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# Guidance for Practitioners When Selecting Low-growing Shrubs for Challenging Urban Sites: A Systematic Literature Review of Information on Drought Tolerance and Ecosystem Services

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***Abstract.* Urban sites are often characterized by limited space and harsh growing conditions, which present many challenges for plants. Shrubs constitute a significant proportion of the plant material used in urban plantings. Because of their variability in size, form, and habitat requirements, they are helpful design elements for the greening of cities. Therefore, it is incumbent on practitioners to have detailed information about the tolerance of shrubs to environmental stresses to inform their choices. The increasing prevalence of dry and unpredictable rainfall patterns further compounds these. The issue of water stress represents a significant constraint for plants in urban environments. Consequently, those responsible for selecting plants for such areas must consider drought tolerance when making their choices. The objectives of this study were to ascertain the current availability of information regarding drought tolerance and the provision of ecosystem services of selected shrub species and to evaluate the extent to which this information provides guidance to practitioners. To achieve this, books, nursery catalogues, and academic articles were subjected to a review process. A total of 10 European nurseries were consulted to select five common and five uncommon low-growing shrub species for the subsequent literature screening. The species-specific information was extracted by considering findings concerning the tolerance to environmental stresses, the provision of ecosystem services, the recommendations for use in urban environments, and the natural habitat of the species. The findings indicated that extant information was available for most species. However, this information was frequently generic, contradictory, concerned with botanical characteristics rather than site-related information, or excessively focused on a singular stress factor in a controlled setting, thereby limiting its utility for practitioners. The knowledge documented in books is predominantly unsubstantiated and based on the author's experiences and qualitative observations. These findings underscore the necessity for reliable quantitative assessments of stress tolerance in numerous widely used shrub species to inform professionals' plant selections for urban environments and ecosystem services.**

In natural ecosystems, shrubs (hereafter referred to as woody perennial plants with a diameter at breast height of less than 13 cm, with several major branches arising from near the base of the main stem) are integral components of nine biomes that characterize the vegetation in savannah, arid region, temperate zone, mediterranean, mountainous, and arctic ecosystems (Archibold 1995). They are found in various habitats, from forest understory to dunes, riverbanks, floodplains, peatlands, and wetlands, demonstrating a high degree of tolerance to a range of climates and growing conditions. Shrubs exhibit remarkable morphological diversity and adaptations within regions and across gradients (Schenk et al. 2008). Together with trees and herbaceous vegetation, shrubs form distinct plant communities, such as the chaparral, which are shaped by the mediterranean climate, the Caatinga in the Brazilian Uplands, and the Guajira in northern parts of Colombia and Venezuela (Archibold 1995; McKell 2012). Several published books have described shrubs in their native habitats (Adelman and Schwartz 2017; Kolbek et al. 2013; Leuschner and Ellenberg 2017). These provide valuable insight into the conditions in which species grow in various climates, soils, and habitats across the globe.

From design and functional standpoints, shrubs represent a significant portion of the plant material used in public and private planting schemes. They are fundamental to creating landscape structure and tridimensionality in the urban green infrastructure. Together with trees and perennial and annual herbaceous plants, they generate diverse and spatially complex arrangements vital for supporting biodiversity (Hitchmough 2017).

Recent research of shrubs and the provision of ecosystem services (Blanusa et al. 2019) has demonstrated that shrubs are capable of providing microclimate alteration, flood and pollution mitigation, biodiversity provision, and temperature mitigation, particularly on south-facing walls (Thomsit-Ireland et al. 2020). Nevertheless, providing green space in densely populated and confined urban environments is becoming a significant challenge. In an urban context, shrubs are becoming increasingly important because of their smaller stature, which allows them to occupy spaces that would otherwise be reserved for parks and large trees (Haaland and van den Bosch 2015). Implementing shrubs, hedges, green walls, and green roofs in street canyons has been demonstrated to reduce street-level concentrations of pollutants including $NO_2$ and particulate matter by up to 40% and 60%, respectively (Pugh et al. 2012).

Shrubs are undoubtedly valuable for greening urban areas; nevertheless, trees remain the focus of academic research within the horticulture and landscape design professions. Classical and highly cited publications of woody plants typically exclude shrubs (Götmark et al. 2016). The number of scientific publications of shrubs is considerably lower than that of trees. A search within scientific journals in Scopus (a multidisciplinary abstract and citation database) in Jun 2024 using the search terms "shrubs/trees AND environmental stress AND urban environments" retrieved 30 publications for shrubs and 241 for trees. This supports the aforementioned thesis and poses a challenge for finding sufficient information about the stress tolerance of shrubs in the academic literature.

The urban environment presents a series of challenges for shrubs, including elevated temperatures, low air humidity, periods of critical water stress, unbalanced nutrient supply, high lime content and pH of soils, limited soil volumes, soil compaction, soil and air pollution, and de-icing salt (Craul 1999; Pauleit 2003; Sieghardt et al. 2005). It is of significant importance to have clear guidance regarding the capacity of different shrub species to withstand these conditions. Furthermore, climate models indicate that substantial climatic shifts will likely occur in the coming decades. For instance, the climate (referencing precipitation and average temperatures) in London by 2050 is projected to resemble the current climate in Barcelona. Stockholm is expected to exhibit climatic characteristics similar to those of Budapest (Bastin et al. 2019). Furthermore, cities are expected to shift toward the subtropics, with cities from the Northern Hemisphere moving toward warmer conditions, on average, approximately1000 km south (at a velocity of ≈20 km·year$^{-1}$), and cities from the tropics moving toward drier conditions (Bastin et al. 2019). Therefore, practitioners such as landscape architects and garden designers must prioritize tolerance to changing conditions when selecting plants for urban sites rather than focusing exclusively on esthetic characteristics. In light of the recent series of dry summers and the unpredictability of rainfall patterns in Central Europe over the past 5 years, it is becoming increasingly evident that shrubs must be supported by scientific evidence attesting to their suitability and resilience in current and future urban dry climatic conditions if they are to survive in the long term and optimize the delivery of ecosystem services. As Sjöman et al. (2023) have observed, the lack of quantitative assessments of stress tolerance in many available and widely used shrub species makes the selection process complicated and erratic.

