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Abstract

In Chile Santiago, urban plants are highly vulnerable to drought, as they are mainly exotic from the northern hemisphere with temperate origins. We hypothesize that, although species may generally differ in their response to water restriction, we would find high growth and survival rates among native species of central Chile. The goal was to determine the effect of the year season and an irrigation gradient on the growth and survival of native plant, in order to evaluate potential plant for use in urban green areas of central Chile. Four plots of 20 m² were located in the Santiago center. In June 2024 twelve species were planted and from November 2024 to March 2025 were irrigated with 13.3, 10.1, 1.7 and 1.4 L/m²/day in each o the lots. The GLM and Kaplan-Meier survival analyses were used. Shoot growth rate was highly variable among species, among irrigation treatments applied, and among year seasons. Eight species shown water-related growth and shoot growth during the winter was very small and higher in spring. Two species showed evidence of water-related survival; in the other 10 species, no significant differences were found between irrigation treatments. Winter was the season with the highest survival rates for eleven species. In conclusion, the evidence suggests that using native species with low water requirements is an effective and efficient way to use water in the urban green area of central Chile.

Keywords: urban plant; native plant; plant survival; plant growth; water use; central Chile

1. Introduction

Urban vegetation is known to improve air quality, ameliorate summer heat island temperatures, lower cooling costs [1], reduce storm water runoff [2], reducing atmospheric carbon dioxide [3], and improves various indicators of social and individual development among residents [4–8]. Urban populations have a very positive average opinion of urban vegetation, particularly valuing its shade, aesthetics, air quality, and noise reduction [9].

The lack of vegetation in central Chilean cities (e.g. only 5.7% of Santiago's population has access to >9 m² green space/inhabitant) is accentuated by the unsustainable design of urban areas [10], and characterized by high maintenance and irrigation demands and driven by the selection of plant species that are not adapted to regional urban conditions (soil, atmosphere, water, nutrients). Urban vegetation in cities in central Chile is also deteriorated and stressed by climate change [11], along with adverse growing conditions including compacted soil, extreme heat, lack of nutrients, drought, damage from cars, pruning, and vandalism [12]. Any plan for the development or replacement of urban vegetation in the region should thus be based on experimental evidence in real urban areas, at least considering the survival and growth of potential urban plants. Unfortunately, experimental

studies with native species are not common in urban areas located in the Mediterranean-type climate region of central Chile.

Vegetation survival and growth in an urban setting depends on planting location, installation, and post-planting care, between others [13,14]. For example, the most common environmental conditions influencing urban tree mortality are related to water stress, nutrient deficiency, and soil compaction [15,16]. Plant species that successfully colonize and persist in public areas would likely possess traits for stress-tolerance or avoidance. In seasonally dry ecosystems, such as those of central Chile, water is the limiting factor for vegetation growth and survival [17]. It is important to know which species persist and how plant communities change over time so that urban area can be designed to support urban biodiversity for future generations.

Due to the variability in urban tree care during and after planting, it is important to choose plant species with a high chance of survival and growth, and with minimal supplemental care required after installation [18]. Published studies have primarily focused on urban trees' survival and growth, and the majority of research about urban tree success comes from experiments conducted in relatively controlled nursery settings rather than in sites exposed to urban tree environments. However, other living forms such as urban herbs and shrubs can provide diversity and functionality to urban ecosystems, while survival and growth are conditioned by the urban habitat.

A study of this characteristic has important implications for urban species selection in a changing climate. Cities located in Mediterranean-type climates are particularly vulnerable to climate change. Mainly are predicted to face reduced annual precipitation, temperature increase, and intensified rainfall events [19]. In Santiago, Chile, urban trees are highly vulnerable to drought, as they are mainly exotic species that not adapted to water scarcity, forcing municipalities to use potable water for irrigation [20]. Assessing tolerance or resistance to climate change for potential urban plants helps architects and urban landscape designers select plants suited to a city facing water scarcity [21].

In this study, we estimated the survival and growth rates of seedlings over 10 consecutive months through seasonal monitoring of 12 potential native species of central Chile for use in urban green infrastructure in Santiago. For the analyses, the cumulative survival rate and the growth index of the shoot per season of the year were used for each species tested. These indicators are widely used in demography and population ecology.

We hypothesize that, although species may generally differ in their response to water restriction, we would find high survival rates among native species in central Chile during the first year of the trial in an urban area. The main purpose of the study was to determine the effect of the season and an irrigation gradient on the growth and survival of native species in order to evaluate potential plant species for use in green areas in Mediterranean-type climate cities in central Chile.

2. Results

2.1. Shoot Growth

Shoot growth varied among species (**Figure 2**A). The species with the highest average growth during all the study period were the shrubs *Baccharis linearis* (16.7 ± 1.8 cm), *Andeimalva chilensis* (14.3 ± 1.1 cm), *Sphaeralcea obtusiloba* (12.0 ± 1.6 cm), and the tree *Vachelia caven* (13.0 ± 1.8 cm). At the opposite end of the spectrum, the woody *Cistanthe laxiflora* (0.6 ± 1.3) and the succulent herbs *Puya alpestri* (2.9 ± 1.8 cm) and *P. coerulea* (2.0 ± 1.9 cm) showed the lowest average growth of the species studied during the study period. The average growth of woody species (9.5 ± 0.6 cm) during the study period was higher than that of non-woody species (3.3 ± 0.8 cm), with a significant difference between both (F = 37.98; $p < 0.001$).

