

Article

# Green spaces more adapted and resilient to the current and future climatic conditions in the south of Portugal (Algarve): Xerophytic gardens using xeromorphic succulents

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**Abstract:** Considering the current climate conjuncture, it is a consensus that green spaces in large contemporary urban areas should be increasingly more numerous and simultaneously more sustainable, being adapted to the edaphoclimatic conditions of the site, and with reduced maintenance costs. In the case of Algarve, where this research is focused, the current and future water availability, assumes a preponderant role in the design of green spaces, where the demands mentioned above can only be achieved if we deviate from conventional landscape practices and develop holistic strategies of management and design of green spaces that integrate different areas of knowledge and not merely aesthetic issues. In this context, this work aims to develop more adapted and resilient landscaping practices to the current and future climatic conditions of the Algarve, thus reinventing the concept of landscaping in the south of Portugal. Thus, it will be of paramount importance to develop more sustainable, resilient and tolerant projects to worsening ecological conditions, particularly limitations associated with water availability. The xeromorphic succulents are a group of plants with mechanisms of tolerance to water stress and with very specific characteristics, being succulence one of the most relevant. Studies on these mechanisms are increasingly frequent, which may prove to be very advantageous in our adaptation to future climatic challenges. In addition, their ornamental potential is enormous, since their bold forms and colours are a veritable sensory explosion, which, combined with their morphological and physiological characteristics, make them the species of choice in the reconversion or creation of xerophytic gardens.

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## 1. Introduction

One of the biggest problems we face in the 21st century is prolonged drought [1], which will be exacerbated by climate change and the solution to which is to apply sustainable solutions that promote resilience, such as choosing plant species according to the soil and climate needs of the location where they are implemented [2]. Currently, in the region of Algarve (South of Portugal), the majority of landscape practices still neglect these two concepts (sustainability and resilience), as the soil and climate needs of the vegetation used in public or private green spaces do not correspond to the local reality [3]. Thus, we are faced with a paradigm that, in the context of adapting to climate change, will have to be overcome, since water will be an increasingly scarce resource, and the introduction of xeromorphic succulents in xerophytic gardens can provide a balanced and sustainable option.

Throughout history, gardens have reflected the different cultural stages of different societies, and have become a reflection of the past and a record of collective memory [4]. However, the value of a green space goes beyond aesthetics or beauty, as they directly and indirectly provide multiple benefits for human health and well-being, known as ecosystem services, such as air purification or the reduction of "heat islands" [2].

Vegetation is one of the most striking elements in the design of an outdoor space, as it not only enriches it but also energises it, promoting its balance and diversity. It is therefore necessary to have a solid scientific knowledge about the vegetation used, choosing species not only according to aesthetics features, such as, shapes, sizes, textures and colours, but also with a perspective of environmental sustainability, which is essential to promote climate resilience in the future. In this context of sustainability, in addition to water resources, it is also necessary to take pedological resources into account, as climate change tends to promote soil desertification.

The art of building green spaces with low water requirements is commonly referred to as dry gardens or desert gardens, as they recreate an arid landscape characterised by xerophytic plants. In this context, the term Xeriscape emerged in the early 1980s in the city of Denver (Colorado, USA), combining the Greek word "xeros", which means arid, with the English word "landscape" [5]. This term, whose main objective stems from the need to use water efficiently, offers a holistic vision, mainly based on the efficient use of water and sustainable design, plant selection and maintenance techniques, with multiple ecological, economic and aesthetic benefits [5].

Xeromorphic succulents are a viable option in edaphoclimatic terms for the Algarve's green spaces, however it is necessary to take into account their invasive potential, particularly non-indigenous species that may compete with native flora and may jeopardise a site's native biodiversity when applied without rigorous planning. Therefore, in-depth technical and scientific knowledge of this type of vegetation, as well as any other type of exotic vegetation, is essential.

The aim of this work is highlight the importance of non-invasive xeromorphic succulents in the design and conversion of public or private green spaces, by reinventing landscape practices in the region of Algarve, contributing to its adaptation and resilience to the phenomenon of climate change.