Given that water stress represents a significant challenge for plants in urban environments and is likely to intensify in many regions in response to future climate change (Caretta et al. 2022), it is vital to gain an understanding of the existing published information regarding the stress tolerance of shrubs, both in the scientific literature and literature directed to plant use. This will enable the assessment of whether this information can be used to support practitioners in selecting shrubs for use in dry urban sites. The initial step is to characterize the type of species-specific information currently available and its dissemination in books and articles concerning the drought tolerance of selected low-growing shrubs and their capacity to deliver ecosystem services. This first step will entail an evaluation of the current body of information in dendrology literature, nursery catalogues, literature directed at plant use, and scientific articles. A review of the literature enables the identification of research and knowledge gaps concerning the use of shrubs in urban environments and the necessity for reliable quantitative data to support practitioners in their plant selection for urban environments. In the context of this literature review, the focus is on low groundcover shrubs, which represent a significant functional group of shrubs in public spaces. They can create visually appealing and economically sustainable plantings with minimal maintenance.

The objective of this study was to provide responses to the following research questions:

- Which site-related information is currently available in the different types of literature concerning low-growing shrubs' heat and drought tolerance and suitability for public schemes?
- What guidance regarding the delivery of ecosystem services by low-growing shrubs is available in the current literature?
- What insights can be assembled from the existing literature about low-growing shrubs regarding their drought tolerance and suitability for public landscapes?

*Methodology.* In this study, a systematic literature review was conducted to identify and evaluate available literature about the aforementioned research question to derive conclusions following the perspective of Rousseau et al. (2008), whereby a literature review should be regarded as a comprehensive accumulation, transparent analysis, and reflective interpretation of empirical studies pertinent to a specific question. Hence, the systematic review was conducted using a transparent and replicable process, which, in this study, was based on the Prisma Flow Diagram guidelines (PRISMA n.d.).

*Plant selection.* During the identification stage, 10 low-growing ground-covering shrub species were selected for this review through interviews with 10 nurseries specializing in cultivating woody plants in the United Kingdom, the Netherlands, Belgium, Germany, and Sweden. A questionnaire comprising two questions was sent to each nursery via e-mail. The initial query sought to ascertain the five most prevalent low-growing shrubs (with a height of less than 1 m) sold and cultivated by each company over the past 2 years. This was to identify five well-known and widely used shrubs across northern and central Europe. The second question aimed to find five uncommon or untraditional shrubs with potential for future urban climatic conditions based on the considerable expertise of the nurseries regarding cultivating a wide range of plant material and their understanding of the tolerance and water requirements, growth habits, and seasonal characteristics of the species, which enabled them to achieve notable success. All interviewed nurseries responded to both queries. All the responses were collated and compared with highlight duplications of the same species among multiple nurseries. Subsequently, five common and five uncommon shrub species were selected from all the responses received based on the frequency with which they were recommended, with a minimum of two identical answers (Table 1).

*Reviewed literature.* The literature was subjected to a categorization process to form four distinct groups (Supplemental Table 1 in the Appendix). The literature used in this study comprised books and catalogues in English that are adopted for teaching and research purposes in landscape architecture, botany, and garden design. The four categories are the following:

1. **Books about dendrology** are used for research and teaching in botany and landscape architecture in the United Kingdom.
2. **Books about plant use** (horticultural literature) for research and teaching in the fields of botany and landscape architecture in the United Kingdom.
3. **Nursery catalogues** from the largest and most well-known woody plant nurseries in central Europe, which offer nursery catalogues in English. These nurseries export plants throughout Europe and the European Union, and landscape architecture and garden design firms in the United Kingdom commonly utilize them to specify and select trees and shrubs. This category provides the most

Table 1. Species of 10 woody plant nurseries across Europe selected for this study through an interview process.

| Common shrubs | Uncommon shrubs |
|---|---|
| *Euonymus fortunei* Turcz. | *Abelia zanderi* Graebn. |
| *Hydrangea macrophylla* Thunb. | (syn. *Zabelia dielsii* (Graebn.) Makino) |
| *Lonicera ligustrina* var. *yunnanensis* Franch. | *Ceanothus thyrsiflorus* var. repens McMinn. |
| (syn. *Lonicera nitida* E.H.Wilson.) | (syn. *C. thyrsiflorus* var. thyrsiflorus) |
| *Spiraea japonica* L.f. | *Cistus* ×*purpureus* Lam. |
| *Symphoricarpos* ×*chenaultii* Rehder. | (*C. creticus* × *C. ladanifer*) |
| (*S. microphyllus* × *S. orbiculatus*) | *Diervilla lonicera* Mill. |
| | *Rhus aromatica* Aiton. |

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All authors contributed to the study conception and design. Giacomo Guzzon and Henrik Sjöman performed a literature search, data collation and analysis. Giacomo Guzzon wrote the first draft of the manuscript and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.
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recent information about cultivated species across central Europe.

