautions" to minimize impacts on water and land.

4. Discussion

Landscape regulations across regions reflect their local climatic and environmental contexts. This pattern manifests in a stronger emphasis on water quality, stormwater, and flood mitigation in the eastern regions of the U.S. with higher annual precipitation. Meanwhile, in warm regions, water conservation through irrigation restrictions and other practices are relatively common. This trend is especially strong in Los Angeles, where recent droughts and water shortages have spurred action across the state (Pincetl et al., 2019). Watering restrictions are less common in arid Phoenix and tropical Miami, perhaps due to political forces overpowering hydro-climatic conditions (Hill and Polsky, 2007). In contrast to water restrictions, surprisingly, regulations on heat mitigation did not have a distinct climatic pattern since such regulations are more common in the Boston and Minneapolis areas than Phoenix and Los Angeles. Regardless, promoting and designing climate-adapted yards will be critical for landscape sustainability into the future.

As a whole, some regions appear better positioned to provide environmental services. For example, municipalities in the Minneapolis–St. Paul and Boston regions have more ordinances covering biological conservation and water quality protection compared to Phoenix and Miami, where municipalities stress the aesthetic quality of landscapes and nuisance avoidance. Since neat and orderly landscapes tend to meet aesthetic preferences more than naturalistic landscapes with ecological benefits (Nassauer, 1995), the emphasis on well-maintained and weed-free yards could constrain the design of landscapes that have the vegetation structure to support local wildlife (Lerman et al., 2018). Local weed laws that restrict plant height could have consequences for pollinators since reduced mowing supports pollinators and for prairie restoration in mid-western cities (Ramer et al., 2019). While some laws could change to better support wildlife habitat, yard designs and management should also uphold their aesthetical appeal and minimize nuisances for overall landscape sustainability.

The lack of attention to native plants in municipal regulations and requirements for removing woody debris in residential yards may also limit wildlife-friendly yards in cities. For example, native plants influence habitat quality by increasing the availability of food resources (e.g., caterpillars), specifically for habitat specialists (e.g., insectivorous birds; Narango et al., 2018). Moreover, dead-wood provides habitat for cavity nesting wildlife (Kane et al., 2015). Similar to existing native or climate-adapted plant guides, guidelines for maintaining aesthetically appealing landscapes that offer wildlife or other environmental benefits could encourage more sustainable landscaping practices. The National Wildlife Federation (2019) and National Audubon Society (2019) both have programs that guide households on how to incorporate wildlife-friendly features into their landscapes. Municipalities that allow and incorporate these features could help promote action for biological conservation in yards, though nuisance tradeoffs (e.g., termites attracted to dead wood) should be proactively managed.

Some patterns in regulated goals and activities signal contradictions that could lead to confusion, inaction, or unintended consequences. For example, water quality is a prominent goal, yet relatively few municipalities (outside of Minnesota) control yard chemicals such as fertilizers and pesticides, and some even encourage them. Similarly, some landscape ordinances emphasize water conservation and recommend irrigation to maintain the health and appearance of vegetation. In general, municipal ordinances tend to overlook potential contradictions or tradeoffs, perhaps due to the linear nature of documents with sections focused on singular objectives. Additional planning efforts are therefore needed to achieve multifunctional landscapes by identifying tradeoffs and synergies embedded in landscaping ordinances (Fagerholm et al., 2019). Coordination among municipalities could also help avoid tradeoffs across municipalities while 'scaling up' the impacts of landscape regulations and programs.

Many regulations on residential landscapes, including minimum vegetation requirements, apply to their initial development or redevelopment. Since residents do not always change existing yards to suit their preferences, initial plantings and yard features often persist into the future (Larson et al., 2017; Wheeler et al., 2020). These dynamics underscore the role of developers in establishing the landscapes that residents manage. As a result, developers are an essential target for sustainable landscape change.

Given the limitations of our research, we have several recommendations. First, research on how regulations are interpreted, monitored, and enforced is critical to understanding their ultimate impacts. Especially given the ambiguity in the language of regulations (e.g., aesthetically appealing, healthy), some regulations may be difficult to apply, so enforcers may have to rely on personal interpretations for implementation (Engebretson et al., 2020). Second, while this research covers metropolitan municipalities across the U.S., similar research is needed in other places—including rural areas and other countries—in order to fully understand how formal institutions influence the ecosystem services and disservices derived from residential yards and gardens in diverse environmental, cultural, and political contexts. Lastly,

additional analyses are needed to understand how and why landscape regulations vary across municipalities.

5. Conclusion

Our study offers insights into how local governments regulate residential landscapes for various purposes across diverse U.S. regions. Potential constraints on sustainable landscape change include local priorities emphasizing aesthetics and nuisance avoidance over environmental goals such as biodiversity; rigid regulatory documents that curb flexibility and holistic planning for multifunctional landscapes; and a lack of consideration of the tradeoffs inherent in landscape design and management. By extension, recommendations for landscape sustainability should involve guidelines on how to design and maintain yards for biological conservation purposes; sustainable yard designs—including by developers—that aim for synergistic environmental and social outcomes; and coordinated approaches to anticipate and manage multiple objectives in the face of tradeoffs. Finally, we recommend future research to improve knowledge and practice about how regulations are or might be developed and implemented in ways that may enhance or constrain the delivery of multiple ecosystem services while minimizing disservices.

CRediT authorship contribution statement

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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

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