## 2. Materials and Methods

The contents of this paper were the result of a systematic literature review in different languages, mainly focussed on the Mediterranean region. This bibliographical review was based on material and literature already developed in scientific articles, books and theses, with a specially attention in the case of scientific articles, studies and research carried out in regions with similar soil and climate characteristics to the Algarve. In the case of online research, it was used databases such as Web of Science, Scopus, SpringerLink, Elsevier, among others, carrying out an advanced search using keywords.

The typologies an edaphoclimatic characteristics of xeromorphic green spaces followed past works from Rivas-Martínez [6], Rivas-Martínez et al. [7], Lake [9], Ringleb [10], Gildemeister [11], da Costa [12], Hartshorne [13], Van Mechelen et al. [20], Hewitt [21], Lee et al. [22], Modaihsh [15], Valera [16], Lightfoot [17] and Schmithals [18]. Evolution and morphophysiological characterization of xeromorphic succulents followed Males [23], Speirs [24], Grace [25], Mahrs [26], Edwards [27], Landrum [28], Griffiths and Males [29], Heyduk [30] and Oldfield [31]. The xerophytic green spaces in the context of climate change follows Calvin et al. [1], Webster [2], Çetin [5], Pörtner et al. [37], Leal et al. [38], Miranda et al. [39], AMAL [40] and Santos et al. [41]. The invase potencial of xeromorphic succulents followed EU Regulation n.º 1243/1014 [32], Capuano [33], Kettunen [34], Marchante [35], and Decree-Law No. 92/2019 [36]. The bioclimatological analysis was carried out according to Rivas-Martínez [6] and Rivas-Martínez et al. [7].

### 3. The xerophytic green spaces

According to Rivas-Martínez (2007) [6], xerophyte, means "having an affinity for dry environments or being able to live in climates with low rainfall. Plants or plant communities adapted to dry environments, both those created by climate and soil conditions". A xerophytic green space can therefore be defined as a green space made up of plants perfectly adapted to dry conditions, i.e. xerophytic plants adapted to low water availability. In the natural environment, these spaces appear in rocky and/or sloping areas, in extreme soil and climatic conditions, with dry climates and low levels of nutrients in the soil, as is the case of the Mediterranean climate. The Mediterranean macroclimate is characterised by at least two consecutive months of aridity during the hottest period of the year, i.e. when the average rainfall (mm) for the hottest two months of the summer quarter is less than double the average temperature [7], which in the case of the Algarve region coincides with the hottest months (July to September). It is also characterised by an average annual temperature of 18.3°C and average annual rainfall of 600 mm [7], mostly between November and March. This rainfall is distributed quite irregularly, alternating between years of severe drought and abundant rainfall. This means that the Algarve has the right soil requirements and climate conditions to reinvent itself in terms of landscaping, privileging xerophytic gardens over the predominance of Anglo-Saxon gardens [8], whose water consumption and maintenance make them incompatible with future climate scenarios.

When it comes to xerophytic green spaces, we are often faced with extreme and challenging conditions in terms of their construction and maintenance, as high temperatures and a lack of rainfall, for prolonged periods [9], are determining factors in plant development. Even so, designing a xerophytic garden is an ambitious goal, but it seemed achievable, as they have several advantages, many of which are compatible with contemporary lifestyles, such as: reducing the amount of water used, which according to a study conducted in Madrid (Spain) houses with gardens consume between 2.5 and 4.5 times more water than houses without a garden area [8]; low maintenance requirements, reducing costs and energy by more than half [10]; and a lower occurrence of phytosanitary problems [9], which in turn significantly reduces the garden's ecological footprint.

In order to thrive in extremely dry conditions, it is necessary to have a detailed knowledge of the site and the vegetation that will be used, at the phytoecological, morphological and physiological levels. Thus, garden sustainability and mitigating the rapid depletion of the natural resources, especially water, are promoted. In the case of xerophytic green spaces, species with morphophysiological mechanisms, which allow them to store water for long periods, are a legit choice, as they significantly reduce the need of watering [11].