4. **Scientific literature** was extracted from two different databases: SCOPUS (an abstract and citation database within the field of life science) and Web of Science (a platform that provides access to multiple databases that provide reference and citation data from academic journals, conference proceedings, and other documents in various academic disciplines). The scientific literature was extracted from each database by searching for the species name and a keyword. The keywords used for this search were "urban environment," "ecosystem service," "drought tolerance," "heat tolerance," and "climate change." The selection of these keywords was informed by a series of trials that involved the utilization of various combinations of these more general keywords. The rationale behind this approach was to identify combinations that yielded more results in the specified search databases. Only scientific articles in English were included in this review. Sixty-three articles were identified through the aforementioned search criteria, of which only 49 included relevant information. The remaining articles did not contain any information about tolerance to environmental stresses or ecosystem services provided or were duplicates because they appeared in both databases or were repeated for the same species under a different keyword search.

The process for identifying, screening, and including studies in this literature review is divided into three main stages: identification, screening, and inclusion.

During the identification stage, records are identified by searching scientific databases and other sources, including registers, manual searches, citations, and websites. During this phase, the total number of records retrieved is reported, and any duplicates are removed. During the screening stage, the titles and abstracts of the remaining records are assessed for relevance in accordance with the research question, and any irrelevant records are excluded. Subsequently, the full-text articles, books, and catalogues of potentially relevant records are subjected to an assessment of eligibility based on the predefined research criteria. During the final stage, the studies that meet the requisite criteria are included in the final analysis, and the total number of studies included is reported.

The screening review focused on information accessible to the general public, landscape architects, and professionals in urban forestry and planting design in the United Kingdom. It was limited to literature in English. The aforementioned species were used to screen the literature and identify information and discrepancies related to their environmental stress tolerance (urban environment in general, drought, heat, climate change) and ecosystem services.

To ascertain the species-specific tolerance to environmental stresses and ecosystem services provided, the information found in the literature was selected according to the following criteria:

1. The degree of tolerance to environmental stresses, including pollution, shade, exposure, drought, soil compaction, heat, hardiness, salt, and wind.
2. The provision of ecosystem services, such as habitat creation and wildlife value, carbon sequestration, air and water purification, and erosion control.
3. The recommendations for use in urban environments.
4. The species' natural habitat, which may indicate whether a species can tolerate extreme and challenging growing conditions commonly found in cities.

Then, the data obtained from the literature review was subjected to qualitative and quantitative analyses. The quantitative analysis is based on sources that provide guidance regarding the tolerance to different growing conditions and the capacity to deliver ecosystem services between the various shrub groups included in the study. The objective is to ascertain differences between species groups and aforementioned criteria presented in the studied literature (Tables 2–4). The qualitative analysis is based on a detailed evaluation of the available information from multiple sources and between different species in accordance with the aforementioned screening criteria (Supplemental Appendix).

## Results

A more detailed quantitative analysis revealed substantial data about environmental stresses among the five most commonly occurring shrub species. The relevant findings without duplications after the identification stage that were collated from all sources amounted to a total of 151 across the five common species. The most findings were observed for *Euonymus fortunei*, *Spiraea japonica*, and *Hydrangea macrophylla*, with 38, 33, and 32, respectively. The mean number of relevant findings per species was 30.2. A total of 62 relevant findings were identified in the literature for the five uncommon shrub species. *Rhus aromatica*, *Diervilla lonicera*, and *Ceanothus thyrsiflorus* var. repens had the highest scores, with 17, 14, and 13 findings each. The average number of findings for each species in the uncommon shrubs category is 12.4 (Table 2).

The selection of species-specific information from books, nursery catalogues, and academic articles was based on the following four criteria: the tolerance to drought and other environmental stresses; the provision of ecosystem services; the recommendations for use in urban environments; and the species' natural habitat. Compiling the findings according to these criteria made it possible to determine the typology and abundance of available information for each plant species (Table 3) and for each type of literature (Table 4).

Table 3 shows that a total of 135 findings concerning drought tolerance and other environmental stresses, particularly heat, shade, wind, salt, compaction, and soil reaction, were available. Forty-seven findings were available for the species' natural habitat category. However, most sources focused on the geographical origin of a given species rather than the habitat where this species can be found. Only 19 findings about the provision of ecosystem services were available for all species studied. Erosion control, litter decomposition rates, air purification, water treatment, and insect food supply were the ecosystem services provided by the shrubs in this study. Twelve findings were compiled to make recommendations for use in urban environments, showing that most authors are unfamiliar with the complex growing conditions in urban environments.

Table 4 shows that the literature that provides the most findings overall is that directed at plant use, with 110 findings, followed by the dendrological literature with 43, scientific

Table 2. Quantitative analysis of findings of the 10 selected species across the various types of literature, including the number of sources with relevant information.

| Species | Literature directed at plant use (n = 21) | Dendrological literature (n = 5) | Nursery catalogues (n = 6) | Scientific articles (total for all species) (n = 63) | Total |
|---|---|---|---|---|---|
| Uncommon species | | | | | |
| *Abelia zanderi* | 1 | 3 | 0 | **2**/15 | **6** |
| *Ceanothus thyrsiflorus* (var. repens) | 7 | 4 | 0 | **2**/5 | **13** |
| *Cistus ×purpureus* | 10 | 2 | 0 | 0 | **12** |
| *Diervilla lonicera* | 7 | 5 | 2 | 0 | **14** |
| *Rhus aromatica* | 8 | 5 | 0 | **4**/12 | **17** |
| Total for uncommon species | | | | | **62** |
| Common species | | | | | |
| *Euonymus fortunei* | **17** | **5** | **6** | **10**/23 | **38** |
| *Hydrangea macrophylla* | 18 | 4 | 5 | **5**/17 | **32** |
| *Lonicera nitida* | 12 | 5 | 4 | **2**/6 | **23** |
| *Spiraea japonica* | 15 | 5 | 6 | **7**/26 | **33** |
| *Symphoricarpos ×chenaultii* | 15 | 5 | 5 | 0 | **25** |
| Total for common species | | | | | **151** |
| Total | **110** | **43** | **28** | **32** | **213** |