Shoot growth rate varied among the irrigation treatments applied in the 66.6% of the evaluated species (Table 1). In particular, in all species which showed evidence of water-sensitive growth, individuals subjected to a higher irrigation volume tended to show greater shoot average growth. Overall, the combined water-sensitive growth species in the treatment with higher irrigation (average

9.9 cm throughout the test) was > 50% higher than the combined water-sensitive growth species in the treatment with lower irrigation (average 3.3 cm throughout the test).

Table 1. Shoot growth index (±1 E.D.) and survival rate (final %) for each irrigation treatment applied to the 12 species of native plants from central Chile tested in the experimental plots. N = total number of individuals tested per species. Note: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; n.s. = $p > 0.05$.

Species	N	Dependent variable	13.3 L/m²/day	10.1 L/m²/day	1.7 L/m²/day	1.4 L/m²/day	*p*-Value	Responses
Cistanthe laxiflora	45	Growth	2.0 (1.4)[a,b]	2.8 (1.4)[a]	0.4 (1.4)[a,b]	-3.2 (1.4)[b]	*	Highly sensitive
		Survival	83.3[a,b]	100[a]	91.7[a,b]	75.0[b]	*	
Nasella laevissima	48	Growth	7.4 (1.2)[a]	10.5 (1.2)[a]	7.9 (1.2)[a]	0.9 (1.2)[b]	***	Highly sensitive
		Survival	83.3[a,b]	91.7[a,b]	100[a]	66.7[b]	*	
Andeimalva chilensis	72	Growth	22.3 (3.3)[a]	17.7 (3.3)[a]	5.6 (3.3)[b]	11.6 (3.3)[a,b]	**	Sensitive
		Survival	83.3	72.2	61.1	83.3	n.s.	
Colliguaja odorifera	24	Growth	10.7 (2.1)[a]	5.0 (2.1)[a,b]	1.4 (2.1)[b]	3.5 (2.1)[a,b]	*	Sensitive
		Survival	100	100	83,3	100	n.s.	
Puya alpestri	24	Growth	5.6 (1.1)[a]	3.6 (1.1)[a,b]	1.2 (1.1)[b]	1.3 (1.1)[b]	*	Sensitive
		Survival	100	100	100	100	n.s.	
Puya coerulea	23	Growth	3.8 (0.8)[a]	3.6 (0.8)[a]	0.02 (0.9)[b]	0.02 (0.9)[b]	**	Sensitive
		Survival	100	100	100	80	n.s.	
Senna cumingii	35	Growth	11.0 (2.2)[a]	4.1 (2.3)[a,b]	-0.4 (2.2)[b]	4.7 (2.2)[a,b]	**	Sensitive
		Survival	88,9	75,0	77,8	100	n.s.	
Vachelia caven	24	Growth	16.7 (2,7)[a,b]	21.6 (2.7)[a]	6.2 (2.7)[b]	7.3 (2.7)[b]	***	Sensitive
		Survival	100	100	100	100	n.s.	
Baccharis linearis	24	Growth	15.3 (2.1)	19.5 (2.1)	19.5 (2.1)	12.4 (2.1)	n.s.	Non-sensitive
		Survival	100	100	100	100	n.s.	
Balbisia peduncularis	36	Growth	8.1 (2.7)	3.1 (2.7)	7,6 (2.7)	6.2 (2.7)	n.s.	Non-sensitive
		Survival	77.8	66.7	100	100	n.s.	
Encelia canescens	47	Growth	0.9 (2.9)	4.1 (2.9)	5.4 (2.9)	2.9 (3.1)	n.s.	Non-sensitive
		Survival	41.7	58.3	75.0	63.3	n.s.	
Sphaeralcea obtusiloba	32	Growth	13.9 (3.0)	16.0 (3.5)	7.9 (3.0)	11.2 (3.0)	n.s.	Non-sensitive
		Survival	100	100	87,5	100	n.s.	

The woody *Cistanthe laxiflora* (-3.2 ± 1.4 cm), the herb *Nasella laevissima* (0.9 ± 1.2 cm), the succulents *P. alpestri* (1.3 ± 1.1 cm) and *P. coerulea* (0,02 ± 1.1 cm) showed very low average growth in the lowest irrigation volume treatment (Table 1). In fact, *C. laxiflora* and *S. cumingii* stand out because they were the species that showed negative growth in response to the lowest water treatments of 1.4 L/m²/day and 1.7 L/m²/day, respectively (Table 1).

The remaining four species were *Baccharis linearis*, *Balbisia peduncularis*, *Encelia canescens*, and *Sphaeralcea obtusiloba*. They did not exhibit water-sensitive growth, and there was no statistical difference in shoot growth between the applied irrigation treatments (Table 1).

Shoot growth was highly variable among year seasons in all the species tested (Table 2). In the 12 species, shoot growth during the winter season was very small, it was even negative in *E. canescens* (F = 12.25; $p \leq 0.001$), and in *S. obtusiloba* (F = 19.65; $p \leq 0.001$) although without differences among treatments in both species (Table 2). However, spring was the most productive season, except for the tree *V. caven* (**Figure 1**A), which grew faster in summer (F= 20.31; $p < 0.001$). In contrast, growth in *C. laxiflora* decreased significantly and was negative during the summer (F= 10.09; $p < 0.01$). The combined growth of the 12 species was also significantly higher in spring than in winter or summer (F = 52.53; $p < 0.001$). A similar pattern, although more pronounced, was found when comparing woody species with non-woody species combined (**Figure 1**B, Table 2).