#### 3.1. Typologies of xerophytic green spaces

Commonly, xerophytic green spaces can be divided into two distinct typologies: Desert and Mediterranean. Both types share a common denominator: species with high drought tolerance. This study discusses desert-style xerophytic green spaces, not only because it meets the need to mitigate the effects of climate change, at a green spaces level, but also to break down the prejudice surrounding the use of xeromorphic succulents in landscape architecture interventions in the Algarve region. This group of plant species, with their geometric or peculiar shapes and colours, are the hallmarks of these gardens. Poor, sandy soils are another distinctive feature of this type of garden, which is one of the fundamental requirements for the installation of xeromorphic succulents.

#### 3.2. Main edaphoclimatic characteristics

Evaluating the soil and climate characteristics of a given location when designing a green space is fundamental to the success of the green space. These characteristics will

determine the success of the installation of plant species, as well as the allocation of resources needed for their maintenance. These characteristics are the most suitable for xeromorphic succulent vegetation.

### 3.2.1. Soil

Pedological characteristics determine the success of a species, that is, depending on the structure and texture of the soil [12].

Identifying the soil's texture is one of the first parameters to be analysed, as this will help determine the rates of drainage and water accumulation in the soil [13]. Sandy soils, those with a light texture, are made up of particles between 0.02 and 2 mm [12] and are characterised by their low water storage capacity and low concentration of nutrients and organic matter, since drainage is high and there is greater leaching of essential nutrients, making them poor soils with a more acidic pH, since they have less capacity to retain calcium. On the other hand, clay soils, those with a heavy texture, are made up of particles smaller than 0.002 mm [12] and are characterised by a high water retention capacity, which leads to drainage problems as water infiltration occurs very slowly. Succulents are adapted to poor, sandy soils with a pH between 5.5 and 6.5 [14] and high drainage rates, conditions that should be replicated when designing a xerophytic desert garden. Providing xeromorphic succulents with efficient drainage conditions is a crucial factor for their success, as poor drainage promotes root rot, among other diseases. Water storage in soil is a major concern in arid and semiarid regions, there is a necessity of conserving soil water [15]. Sand mulches, such as gravel or pebbles, is a procedure that seeks to break capillarity from the deep layers of the soil and thus reduce water loss through evaporation and suppress evaporation [15]. This gravel-mulch technique has been known since ancient times, going back to the *Treaty of Agriculture* written by Ibn Luyun, in 1348 [16], and has been vindicated today [17], especially for gardening [18].

### 3.2.2. Water

As a result of their adaptation to arid climates, xeromorphic succulents have very low water requirements. However, as periods of drought in the Mediterranean region are becoming longer, sporadic watering is necessary [9]. When an irrigation system needs to be installed, it should be an automatic drip system, as this is the type that promotes the most efficient use of water (95% efficiency) [19]. Watering should be carried out during periods of lower heat (early morning or late afternoon). According to a study conducted in Israel in 2014, it was concluded that xeromorphic succulents on a green roof should be watered with 1.3 to 3.1 mm/day in the hottest months of the year [20].

Another expedient way of checking the need for watering, which reflects the maximum capacity of the tissues to store water, is the thickness of the leaves, in other words, the thicker the leaf of the succulent, the lower its water requirements [14].

### 3.2.3. Radiation

Exposure to solar radiation is fundamental to the success of a xerophytic garden. Most xerophytes need at least 4 hours of sunlight a day [21]. Exposure to the north should be avoided, as most xeromorphic succulents do not get enough light and can become stunted (Figure 1).