Table 3. Information extracted for each species subdivided according to the criteria used to screen books, nursery catalogues, and academic articles, including the number of sources with relevant information.

| Species | Tolerance to drought and other environmental stresses | Provision of ecosystem services | Recommendations for urban environments | Species' natural habitat | Total |
|---|---|---|---|---|---|
| *Abelia zanderi* | 3 | 0 | 0 | 3 | **6** |
| *Ceanothus thyrsiflorus* (var. repens) | 7 | 0 | 0 | 6 | **13** |
| *Cistus ×purpureus* | 9 | 0 | 0 | 3 | **12** |
| *Diervilla lonicera* | 5 | 0 | 2 | 7 | **14** |
| *Rhus aromatica* | 7 | 0 | 2 | 8 | **17** |
| *Euonymus fortunei* | **24** | **9** | **3** | 2 | **38** |
| *Hydrangea macrophylla* | 27 | 0 | 1 | 4 | **32** |
| *Lonicera nitida* | 13 | 1 | 2 | 7 | **23** |
| *Spiraea japonica* | 22 | 4 | 1 | 6 | **33** |
| *Symphoricarpos ×chenaultii* | 18 | 5 | 1 | 1 | **25** |
| Total | **135** | **19** | **12** | **47** | **213** |

articles with 32, and nursery catalogues with 28. Table 4 also shows that most of the tolerance to environmental stresses criteria findings were found in the literature directed at plant use (78 findings). Moreover, it shows that most findings regarding the species' natural habitat were found in the dendrological literature (24 findings), most findings concerning the provision of ecosystem services were found in scientific articles (10 findings), and most findings for recommendations for urban environments were found in the literature directed at plant use (nine findings).

*Literature directed at plant use.* The 21 books about plant use reviewed in this study contain a substantial amount of information regarding the tolerance of shrubs to environmental stresses, with a particular focus on cold hardiness, water supply and drought tolerance, soil typology and pH reaction, and habitat preferences for optimal growth. A few authors expanded this information by describing the geographical distribution of species in the wild, such as Kelly and Hillier (1995), who, regarding *Ceanothus thyrsiflorus*, stated "native habitat being chaparral, bushy brushwood at elevations where the climate is considerably chillier than on the coastal plain below," and Phillips and Rix (1989), who added "native to California from Marin to Monterey Co., growing in scrub and on cliff tops near the sea. Full sun; tolerant of summer drought. One of the hardiest species, to −15 °C."

Regarding *Hydrangea macrophylla*, Lawson-Hall and Rothera (2005) affirms that it "is only found in a few coastal areas of central Honshu. It is versatile, easily cultivated and adaptable. With its origins in a warm, temperate, maritime climate free from extremes, these are the conditions that *H. macrophylla* prefers," and Thomas (1992) states that this species originates "from southeast coastal regions of Japan." On *Euonymus fortunei*, Phillips and Rix (1989) writes it is "native of Japan, Korea and China, in woods and scrub." With regard to Lonicera nitida, Thomas (1992) states it is native to "W. Sichuan and Yunnan, China," and Phillips and Rix (1989) remarks that it is "native to Yunnan and West Sichuan, in scrubs and along streams at 1200–3000 m."

Additionally, several authors have outlined species' capacity to adapt to various environmental conditions. For example, Flint (1929) presents bar graphs for each species, illustrating the spectrum of adaptability to wind, sunlight, soil moisture, and soil reaction. Hightshoe (1988) asserts that *Diervilla lonicera* is indigenous to various habitats, including "forests, old fields, glades, and regions spanning the northern latitudes. It is found in a range of soil moisture conditions, from upland mesic to dry, and is also adaptable to woodland borders, wayside thickets, rocky areas, open sandy or rocky woods, clay or rock slopes, cliffs, and dunes."

Only a few authors have addressed the species' tolerance to urban conditions in any detail. Krüssmann (1982) presents a list of plants capable of tolerating air pollution, including *Lonicera nitida*. Hightshoe (1988) further expands the species' urban tolerance by differentiating the resistance to various environmental factors, such as drought, heat, pollution, salt, lighting, mine spills, and soil compaction. Hightshoe (1988) lists *Diervilla lonicera* as drought and heat-resistant, soil compaction-resistant and mine spill-resistant. Furthermore, Stoecklein (2011) suggests that a species may tolerate drought, urban conditions, and salt and categorizes *Cistus ×purpureus* as a drought-tolerant and salt-tolerant plant, *Diervilla lonicera*, *Euonymus fortunei*, and *Symphoricarpos ×chenaultii* as drought-tolerant and urban condition-tolerant plants, *Hydrangea marcophylla* as a salt-tolerant and urban condition-tolerant plant, and *Spiraea japonica* as an urban condition-tolerant plant. However, no sources describe whether species are tolerant to urban conditions and do not provide an in-depth description of what urban conditions represent as a growing environment. The term "urban conditions" encompasses a wide range of growing environments, and the sources in question do not provide sufficient information to enable a more precise characterization.