(**a**)   (**b**)
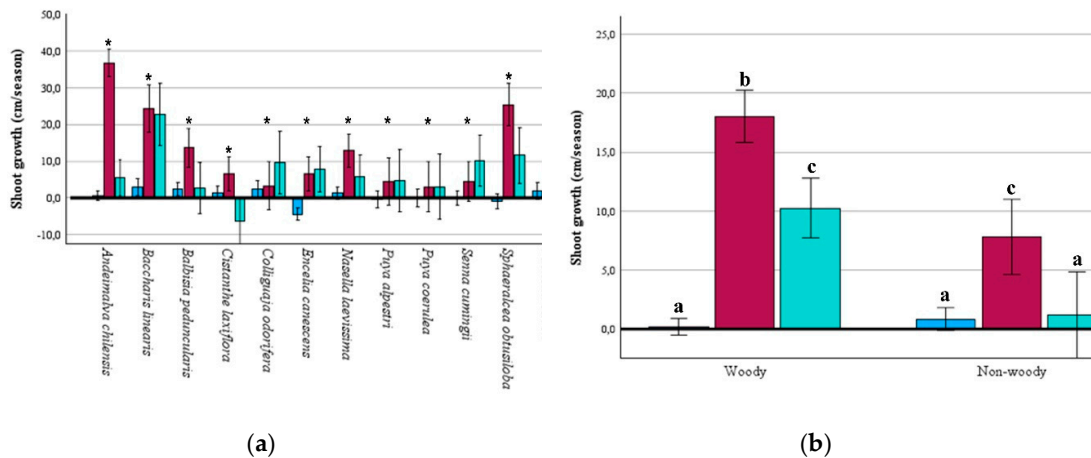
Figure 1. (**a**) Shoot yield index for winter, spring, and summer seasons in 12 native plant species from central Chile. Bars represent ±1 E.D. * indicate statistically significant differences among seasonal for each species assessed according to Bonferroni test (p ≤ 0.05); (**b**) Shoot yield index for winter, spring, and summer seasons for woody and non-woody species combined. Bars represent ±1 E.D. Different letters (a-c) above the bars indicate statistically significant differences among seasonal according to Bonferroni test (p ≤ 0.05).

Table 2. Generalized linear model of repeated measures results showing the effect Intra-subject, contrast Intra-subject and of the four irrigation treatments on the growth index by performing Inter-subject tests. N = total number of individuals tested per species. Note: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; n.s. = $p > 0.05$.

		Effect Intra-subject				Contrast Intra- subject				Effect subject	Inter-subject
		TIME		TIME × TREAT		TIME		TIME × TREAT		TREAT	
Especie	**N**	F-Value	*p-*Value	F-Value	*p-*Value	F-Value	*p-*Value	F-Value	*p-*Value	F-Value	*p-*Value
Andeimalva chilensis	72	41.43	***	4.00	**	79.58	***	5.37	**	4.78	**
Baccharis linearis	24	36.96	***	2.61	*	63.80	***	2.67	n.s.	2.68	n.s.
Balbisia peduncularis	36	7.71	**	1.62	n.s.	17.03	***	1.71	n.s.	0.70	n.s.
Cistanthe laxiflora	45	10.09	**	0.29	n.s.	10.24	**	0.11	n.s.	3.61	*
Colliguaja odorifera	24	4.34	*	3.21	*	6.04	*	4.88	*	3.80	*
Encelia canescens	47	12.25	***	0.97	n.s.	20.26	***	0.57	n.s.	0.74	n.s.
Nasella laevissima	48	30.19	***	3.53	**	33.20	***	0.34	n.s.	11.33	***
Puya alpestri	24	13.82	***	5.74	***	18.74	***	5.48	**	3.55	*
Puya coerulea	23	7.71	**	2.60	n.s.	18.19	***	6.30	**	6.10	**
Senna cumingii	35	7.59	**	2.33	n.s.	10.35	**	2.37	n.s.	4.71	**
Sphaeralcea obtusiloba	32	19.65	***	3.38	**	27.26	***	5.06	**	1.2	n.s.
Vachelia caven	24	20.31	***	4.59	**	47.77	***	6.92	**	7.59	**
Non-woody	140	21.03	***	1.45	n.s.	34.11	***	0.09	n.s.	8.63	***
Woody	294	63.15	***	8.27	***	46.97	***	7.44	***	5.73	***

2.1. Species Survival

The final cumulative survival rate for the 12 species combined averaged at 85.9%. At one extreme, *B. linearis*, *P. alpestri*, and *V. caven* had a final cumulative survival rate of 100% (**Figure 2**A). At the other extreme, the species *A. chilensis* and *E. canescens* achieved a final cumulative survival of 75.0% and 59.6%, respectively (**Figure 2**A). Even *E. canescens* achieved a statistical survival rate lower than *A. chilensis* ($\chi^2 = 4.56$; $p = 0.033$) and, consequently, lower than all the species tested. The rest of the 10 species showed a cumulative final survival rate of at least 85.4%.

The 12 species showed survival rates above 80% in each season monitored (**Figure 2**A). Winter was the season with the highest survival rates for all species except *E. canescens*. Ten species showed 100% survival during winter (**Figure 2**A). The species *C. odorífera*, *P. coerulea*, and *S. obtusiloba*

achieved a final survival rate of 100% in at least two seasons (**Figure 2**A). Four species had a final survival rate of 100% during the summer: *B. linearis*, *P. alpestri*, *P. coerulea*, and *V. caven*.