**Figure 1.** Stiolated specimen of *Echeveria* sp. © Delisa Xarepe.

Light has a major impact on flowering, so this means flowering only occurs when a certain number of hours of light per day are accumulated. In some species, such as those of the genus *Crassula* L. or *Schlumbergera* Lem., flowering only occurs if the daily light is less than 12 hours [21], i.e. they are short-day plants. Photoperiod also has an impact on CO<sub>2</sub> absorption in CAM plants, with a tendency for greater accumulation in conditions of more intense and prolonged radiation and at temperatures between 10 and 22°C [22]. According to a study conducted by Lee et al. (2006) [22], the maximum rate of CO<sub>2</sub> absorption in *cactaceae* family occurred for a photoperiod of 16/8 hours day/night (D/N), a temperature of 30/20°C (D/N) and radiation of 300 mmolm<sup>-2</sup>s<sup>-1</sup> [22].

Occasionally, associated with high temperatures, the plant may be receiving too much radiation, which promotes the potential to cause damage to the photosynthetic tissues, easily observed as burns [14].

#### 3.2.4. Temperature

Although succulents are morphologically prepared to withstand situations of aridity and extreme temperatures, it has been found that they grow best between 10 and 32 °C [21]. In cases where temperatures drop below 0 °C at night, succulents show a set of morphological adaptations, such as pubescence, and biochemical adaptations, such as the production of phenolic antioxidant compounds (very common in alpine succulents) (Figure 2), which prevents damage caused by the cold [23]. However, the vast majority of xerophytes from arid environments do not tolerate frost, so it is necessary to take certain measures if the garden is located in an area at risk, the most common strategy being to cover it with a geothermal blanket [13]. Species belonging to the genus *Sempervivum* L., *Sedum* L. or *Rosularia* (DC.) Stapf tolerate frost and are more resistant to temperatures below 0 °C [23].

#### 3.2.5. Nutrition and fertility

The physiological adaptations of xeromorphic succulents give them a high capacity for survival in extreme soil and climate conditions. This means that their nutritional needs are not demanding, although fertilisation during the active growing season is advantageous [9]. In addition, plants that grow in warmer climates find it more difficult to absorb nutrients from the soil, so these fertilisations, especially chemical ones, should always be moderate, otherwise there is a risk of phytotoxicity [9]. In the case of nitrogen fertilisers, when fertilisation is not correct, there is disproportionate growth, which makes the plant weaker and more susceptible to pests and diseases [14]. Slow-release fertilisers are the most appropriate option in these cases because, as their name suggests, there is a gradual

release of nutrients. This fact is especially important with the nutrient calcium, because, as it has been mentioned, it leaches very quickly in sandy soils.

It is important not to fertilise during the plant's dormant period, as the fertiliser ends up promoting growth during the resting period, which is basically a defence mechanism for the plant itself against adverse conditions [14].

#### 4. The evolution and eco-morpho-physiological characterization of xeromorphic succulents

The term "succulent" comes from the Latin word *sucus*, which means "juice" or "sap" [14] something that derives from the characteristics of its fleshy tissues, due to their high water storage capacity.

Currently, the common ancestor from which succulents evolved has not been identified, as there are no fossil remains [24]. However, according to Speirs (1980) [24], they could not have evolved more than 135 million years ago, when the first angiosperms (flowering plants) appeared, and today succulents represent between 3 and 5% of all species belonging to this botanical division [25] with around 20000 species currently known, distributed among 60 families [26]. It is distributed on all continents except Antarctica, although the greatest centres of diversity are found on the American and African continents [23].

Among other factors, environmental changes drive the evolution of species, as failure to adapt to new environmental conditions leads to their extinction. Many of the physiological and morphological mechanisms of xeromorphic succulents resulted from this adaptation, with succulence being the feature that stood out the most, as it enabled the internal storage of water for long periods.

According to Edwards (2017) [27], around 5-10 million years ago, the earth's landscape underwent very abrupt environmental changes, marked by an increase in aridity, a drop in temperature and a decrease in the concentration of CO<sub>2</sub> in the atmosphere. These changes triggered an accelerated process of succulent speciation, in other words, the emergence of new species [14]. Thus, with the decrease in rainfall there was an increase in aridity, which led to those plants that were pre-adapted with drought-resistant mechanisms, such as succulence, expanding rapidly across the territory.