Very little information was found in this category concerning the provision of ecosystem services, which is arguably unsurprising because the notion of selecting plants for the provision of ecosystem services is a comparatively recent perspective that may not have been given the same degree of attention as it has today. However, MacKenzie (2002) writes about *Euonymus fortunei*, saying that "their extensive root system helps to check erosion," and about *Symphoricarpos ×chenaultii*, saying that "it is excellent for erosion control on steep embankments." Moreover, Krüssmann (1982) writes about *Symphoricarpos ×chenaultii*, saying that it is "a bee-attracting plant."

The information presented in these 21 books about plant use is typically not referenced to other sources or scientific studies, which gives the impression that the data are primarily based on the author's experience and qualitative observations. Indeed, Dirr (2004) recounts his observations of *Hydrangea macrophylla*, noting that "in my travels through the United States, I have witnessed impressive plantings that appear to be indestructible." The mean number of species included in the books reviewed is 5.2. The study by Thomas (1992) covers nine species (the highest number of species). The majority of books included in this study encompass a range of five to seven species, reflecting the authors' propensity for examining native, hardy, and commonly planted species within their respective countries of residence. A notable distinction between the number and diversity of findings documented for commonly and less commonly encountered species can be observed. For the former, the abundance of findings per species elucidates their habitat requirements, environmental tolerance, and resilience, facilitating a comprehensive understanding of their characteristics.

Table 4. Information extracted for each type of literature subdivided according to the criteria used to screen books, nursery catalogues, and academic articles, including the number of sources with relevant information.

| Type of literature | Tolerance to drought and other environmental stresses | Provision of ecosystem services | Recommendations for urban environments | Species' natural habitat | Total |
|---|---|---|---|---|---|
| Literature directed at plant use | 78 | 4 | 9 | 19 | **110** |
| Dendrological literature | 18 | 1 | 0 | 24 | **43** |
| Nursery catalogues | 20 | 4 | 3 | 1 | **28** |
| Scientific articles | 19 | 10 | 0 | 3 | **32** |
| Total | **135** | **19** | **12** | **47** | **213** |

*Dendrology literature.* A review of the existing literature within the field of dendrology revealed that the majority of information available for the selected species is often concerned with the botanical characteristics (including, but not limited to, flower color, cultivars, leaf shape, typical habit, and ultimate size) of a given species. However, the literature also included information regarding the preferred growing conditions [soil moisture, soil typology, soil reaction (pH), sun exposure, and winter hardiness] for optimal growth and most common landscape use, such as groundcover, shrub border, or seaside planting. The information seems to be based on the author's experience and qualitative observations in gardens and arboreta because there is limited transparency regarding other sources for these conclusions. In horticultural settings, a species may exhibit markedly different performance under nonoptimal conditions, frequently observed in urban environments, thus making these conclusions less useful for urban plant use. For example, Dirr (2009) discusses *Euonymus fortunei* and states that a plant in his garden in Georgia exhibited "excellent vigour and good heat tolerance." Additionally, he refers to *Diervilla lonicera*, which "has not demonstrated the same vigour as *D. sessilifolia* in Minnesota Landscape Arboretum tests" or "has exhibited severe chlorosis in some regions of the Midwest, requires acidic soil for optimal growth, as demonstrated robust performance in Zone 7." Another example of this observationally perspective is presented by Bean (1980), who describes the growth of *Ceanothus thyrsiflorus* at Kew as follows: "despite being situated in an unprotected and exposed position, the plant has reached a height of 20 ft and has withstood all but the severest winters uninjured" (Supplemental Table 2 in the Appendix).

Moreover, species' geographical origin and distribution are frequently described in dendrology literature, yet the growing conditions are not always mentioned. For example, Bean (1980) states that *Rhus aromatica* is native to eastern North America, while Krüssmann (1986) expands this to include that it is native to the eastern United States, and that it grows on dry, gravelly stream banks in full sun in its habitat. Practitioners can use this information to assess whether a species has the potential to thrive in a similar habitat in an urban context. However, applying these data in environments and climate zones at different latitudes with varying lengths of growing seasons is not straightforward. Furthermore, the authors do not describe the range of habitats in which the species naturally occurs, which would be a helpful way to understand the ecological amplitude of a species. In this particular literature category, there is a paucity of information regarding the provision of ecosystem services and recommendations for urban environments. This is primarily because this category of literature does not have a tradition of taking a more horticultural perspective with clear recommendations regarding its potential use for urban environments. The paucity of attention accorded to the selection of plants for ecosystem services in this literature is likely attributable to the recent emergence of this perspective within the field of urban ecology. This perspective does not dominate the focus of dendrological literature.

*Nursery catalogues.* All nursery catalogues provided detailed information regarding the botanical characteristics, cold hardiness, soil requirements, and habitat requirements of the species in question. In addition to the information mentioned, Bruns (Bruns Catalogue 2023), Lappen (Lappen Tree Nurseries Catalogue 2023), Ebben (Ebben Nursery Catalogue 2024), and Lorberg (Lorberg Nursery Catalogue 2023) provided further detailed data regarding specific parameters of urban climate, including heat, drought, air pollution, root competition, and salt spray tolerance. Ebben (Ebben Nursery Catalogue 2024) further expands this with information on ecosystem services, describing whether a species is a host or forage plant for bees and butterflies and assigning it a nectar and pollen value. Two catalogues (Bruns Catalogue 2023; Lorenz von Ehren 2023) include comprehensive tables outlining the light requirements, wind tolerance, flooding, suitability for urban and industrial sites, and drought and salinity tolerance of the species under consideration. It was impossible to identify references to other books or scientific articles for most categories in the catalogues under review. In addition, Lorenz von Ehren (2023) includes a dedicated chapter about insect pastures, which presents a comprehensive list of woody plant species that provide nectar and pollen to a diverse range of insects, including bumblebees, wild bees, butterflies, hoverflies, and other pollinators. This chapter presents a list of two species that were the subject of this study: *Spiraea* spp. and *Hydrangea macrophylla*. Additionally, the chapter concludes with a list of references to books and scientific articles.