The combined non-woody species had better survival rates during winter and summer as well, while the combined woody species had higher survival rates only during winter (**Figure 2**B).

On the other hand, only 2 species showed evidence of water-sensitive survival (Table 1). The species *C. laxiflora* and *N. laevisima* showed statistically lower survival rates in the lower irrigation treatment (1.4 L/m²/day). In the other 10 species tested, no significant differences were found between irrigation treatments.

No evidence was found that shoot growth rate was associated with the final survival rate or the survival rate achieved according to the irrigation treatment applied to the species tested.

(**a**)   (**b**)
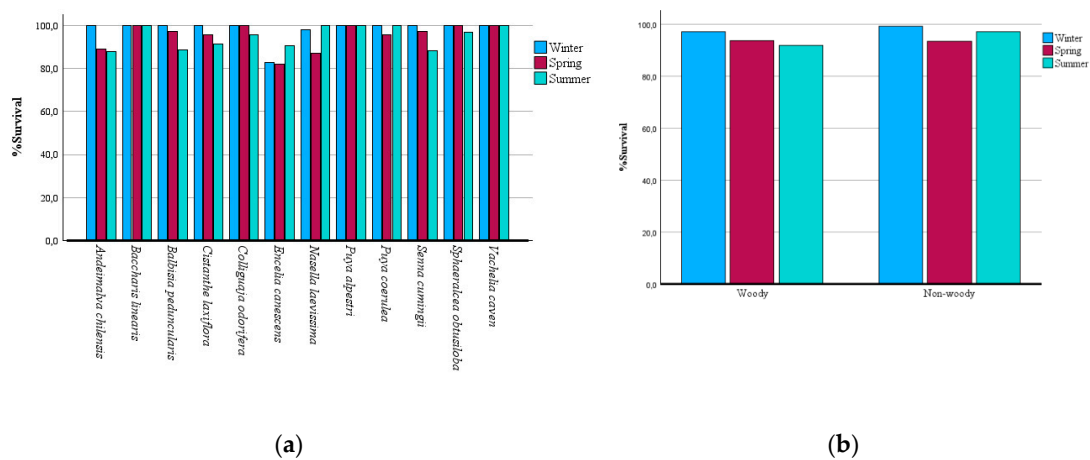
Figure 2. (**a**) Survival percentage during for winter, spring, and summer seasons in 12 native plant species from central Chile; (**b**) Survival percentage for winter, spring, and summer seasons for woody and non-woody species combined.

3. Discussion

Vegetation in public areas of cities has emerged as a key component of nature-based solutions in socio-ecologically stressed urban environments, although the biogeographical origin of its components has not been sufficiently emphasized in central Chile [36]. Several studies of Mediterranean-type climate regions around the globe suggest that native species should be preferred because they contribute more to ecosystem functioning and the ecological integrity of urban environments, and provide a greater number of ecosystem services [37–41]. Additionally, it could be crucial to select native species not only for their ecological features, but also having evolved in particular habitats characterized by summer drought stress similar to those present in the urban area of central Chile [42]. This further inclusion could greatly expand the number of plants potentially suitable for growing in cities with Mediterranean-type climates. The present study fits within this conceptual framework.

In regions with a Mediterranean-type climate, methodologies have been designed to identify potential native species that are not used in various urban vegetation contexts. These methodologies use bibliographic information on the species ecology, distribution, and performance in their natural conditions [43]. At first approach, this is an appropriate strategy for defining the potential components of urban vegetation that should be selected. However, it should not be forgotten that experimental evidence should also be gathered in the contexts of diverse urban habitats [44].

One set of evidence comes from assessing the condition and health of historic vegetation in different areas of the city [45]. A second set comes from managing and monitoring vegetation from the moment an urban green area is implemented, even if it was not considered an experimental design from the outset [46]. This study is closer to the second group, as it sought potential native

species to be used in public areas in experimental urban contexts in a central Chile city. Although published information on native species from central Chile was used for an initial selection of potential species (see Table 3), the plants were then subjected to an experimental procedure to evaluate their performance in real urban conditions.

The results of this study showed that the irrigation gradient tested did not affect survival in 83% of the potential native species selected for use in urban areas of central Chile. The result is consistent with studies of Mediterranean species in natural conditions, where survival differences due to irrigation are not always observed, probably because these species have low water requirements [47–49]. In fact, the results show that overall final survival is greater than 80%, with the exception of the *E. canescens* shrub. It should be noted that the first year is a bottleneck for urban plant survival, due to the stress suffered by individuals during their transfer and transplantation, including the effects of environmental pollution [13,50]. Our results even showed that survival was high after summer water stress.

On the other hand, the results showed that shoot growth in the tested species was highly variable between species (**Figure 1**A). They also showed that approximately 66% of the species studied were significantly affected by the irrigation gradient. However, all species studied had shoot growth practically stop during the winter season regardless of the treatment applied (**Figure 1**A). The highest shoot growth in woody and non-woody species was in the spring season (**Figure 1**B).

Consequently, the research shows that the species studied exhibit temporal variation in their water behavior patterns consistent with species from Mediterranean-type climates, characterized in central Chile by a winter influenced by the polar jet stream, numerous frosts with snow at higher elevations, an extended period of summer drought, and high interannual variability and temperatures [51]. Results show that these plants stop or slow down shoot growth during the winter and summer seasons, respectively. However, survival was not significantly affected in both seasons. According to the literature, cold ocean currents on the west coast of Mediterranean-type climate regions moderate temperatures, allowing survival and plant growth in the late winter and early spring [22].