Succulence feature is not exclusive to leaves; it can occur in other structures such as stems, roots or bulbs [25]. As a result of their adaptation to the environment, succulents can be found in different shapes, colours and sizes, where their phenotype reflects millions of years of evolution [28]. All succulents have 3 common and fundamental features, namely [29]:

- Low ratio of leaf surface area to volume (SA:V), making it possible to minimize transpiration losses while maintaining a maximum volume for water storage;
- Water storage capacity in the Hydrenchyma cells, which can reach 90-95%;
- A wide variety of appendages on the epidermis, such as spinose structures, trichomes or epicuticular waxes, which prevent water loss through evaporation Figure 2).



**Figure 2.** Spinose structures (*Melocactus multiceps*), trichomes (*Kalanchoe tomentosa*) and epicuticular waxes (*Echeveria* 'Purple Pearl'). © Delisa Xarepe.

Succulents have a high thermal capacity, which allows them to gradually release radiation in the form of heat during the night, ensuring that their tissues are protected against low night-time temperatures [29].

Another feature that enables succulents to survive in environments with adverse ecological conditions is their high capacity for asexual reproduction (Figure 3), especially by cuttings, where they develop adventitious roots from small detached fragments [23].



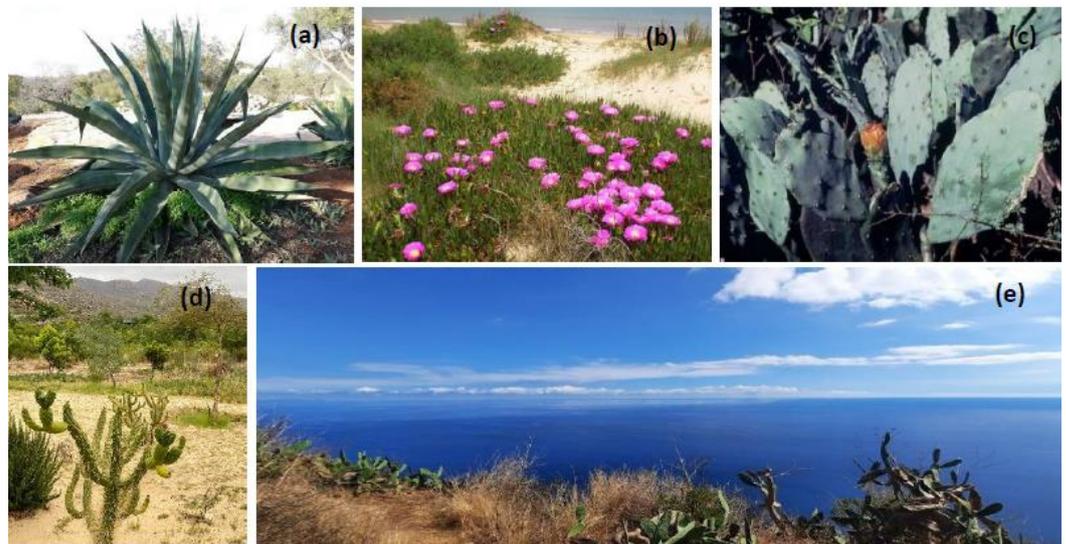
**Figure 3.** Leaves detached from a specimen of *Echeveria* sp., which gave rise to two new individuals through asexual reproduction. © Delisa Xarepe.

The photosynthesis mechanism in succulents is also adapted to arid environments. Succulents have developed a photosynthetic metabolism called CAM (*Crassulacean acid metabolism*). In CAM photosynthesis,  $\text{CO}_2$  is absorbed and stored during the night and only transformed into sugars during the day, when there is radiation. This strategy allows the plant to significantly reduce the loss of water (a very limited resource in its environment) through transpiration when the stomata open to absorb  $\text{CO}_2$  [30]. By opening the stomata at night, when the temperature is lower and the relative humidity higher, excessive water loss is significantly reduced.