Notably, none of the reviewed nursery catalogues covered all 10 species under consideration. Indeed, the majority of the sources described only five to six species. Moreover, no nursery included *Abelia zanderi, Ceanothus thyrsiflorus*, *Cistus ×purpureus*, and *Rhus aromatica*. The catalogues under review originate from some of Central Europe's largest woody plant nurseries in Germany or the Netherlands and are located in regions with oceanic or continental climates. Consequently, species cultivated in more Mediterranean environments, such as *Ceanothus thyrsiflorus* and *Cistus ×purpureus*, are not traditionally grown in these regions.

*Scientific articles (mismatch).* The 49 scientific articles with relevant information reviewed provided species-specific details about the stress tolerance of most of the 10 species studied, particularly concerning drought, heat, salinity and pollution tolerance, habitat preferences, and invasive potential. However, no scientific article could be extracted from the Scopus and Web of Science databases for *Cistus ×purpureus*, *Diervilla lonicera*, and *Symphoricarpos chenaultii* when the species were combined with the five keywords.

Most of the scientific articles included in this study addressed a specific stress factor and were limited to a few species. The characteristics observed in these articles are as follows.

- The studies were conducted in controlled laboratory settings or through the creation of ad hoc growing conditions. For example, Tomasella et al. (2022) concentrated on root vulnerability to heat on extensive green roofs for four species. Mårtensson et al. (2016) concentrated on plant survival in Rockwool wall panels for seven species. Dzierżanowski (2011) concentrated on vegetation effectiveness in air purification for seven species. Furthermore, given that most studies are conducted in controlled environments where plants may display different behaviors, the information presented in scientific articles does not always align with that found in books and nursery catalogues. For example, an extensive green roof experiment by Tomasella et al. (2022) identified *Ceanothus thyrsiflorus* as the most vulnerable to heat. This vulnerability was attributed to limited root space, which is a factor not mentioned by other authors in books or nursery catalogues.
- Most articles reviewed use advanced plant physiology and morphology terminology to examine stress tolerance. This scientific lexicon challenges practitioners and landscape architects because these topics are not a core component of landscape architecture education.
- Given the nature of these articles, the information extracted from them is relatively sparse and highly specific to a particular experiment design or a specific stress factor. Consequently, it is not readily accessible or replicable for practitioners working in complex urban environments where numerous stress factors are often present simultaneously. Instead, it is necessary to compare different studies and attempt to compare their experimental design and results to discern any differences between them in terms of their capacity to deliver ecosystem services or tolerance of specific stress conditions.

## Discussion

This systematic review addressed the research questions concerning 10 selected shrub species' resilience and ecological value. Additionally, it aimed to determine whether this type of information can guide practitioners in assessing the suitability of these species for public landscapes. The selection of species-specific information from books, nursery catalogues, and academic articles was based on the following four criteria: tolerance to environmental stresses; provision of ecosystem services; recommendations for use in urban environments; and species' natural habitat.

The typology and abundance of available information could be determined by compiling the findings according to the aforementioned criteria (Table 4). A total of 135 findings were identified from the literature sources consulted about the species' tolerance to environmental stresses, particularly drought, heat, shade, wind, salt, soil compaction, and soil reaction. Forty-seven findings were available for the species' natural habitat category. However, most sources concentrate on the geographical provenance of a given species rather than on the habitat in which this species is native. This provides limited insight into the ecosystems in which the specific species grows, which could provide more detailed guidance about its potential tolerance to, for example, challenging growing conditions. Nineteen findings regarding the provision of ecosystem services were identified for all species under consideration. The shrubs under examination were found to provide several ecosystem services, including erosion control, litter decomposition, air purification, and the provision of insect food. Twelve findings were collated to make recommendations for use in urban environments. However, it should be noted that no acknowledgment was made of the specific site situation, indicating a lack of familiarity with the complex growing conditions that characterize urban environments.

Books and nursery catalogues provide detailed information on plant-related characteristics, including height, width, flower color, winter hardiness, habitat requirements, and additional drought, pollution, and heat tolerance data. However, most books and nursery catalogues do not cite other sources, creating the impression that the information is primarily based on the author's experience and qualitative observations. Furthermore, it can be observed that authors tend to focus their writing on species with which they are familiar, given that they are native, hardy, or commonly planted in the country in which they reside and conduct their research. This is exemplified by Adelman and Schwartz (2017), Hightshoe (1988), and Dirr (2011). Personal experiences are often assessed very subjectively. They are not transferable to other situations, even if this is frequently suggested in this type of literature. In the case of nursery catalogues, it is clear that these businesses want to sell the goods they offer. They have an economic interest and want to maximize the selling of their plants, which could also influence the information they provide.

The review also revealed discrepancies and inconsistencies in species-specific information for numerous species, thereby supporting the hypothesis that the available data are scarce, frequently contradictory, and challenging to collate. For example, concerning *Cistus ×purpureus*, Flint (1929) states that the plant thrives when cultivated on well-drained soil in full sun. However, Krüssmann (1982) classifies it as a plant for clay soil, which is not typically a well-drained substrate. Regarding *Euonymus fortunei*, Kelly and Hillier (1995) states, "They exhibit remarkable tolerance with regard to soil conditions." These plants can thrive in conditions that are less than optimal and are particularly well-suited to growth in shallow, dry soils over chalk. They display an unusual tolerance to soil compaction and thrive near pathways. However, Lorenz von Ehren (2023) asserts they are "highly susceptible to soil compaction; intolerant of heat and drought." Furthermore, Ebben (Ebben Nursery Catalogue 2024) states that the plant tolerates salt spray, pollution, and dryness, while Davis (1987) adds that it will tolerate dry conditions once established.