Although this topic needs to be studied in greater detail, growth during winter 2024 was probably affected by low temperatures, since the year was particularly cold in central Chile [52]. According to the experimental design, during winter the plots did not receive additional irrigation. The plots were not watered until late spring (November and December) and maintained during the winter with the water that initially saturated the soil and with the natural rainfall and atmospheric humidity regime. Water availability and the water potential of the soil and atmosphere were thus very similar across all experimental plots and sufficient for plant survival at the beginning of spring (**Figure 3**). Slightly above-zero growth during winter in this study is therefore likely due to low temperatures.

The results of this study showed that only the herb *N. laevissima* and the shrub *C. laxiflora* presented highly water-sensitive responses, as both growth and survival were significantly affected (Table 1). In fact, growth was negative in *C. laxiflora* and zero in *N. laevissima*, and in both species, survival was lower in the treatment with less water availability (Table 1, Table 2). Both species concentrated their shoot growth during the spring, and the results even show that *C. laxiflora* suffered significant self-thinning during the summer. ROS (Reactive Oxygen Species) analyses, which were carried out in parallel with this study, indicate potential oxidative stress in the herb *N. laevissima* in midsummer for low irrigation treatments (unpublished data). The environmental stress suffered by this species could explain its low abundance in natural conditions in the Metropolitan Region of central Chile [53] and its displacement by exotic annual plants that use water more efficiently [54]. On the contrary, the same ROS analysis shows the absence of oxidative stress in the *C. laxiflora* shrub in any of the treatments applied during the same period of the year, probably due to the decrease in both the transpiration surface area and water loss suffered by the species during this period of greater water stress [55]. However, *C. laxiflora* survival was negatively affected (**Figure 2**A), probably due to a decrease in the photosynthetic area caused by self-thinning during the summer.

The results of this study also showed that 50% of the species studied were water-sensitive, as only growth was significantly affected by the treatments applied (Table 1). These species are characterized by high survival rates, which are not affected by the irrigation gradient applied. However, growth was practically stopped in low irrigation conditions, especially during winter.

The succulent herbs *P. alpestri* and *P. coerulea* stand out in this group, as they have adapted their photosynthesis to avoid water stress in the summer [56]. Although the results showed that the species were water-sensitive growth, practically stopped in both species when the plants were subjected to 1.7 and 1.4 L/m^2/day, however survival was 100% in all treatments (Table 1). This pattern demonstrates the ability of both succulent species to colonize sites exposed to solar radiation (Table 3) and to avoid water stress in the summer [56]. Even during this season, H$_2$O$_2$ levels associated with water stress are normal in both succulents of this study (unpublished data). However, during the winter, growth was zero in both species, probably indicating stress levels due to cold weather events and good resistance to the same phenomenon, as the average survival rate was close to 100%. A pattern very similar to that found in *P. alpestri* and *P. coerulea* can be seen in the shrubs *S. cumingii*, *B. linearis*, and in the tree *V. caven*. The plants of *S. cumingii* have deep roots that perform hydraulic lifting, allowing them to reach more humid soil layers and move water to dry surface layers, thus avoiding water stress during the summer [57,58]. However, we can also see that summer is the season with the highest mortality rate and the season with the highest growth rate in urban areas as well. With regard to *V. caven*, a dominant species of thorny shrubland [59] and represented in the native urban flora of central Chile [20], research shows high survival rates throughout the year, although growth has been limited under severe water restrictions. On the other hand, unlike *S. cumingii*, in the tree *V. caven* there is no differentiated use of water within the root zone, but rather constant activity to capture the water available at a depth of 100 cm [60]. The last representative of the species water-sensitive is *B. linearis*, which develops shallow roots. This shrub is suitable for colonizing barren soils and remediating soils contaminated by mining [61], making it an attractive candidate for rehabilitating urban soils with abundant fill.

Analysis of the results also detected a group of four potential species that were not water-sensitive to the treatments applied and showed high survival rates, with the exception of *E. canescens* (Table 1). This shrub from arid regions showed a very low survival rate during winter and spring (**Figure 2**A), which could not even be reverted with the increased water availability in the irrigation gradient applied (Table 1). Interestingly, the literature shows that *E. canescens* is a common species that is resistant to low water availability [62]. It is suggested that plants from more arid areas with similar behavior could benefit from the establishment of seedlings in shaded environments, although this hypothesis would need to be evaluated more precisely [18,63]. The ROS analysis for *E. canescens* was consistent with the results for survival and shoot growth in the water gradient (Table 1) because it showed potential oxidative stress during the summer in all treatments, and was even reinforced in the plot with low water availability. The low survival rate of *E. canescens* during winter is probably due to frost stress, which cannot be reversed and recovered from before the onset of summer water stress in plots that are completely exposed to solar radiation. In contrast, although the *S. obtusiloba* shrub also showed oxidative stress during the summer, which was intensified in the low irrigation treatment (data not shown), its survival rate was high with growth not stopping under any water conditions. In this species, there is probably a mechanism associated with secondary metabolites such as proline, sugars, or antioxidants to prevent water stress, which should be evaluated in further studies (Claudia Ortiz-Calderón, pers. comm.).

The last water-insensitive species, the shrub *B. peduncularis*, reduces its water deficit after the application of more irrigation in the summer season. The reviewed literature estimates that *B. peduncularis* responds efficiently to increases in surface water availability and is therefore dependent on rainfall and surface soil moisture [64].