*Cactaceae* are one of the largest families within the succulent group, accounting for around 20% of the total, with 2,000 currently known species [31]. It's important to talk about this family in particular, as it's often thought that all succulents belong to the *Cactaceae* family, something that doesn't correspond to reality, as all cacti are succulents, but not all succulents are cacti. One of the fundamental characteristics that distinguishes cacti from other succulents are the areoles (Figure 4) [21] (small concavities or protrusions where epidermal appendages such as spines, trichomes, etc. are found), which are only found in the *Cactaceae* family. Specimens of the genus *Euphorbia* L., in particular, are often wrongly considered to be cacti because they have spines, since due to the phenomenon of convergent evolution they are morphologically similar, but they are not because they do not have areoles.



**Figure 4.** Areoles of a specimen of *Cereus* sp. © Delisa Xarepe.



**Figure 5.** The five invasive succulent species in mainland Portugal: (a) *Agave americana*, (b) *Carpobrotus edulis*, (c) *Opuntia elata*, (d) *Opuntia subulata* and (e) *Opuntia ficus-indica*. © Delisa Xarepe.

In this review, xeromorphic succulents are presented as an importante option in the face of current unsustainable landscape practices in the Algarve. However, as the vast majority are exotic species, it is necessary to warn of their invasive potential. According to Regulation EU 1143/2014 [32], "invasive alien species are any living specimen of a species, subspecies or lower taxon of animals, plants, fungi or microorganisms introduced from outside its natural habitat; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that can survive and subsequently reproduce." These species are one of the main threats to biodiversity at a global level and can have a significant impact on our daily lives [33], with estimated losses of around €12.5 billion in Europe [34]. There are currently five succulent species in mainland Portugal that are considered invasive: *Agave americana*, *Carpobrotus edulis*, *Opuntia elata*, *Opuntia subulata* and *Opuntia ficus-indica* (Figure 5) [35].

One of the best-known cases in Portugal, but also in other regions of the world, is the case of *Carpobrotus edulis*, commonly known as the "hottentot-fig", native to the Cape region of South Africa, which was introduced for the purpose of fixing dunes and slopes and for ornamental purposes. Currently, this species has been registered as invasive in Portugal since 1999 [35]. Its efficient reproduction, both asexual and sexual (a single fruit

contains between 1,000 and 1,800 seeds), drastically reduces the native flora's ability to compete. This invasive nature is a serious problem for the conservation of native species, as it eliminates their habitat and they compete directly for nutrients, water, light and space, threatening the native flora.

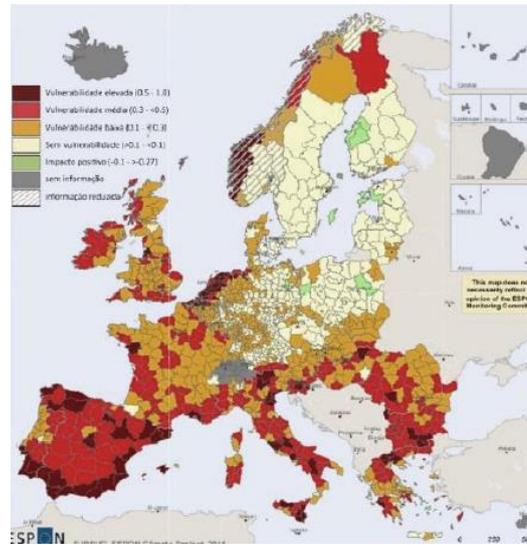
### 5. The xerophytic green spaces in the context of climate change

Green spaces are refuges created by man and are places of serenity, peace and recreation that illustrate the human relationship with nature over thousands of years. They are part of the memory of different cultures and society's values over time and are a fundamental part of any community [4]. Therefore, and taking into account the impact of climate change, this art of making gardens must be supported by sustainability, resilience and adaptation, and take into account bioclimatology of the area where they will be implemented.