More detailed and transparent studies focusing on the physiological tolerance of different species and ecotypes to drought, for example, will clarify the exact capacity of a species to withstand the environment and avoid qualitative and observation-based conclusions. Nevertheless, the challenge persists in establishing a correlation between these meticulously controlled studies and the often intricate growing conditions prevalent in urban environments. This correlation is paramount for properly aligning shrubs with their optimal locations and functional purposes.

In the case of *Hydrangea macrophylla*, Davis (1987) posits that the plant prefers full sun, citing that it "spoils shape and reduces flowering" when subjected to deep shade. Conversely, Gorer (1976) asserts that while the plant thrives in full sun, it can tolerate semi-shade, albeit with a diminished flowering frequency.

With regard to *Rhus aromatica*, Hightshoe (1988) asserts that it is highly intolerant of shade. However, Krüssmann (1982) suggests it may be cultivated on gravel and shaded or north-facing slopes. The available information on *Symphoricarpos chenaultii* does not indicate the optimal growing conditions for this species. McIndoe (2019) describes it as "tough and versatile, adapting to most growing conditions, apart from hot and dry," while Stoecklein (2011) categorizes it as a plant for dry soil, a plant for wet soil, and a drought-tolerant plant.

While books and nursery catalogues occasionally mention the geographical distribution of a species, they seldom describe the actual growing conditions and the range of habitats and edaphic conditions where these species naturally occur. This lack of detail impairs the practitioner's ability to ascertain whether a given species can tolerate a dry urban location.

The prevalence of laboratory and controlled conditions tests used in scientific articles to assess plant adaptability underscores discrepancies in plant behavior between books and scientific publications. For instance, the study by Tomasella et al. (2022) indicates that *Ceanothus thyrsiflorus* is susceptible to high temperatures during the summer months in extensive green roof systems, even when irrigation is provided. However, this is not reflected in all the literature and contradicts some authors, with Forrest (2006) classifying it as drought-tolerant and requiring dry sites with good drainage. Furthermore, Kelly and Hillier (1995) indicates that this species is not well-suited to hot, shallow soils and is native to the chaparral at elevations where the climate is considerably chillier than on the coastal plain below.

Scientific articles generally focus on a single or limited set of stress factors for a few species in a controlled environment. Consequently, while helpful, the results of these tests do not necessarily reflect how a species might perform in an unpredictable urban climate where multiple stress factors coexist. This represents a limitation for practitioners when using these results in complex real-world conditions. Nevertheless, understanding the plant's reaction to a single stress factor, for instance, a species' response to drought, in an isolated test may assist in excluding other stress factors, such as wind, salt, or flood stress, which may coexist in real urban scenarios.

A further evident conclusion from the literature examined is that the acknowledgment of intraspecific variations in a species' drought tolerance is either absent or overlooked. In a study by Sjöman et al. (2023), the water potential at leaf turgor loss of different genotypes of shrubs was evaluated; among them, six different genotypes of *Spiraea japonica*, which exhibited a significant difference in their capacity to tolerate drought. This illustrates the significance of an intraspecific comprehension of the divergence between disparate genetic types of a single species. The literature reviewed in this study characterized the different species as a unified group with analogous traits, although among the species in the study, there is a considerable divergence in the climates and plant environments from which they originated and where distinctive evolutionary traits evolved. A significant avenue for future research is to study and evaluate different genetic types of the same species to understand a species' capacity to handle challenging environments, such as hot and dry conditions. This research would enable the development of more accurate selection criteria for the appropriate genetic material for a given location and climate.

The challenge of identifying suitable guidance for selecting low-growing shrubs in urban environments is that the information derived from scientific studies, including controlled greenhouse experiments, is often difficult to link directly to the city's diverse growing conditions and microclimates. To fulfil the requirements of a scientific approach, the experiments are sometimes simplified to such an extent that they have no relevance for actual use in an urban context. Moreover, these studies require a high level of expertise in translating the results, including a comprehensive understanding of plant physiology, forestry, plant anatomy, and statistical models. This expertise is not commonly found among landscape architects or garden designers. The literature that most closely aligns with the utilization of plants in urban environments comprises nursery catalogues (sales arguments) and literature directed at plant use, with a more divided guide to different types of situations with their unique plant conditions. Nevertheless, this literature remains too generalized, offering vague conclusions such as "drought-resistant" or "sensitive" without providing detailed insight into the specific characteristics that make them resistant or sensitive.

Moreover, it is particularly limited in its scope for more untraditional species, whereby observation-based recommendations are often scarce because of their relatively recent introduction and utilization in a diverse range of contexts and climates. A type of information that is rarely available within the urban forestry community and seldom considered in the design of public green environments is trait-oriented plant selection (Watkins et al. 2021), which considers the evolutionary properties that different species have developed to handle the growing conditions and competition for resources in their natural environment. Ecological traits are plant characteristics that fulfil ecophysiological purposes (functional traits) and explain how the environment impacts an organism's physiology or describing ontological stages (life history traits). They are used for various purposes, including assessments of plant growth, ecosystem services, and interactions between plant individuals and communities. A large body of literature has emerged from the different schools of trait ecology (Díaz et al. 2016; Franco and Silvertown 2004; Kunstler et al. 2015; Salguero-Gómez et al. 2016), and the links between these schools comprise an area of active research (Adler et al. 2013; Laughlin 2023; Struckman et al. 2019). If correctly and consistently interpreted, functional traits could provide plant users with critical guidance about how and where different species are thriving, thus making it possible to predict the development of species under varying growing conditions because they explain why and how certain species are successful in their natural environments.