These types of studies must consider the importance of both current environmental conditions and future climate scenarios in areas undergoing urbanization in central Chile. We selected a group of species that are not only found in the central Chilean Mediterranean-type climate region, but also

in more arid areas in northern Chile. Biodiversity in Mediterranean climate areas is particularly susceptible to global change [65]. Urban vegetation proposals should not only improve the adaptability of urban green infrastructure in a changing environment, but also contribute to the broader goals of biodiversity conservation in a particularly vulnerable and endangered Mediterranean-type area [65–67].

Table 3. Plant species from central Chile selected for the study, indicating family affiliation, life form, and environmental, aesthetic, cultural, and management criteria considered in the potential landscape value of the species for use in urban vegetation in central Chile. Information obtained in [29–32].

Species	Family	Life form	Criteria			
			Environmental	Aesthetic	Cultural	Management
Cistanthe laxiflora	Montiaceae	Perennial herb	Endemic. Tolerant of saline soils, poor in nutrients, and low moisture. Flowers attract native pollinators	Pink fuchsia flowers in spring and summer	No information	Plant in full sun in association with many species
Nasella laevissima	Poaceae	Perennial herb	Endemic. Tolerant in low-moisture soils and poor in nutrients and eroded.	Species with diverse shapes, colors, and subject to the wind	No information	Plant in full sun. Fast growth rate
Andeimalva chilensis	Malvaceae	Shrub	Endemic. Tolerant of saline soils, poor in nutrients, and low moisture. Attracts a diversity of floral fauna.	Extensive pink coloration and attractive appearance of flowering	No information	Plant in full sun, tolerates pruning, and resistant to pests and diseases
Colliguaja odorifera	Euphorbiaceae	Shrub	Endemic. Tolerant in low-moisture soils and poor in nutrients.	Edges of leaves and flowers are reddish in color. Ballistic seed dispersal	Medicinal. Insecticide. Dyeing. Handcrafted	Plant in full sun. Fast growth rate, resists pruning
Puya alpestri	Bromeliaceae	Perennial herb	Endemic. Tolerant in low-moisture soils and poor in nutrients. Attracts hummingbirds and butterflies	Attractive colors, textures, structure, and shapes of the plant. Flowers in spring and fruits in summer	Edible	Plant in full sun and resists pruning
Puya coerulea	Bromeliaceae	Perennial herb	Endemic. Tolerant in low-moisture soils and poor in nutrients. Attracts hummingbirds and butterflies	Attractive colors, textures, structure, and shapes of the plant. Flowers in spring and fruits in summer	No information	Plant in full sun and resists pruning
Senna cumingii	Fabaceae	Shrub	Endemic. Tolerant of saline soils, poor in nutrients, low moisture and fixes nitrogen	Golden yellow flowers in spring and summer	No information	Plant in full sun
Vachelia caven	Fabaceae	Tree	Endemic. Tolerant of saline soils, poor in nutrients, low	A variety of colors	Edible. Medicinal. Fuel.	Plant in full sun. Fast growth rate

|						
			moisture and fixes nitrogen. Attracts birds	throughout the year	Handcrafted. Dye	
Baccharis linearis	Asteraceae	Shrub	Native. Tolerant in low-moisture soils and eroded. Attracts pollinators	Attractive colors, textures, structure, and shapes of the plant	Medicinal	Plant in full sun. Fast growth rate, tolerates pruning, and resistant to pests and diseases
Balbisia peduncularis	Vivianiaceae	Shrub	Native. Tolerant of saline soils, poor in nutrients, and low moisture.	Attractive flowers in spring and summer.	No information.	Plant in full sun.
Encelia canescens	Asteraceae	Shrub	Native. Tolerant in low-moisture soils and poor in nutrients. Attracts native pollinating bees	Yellow flowers in spring and fall	No information	Plant in full sun. Fast growth rate
Sphaeralcea obtusiloba	Malvaceae	Shrub	Endemic. Tolerant in low-moisture soils and poor in nutrients. Attracts native pollinating bees	Lilac flowers in spring and fall. Attractive colors, textures, and shapes of the foliage	Medicinal	Plant in full sun. Fast growth rate and resistant to pests

4. Materials and Methods

4.1. Study Site

Santiago (33° S; 70° W; 550 m.a.s.l.), the Chilean capital, has a Mediterranean climate type, characterized by mild wet winters and warm dry summers (**Figure 3**) [22,23]. The Santiago metropolitan area currently has about 6.3 million people, with a population density of roughly 8,497 inhabitants per Km² [24]. Since the late 20th and early 21th centuries, urban growth has also spread to surrounding areas, mostly consisting of agricultural lands and smaller remnants of semi-natural vegetation [25–27]. Urban vegetation of Santiago is dominated by exotic flora, which represents more than 80% of the total urban flora [20]. We chose Santiago as a study site in central Chile due to the Bio-urban Shelter project designed for public area in Santiago [28].

4.2. Species Selection

We used the landscape value method to select 12 potential native plant species from central Chile for use in urban vegetation in the same region (Fernández et al. 2025). The method consists of four selection criteria: a) environmental criteria, which are native species adapted to the environment where they will be used; b) aesthetic criteria, morphological features that have aesthetic value for the landscape use of the species; c) cultural criteria, which refer to the meanings and values of the use of the flora; and d) management criteria, which is the ability of the species to respond to management and conditions in public area. Consideration was given to ensuring that the selected species were available in nurseries in the region as well, due to potential demand from local governments for use in the Bio-urban Shelter project designed [28].