According to the latest IPCC report, Portugal, as well as the entire Mediterranean basin, is particularly vulnerable to the effects of climate change, not only at an ecological and water level, but also at an economic and social level [37]. The Algarve, which is already experiencing a certain degree of aridity and dryness and has seen increasingly irregular and lower rainfall patterns since 2000 [38], will see these conditions worsen. Therefore, new projects, as well as the adaptation of existing green spaces in this region of Portugal, should involve the implementation of xerophytic gardens, limiting the use of water resources and counteracting the prevalence of the current model of gardens with high water consumption. In xerophytic gardens, xeromorphic succulents may emerge as an option for applying more sustainable vegetation that is balanced with the new environmental conditions, while providing the aesthetic ornamentality that is desired in a garden, but with lower water, energy and maintenance costs.

Green spaces, both public and private, must be recognised as a key player in mitigating the effects of climate change [2]. This can happen through managing the reduction of greenhouse gas emissions or through activities that help sequester (fix) atmospheric carbon. In fact, private gardens may be covered by policies and legislative processes that impose the transition to environmental sustainability [2].

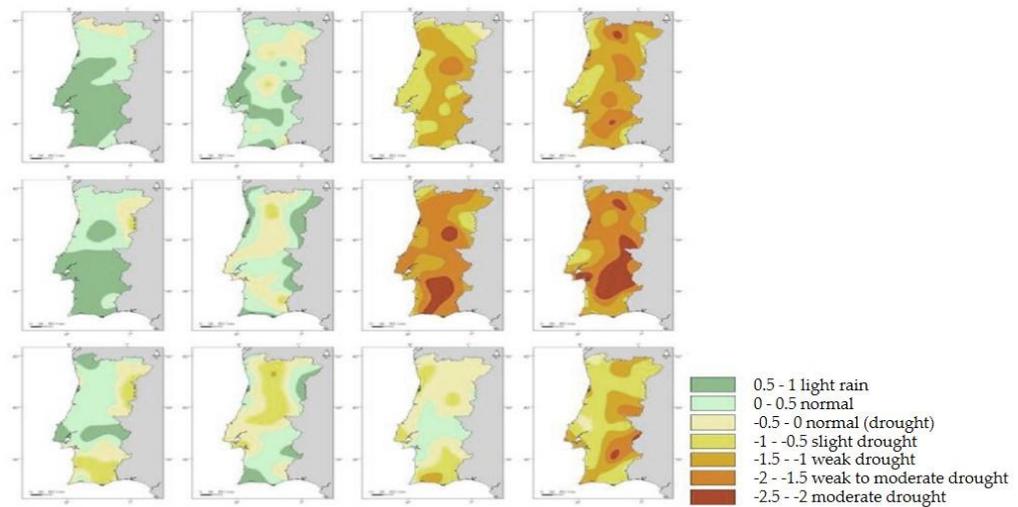
In the particular case of the Algarve, the factor that will determine how we design green spaces, namely public or private gardens, is water availability, which is currently considered one of the main challenges arising from climate change for the southern region of Portugal. In the traditional economic model, natural resources have always been exploited in order to maximise profit, with no intention of preserving or conserving them for many decades. However, natural resources are effectively finite and when their allocation is not managed rationally and efficiently, imbalances occur. Currently, water, as an essential resource for life and for the development of human activities, as well as for the regulation of ecosystems, is a scarce resource in the Algarve, as well as throughout the Mediterranean basin, and this problem is emphasised by climate change. Therefore, taking climate change into account, water resources must be the target of multidisciplinary planning and management, at European level, especially for the Southern Europe countries (Portugal, Spain, Greece, Italy and Bulgaria), with high vulnerability to climate change (Figure 6). For continental Portugal, an increase in maximum summer temperature of 3 °C in coastal areas and 7 °C inland is predicted, accompanied by a greater frequency and intensity of heat waves [39]. At a precipitation level, the scenarios show a decrease in annual precipitation of between 20% and 40%, which is one of the most severe impacts of climate change, especially in the south-east of the Iberian Peninsula, where droughts are expected to be more frequent and severe [38].