The challenge is integrating these trait-related perspectives while selecting and using plants in urban environments in a future climate. This will necessitate research activities that facilitate the conversion of different trait-related aspects into unique urban planting environments, with an understanding of how the distinctive investment priorities of different species align with urban locations. This perspective also allows for quantifying the capacity of different species to cope with various stressors, such as heat and drought. This enables a shift away from the current situation, where guidance is predominantly qualitative and based on observation, leading to numerous contradictions. This, in turn, hinders the utilization of more unconventional species or increases the risk of forcing plants into conditions that may not support their long-term growth and development. The approach of integrating trait-related research with the selection of plants for urban environments is gradually gaining traction in the context of trees (Tamene et al. 2024; Watkins et al. 2021). However, this perspective is currently absent from site-related research of shrubs, although it has the potential to become a significant and influential area of investigation.

Our study aimed to include and screen a comprehensive range of materials that influence and guide the selection of shrubs for the often challenging conditions in urban landscapes. By including nonscientific publications along with peer-reviewed research literature, our study helps to provide a holistic understanding and highlight potential discrepancies between research and real-world practice. This also deepens the exploration, thus helping us to gain a better understanding of the information that influences how professionals view and interact with available data, such as popular textbooks and nursery catalogues, which are often more accessible to practicing professionals than scientific articles. If we only included scientific publications, then we would not capture the real-world context of what may govern shrub selection practices and how these practices may align with planning policies regarding, for example, ecosystem services and nature-based solutions.

## Conclusion

This review revealed that there is a large body of information available across the literature; however, it also showed that the majority of this information is often very generic and concerned with botanic characteristics (dendrology literature) or too focused on a specific stress factor in a controlled environment (scientific literature) to fully support practitioners in selecting shrubs for dry locations. Most of the information extracted from the literature concerns tolerance to environmental stresses of plants growing in gardens and arboreta, particularly drought, wind, salt, soil reaction, and light conditions. Only very few findings describe the species' natural habitat, the provision of ecosystem services, or recommendations for use in urban environments, clearly showing a knowledge gap in guiding practitioners working in complex urban contexts, which are very different and are characterized by more challenging growing conditions than botanical or private gardens. Moreover, books directed at plant use, nursery catalogues, and dendrology literature do not explicitly refer to the location where the experience is gained nor refer to other studies or books, giving the impression that the info is based on the author's knowledge and qualitative observations. The review revealed that the information found was generally sparse, somewhat contradicting, and challenging for practitioners to compile. The lack of uniformity of data and its anecdotal nature across the professional literature further poses a challenge for practitioners.

This study also highlighted the need for future studies to evaluate different genetic types of the same species to understand a species' capacity to handle challenging environments holistically. Furthermore, because of the difficult growing conditions found in cities, there is a need to select plants attentively by also considering their distinctive functional traits. These traits are plant characteristics that can explain why different species are successful in their natural environment and what evolutionary strategies they have adopted to do so successfully. Functional traits are morphological, biochemical, physiological, structural, or phenological characteristics that are expressed in phenotypes of individual organisms and are considered relevant to the response of such organisms to the environment and their effects on ecosystem properties (Violle et al. 2007). To achieve long-lasting planting schemes, it is crucial to align the plant's specific traits with the unique characteristics of each urban planting environment to ensure that the selected species can cope with the on-site conditions.

In summary, to support practitioners in making correct choices when selecting shrubs for dry urban environments, there is a need for the following:

- Expand the knowledge base about the stress tolerance and adaptability of uncommon resilient shrubs that can withstand future unpredictable dry growing conditions.
- Use standardized scientific methodologies to obtain quantitative interspecific and intraspecific stress tolerance data, creating a reliable source of information for practitioners to support their plant selection.
- Find a balance between the requirements of a scientific approach and the relevance of actual use in an urban context.
- Develop a trait-oriented selection methodology by matching plant physiological, phenological, and morphological features, which influence their performance, survival, growth, and reproduction with the distinctive aspects of each urban site.
- Encourage a terminology practitioners can understand and support a practitioner perspective when publishing the knowledge in books and scientific articles.
- Expand experience-based information on shrubs' stress tolerance in cultivated locations and the wild by assessing the range of habitats where a species naturally grows and can be cultivated, advancing the understanding of a species' ecological amplitude, namely, the range of environmental conditions within which a species can survive and function.

Furthermore, there is a need for more proactive collaboration between landscape architects, plant nurseries, researchers, and urban authorities to facilitate the mutual exchange of knowledge and encourage the selection, propagation, study, and use of unusual resilient shrub species that can withstand harsh urban locations. This collaboration could be facilitated by creating an international online platform in English where all information from different sources is compiled for each species, with examples for trees (Hirons and Sjöman 2019), while similar ones for shrubs are absent. This platform would allow academic research to be directly connected with the practice and inform growers and designers about new studies and what species are promising for future cultivation and use. Ultimately, this online platform would support the mutual exchange of knowledge among all professionals while ensuring the long-term resilience of the future shrub population in cities by providing everyone access to comprehensive and reliable qualitative and quantitative assessments of species stress tolerance.

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