Consequently, the selected native plants are represented by trees, shrubs, and perennial herbs (Table 3), which are mostly common species of the thorny shrublands of central Chile and dominant species of a potential community within the urban perimeter of Santiago [33].
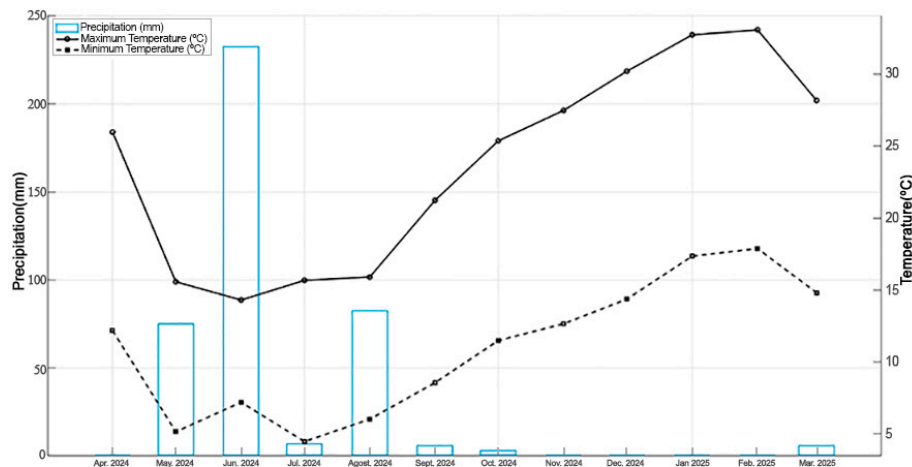
Figure 3. Mean monthly maximum and minimum temperature and precipitation for Universidad Central de Chile, Santiago, for April 2024 to March 2025.

4.3. Experimental Design

The experimental plots are located in the historic center of the city of Santiago, Chile. Two experimental plots were set up on the campus of the Universidad Tecnológica Metropolitana (UTEM, 33.451071ºS, 70.656622ºW) and two similar plots at the Universidad Central de Chile (UCEN; 33.451360ºS, 70.653433ºW).

Each plot had an area of 20 m². The soil in the plots was homogenized with a structure suitable for plant growth. Consequently, 60% of the existing soil in the top 150 cm of the plots was cleaned and loosened for recovery. The remaining 50% of the planting substrate consisted of 20% coarse sand, 15% gravel, and 5% compost, which increased the organic matter in the soil. A 5 cm layer of organic mulch was also added to the surface to prevent weed growth and excessive water loss from the soil. The chemical and biological composition of the soil on the plots was suitable for plant growth, on average: nitrogen = 32 mg/kg, phosphorus = 67 mg/kg, potassium = 374 mg/kg, % organic matter = 2.7; % water retention = 47.86; pH = 7.8 and electrical conductivity = 1.25 mS/cm; alkaline phosphatase = 24.88 ug/g soil h; DAF activity = 39.95 ug Fluorescein/g soil; urease = 17.23 ug N-NH4 /g soil; biomass carbon = 484.96 mg C/kg soil.

The 12 native species selected from central Chile, including woody and herbaceous perennials, were planted in each plot (**Figure 4**A). Three species of geophytes were also planted in the plots as part of a complementary study. The spatial arrangement of the species was the same in the four experimental plots and responded to landscape and monitoring criteria, as the experiment is part of a project on bio-urban shelters in public area in Santiago.

(**a**)   (**b**)
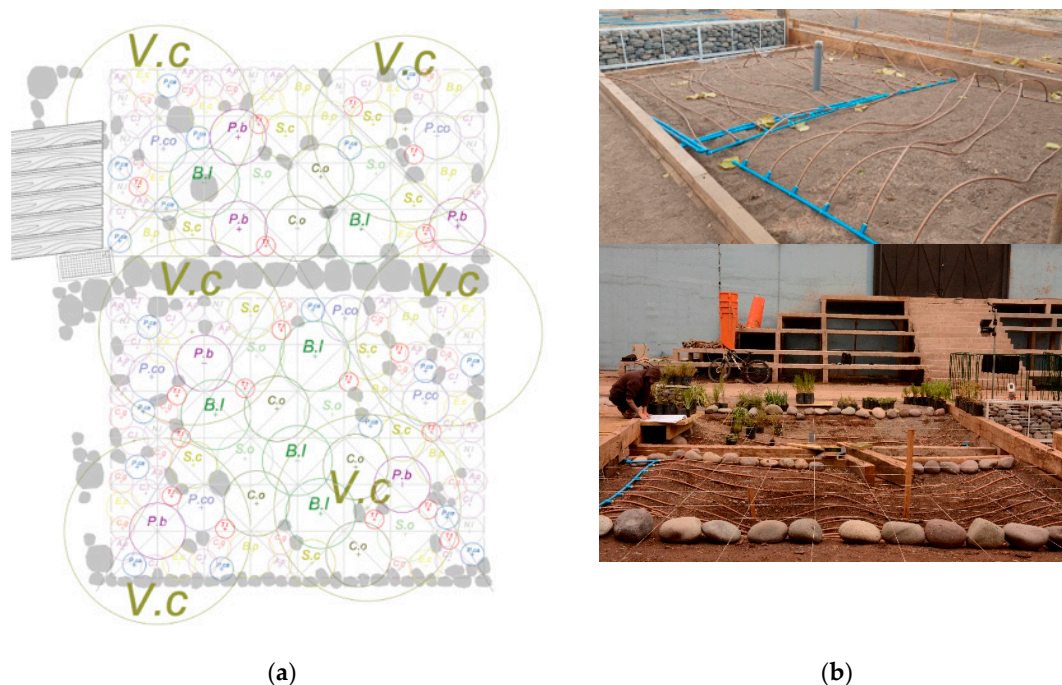
Figure 4. (**a**) Planting plan for the four experimental plots. Two plots were located Universidad Tecnológica Metropolitana and another two Universidad Central de Chile, in the historic center of the city of Santiago, central Chile. Vc= *Vachelia caven*, cl= *Cistanthe laxiflora*, nl= *Nasella laevissima*, Ac= *Andeimalva chilensis*, Co= *Colliguaja odorífera*, Pa= *Puya alpestri*, Pco= *Puya coerulea, Senna cumingii*, Bl= *Baccharis linearis*, Bp= *Balbisia peduncularis*, Ec= *Encelia canescens*, So= *Sphaeralcea obtusiloba*; (**b**) Long-lasting, low-yield automated underground drip system with a pipe with a built-in emitter and Copper Shield technology.

Juvenile plants under two years old were obtained from certified nurseries and, after being purchased, were immediately planted in the plots. The plants were planted in May 2024 in water-saturated soil to avoid stress and mortality. The irrigation system installed was a long-lasting, low-yield automated underground drip system with a pipe with a built-in emitter and Copper Shield technology (**Figure 4**B), which protects the dripper from root intrusion [34]. The hose has a diameter of 16 mm and a flow rate of 2.3 L/h. The automatic irrigation was controlled by a Rainbird ESP LXM programmer. The system was fed by the drinking water system. In each plot, the irrigation lines were buried at a depth of 30 cm and spaced 30.5 cm apart. Each plot was subject to a different water regime. The 2 plots located at UTEM were irrigated daily during the irrigation season with an average of 10.1 L/m²/day and 1.7 L/m²/day. Meanwhile, the 2 plots located at UCEN had an average daily irrigation regime of 13.3 L/m²/day and 1.4 L/m²/day. Irrigation began on 22 November 2024 and continued when the soil moisture content reached 100 cb in the two plots with the higher water availability and 200 cb (2 December 2024) in the other two plots. The water gradient applied represents the recommended irrigation for public green areas in the Santiago Metropolitan Region at the upper end, and conditions considered to be water stress for urban plants at the lower end [35]. The experiment lasted from 29 July 2024 to 03 March 2025.

4.4. Statistical Design

To evaluate survival in woody and herbaceous perennial species, plant shoots were visually monitored at the end of the 2024 winter season, the end of spring 2024, and the end of summer 2025. If the plant shoot was completely dry, the individual was considered dead, considering that it could subsequently regrow at the base of the shoot and its condition could change to alive. To determine the effect of water treatment on species survival, Kaplan-Meier survival analyses were performed. This analysis is based on estimating the conditional probabilities of survival at each monitoring event

or season (winter, spring, and summer) and considering the limit of the product of those probabilities to estimate the survival rate at each event. Kaplan-Meier analyses were also done to determine the effect of water treatment on the survival of woody versus non-woody species in combination.

The growth of each individual will be estimated using the following growth index:

GI = (A + B + C) / 3

A = plant height, B = canopy length, C = canopy width

The growth per individual for each season of the year was estimated by:

$GI_{t1} - GI_{t0}$

t1= end of the current year season,

t0= immediately preceding year season.

The growth index of each individual was monitored at the end of three seasons of the year (winter on 13 September 2024, spring on 17 December 2024, and summer on 03 March 2024).

The growth index was analyzed using a generalized linear model of repeated measures. This analysis determines the effect of the four irrigation treatments on the growth index by performing inter-subject tests. Bonferroni was used for comparisons between pairs of treatments. The data were transformed to $\log_{10}$ if they did not meet normality and homoscedasticity. The effect of the season and its interaction with the treatments was determined using intra-subject effect tests. When the sphericity condition was not met according to Mauchly's test, the Greenhouse-Geisser correction or, failing that, the Huynh-Feldt correction was performed in the intra-subject effect tests. A significance level of $p < 0.05$ was considered in the analyses. Statistical analyses were performed using the IBM SPSS Statistics for PC, version 30.0 (IBM SPSS, Armonk, NY, USA: IBM Corp.2024).

For the purposes of this study: we defined a species as being highly water-sensitive if significant differences in plant growth and survival were observed between the different water treatments applied during the trial. A species is water-sensitive if significant differences in plant growth or survival is observed between the different water treatments applied during the trial. Finally, a species is considered non-sensitive if there are no significant differences in plant growth and survival between water treatments.

5. Conclusions

Survival results show that almost 80% of the native central Chileans species selected for this study were not affected by the water treatments applied, and even reached high percentages in the first year of establishment, which is considered a survival bottleneck for urban plants. However, when water resources were limited to $\leq$ 1.7 L/m²/day, shoot growth can be slowed significantly, because they are water-sensitive species, consequently survival rates may remain high. The study also showed that the main growing season for both woody and non-woody species is spring. Growth is then slowed during the summer, with even biomass being lost.

Finally, growth is stopped during the winter season. In summary, the evidence obtained in this study suggests that using native species with low water requirements in urban projects is an effective and efficient way to use water in Mediterranean-type climate regions such as central Chile.

Conflicts of Interest: The authors declare no conflicts of interest.

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