**Figure 6.** Map of potential vulnerability to climate change in Europe. Based on data from the IRPUD, ESPON Climate Project, 2011.

The Algarve region, in particular, is exposed to various climate vulnerabilities, not only at an ecological and hydric level, but as well at an economic and social level, which will be exacerbated by climate change [37]. The increasingly irregular and lower rainfall patterns, since the year 2000 [38], will worsen with climate change, with a prediction of 40% decrease in rainfall expected [39] and increases in average temperature of 3.6 °C [40]. There is currently a period of 9 to 16 days, when the minimum nocturnal period temperature is above 20 °C, i.e. tropical nights, that is expected to increase for more than 66 days, according to the worst-case scenario (RCP8.5), by the end of the 21st century [40]. As for heat waves, this same scenario (RCP8.5), predicts that their effect will be more devastating in the interior of the Algarve, with up to 20 of these extreme weather events occurring, compared to the current 2 to 13 heatwaves, for the period 2071-2100 [40]. As for the precipitation, it can be said that the Algarve is an "island", this means the only input of water is through precipitation, whose distribution patterns throughout the region show high variability depending on altitude, with higher values in the Highlands ( $\approx 1500$  mm/year) and significantly lower values in the Litoral ( $\approx 500$  mm/year) [40]. Associated with the decrease in rainfall and increase in temperature is a reduction in the recharge of aquifers, the region's main groundwater reserve, which may also be subject to saltwater intrusion due to the rise in average sea levels [37]. The frequency, intensity and duration of droughts are also expected to increase.

It is estimated that, in Portugal, the territorial and sectoral impacts related to extreme weather events could range from 60 to 140 million euros/year for forest fires and 290 million euros/year for droughts (with reference to the 2005 drought, the most severe to date) [41]. It is precisely in the phenomenon of drought that one of the main climatic challenges for the Algarve lies, with the main threats hanging over agricultural and public supply. As is possible to verify in Figure 7, drought indices have become more pronounced over the last few decades, with a greater manifestation of severe drought episodes [39].



**Figure 7.** Distribution of the PDSI (Palmer Drought Severity Index - Palmer, 1965) in Portugal. Averages for the decades 1961-70, 1971-1980, 1981-1990 and 1991-2000. Distributions based on Miranda *et al.*, 2006.

## 6. Conclusions

Climate change is promoting a paradigm shift in Landscape Architecture projects, making it imperative to design green spaces adapted to local ecological conditions. Sustainable management of water resources is something that will have to be improved in the short term in order to guarantee its maintenance for future generations. Hence, the landscape architect's intervention must be based on the sustainability and adaptability of the place, to guaranteeing the allocation of resources.

Xerophytic gardens using xeromorphic succulents are an option that is compatible with climate change scenarios for the Algarve. Recognising this group of plants in climate change mitigation will not only promote further academic research, but also their dissemination in landscape architecture projects. Xeromorphic succulents, with their water storage mechanisms, are a potentially relevant resource for managing water resources in green spaces and can be used in the xerophytic reconversion of these spaces, thus promoting their adaptation to a drier climate with more frequent and prolonged episodes of drought.

Although xeromorphic succulents are well suited for future landscape projects, considering climate change scenarios, it is necessary to bear in mind the invasive potential of some species, being the introduction of *Carpobrotus edulis* a great example of this fact, as described. Even though its introduction was legitimate, the lack of a proper assessment over their ecological features and invasive potential, contributed for the quick dissemination, causing serious economic and ecological damage. Therefore, before installing any species in a landscaping project, especially if it uses non-native plants, it is imperative to have in-depth scientific knowledge and the necessary compliance with the applicable legislation in force (Decree-Law No. 92/2019 [36]), in order to not cause future imbalances in the ecosystem.

## References

- [1] Calvin K. *et al.*. IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. Intergovernmental Panel on Climate Change (IPCC), jul. 2023. doi: 10.59327/IPCC/AR6-9789291691647. Available in: <https://www.ipcc.ch/report/ar6/syr/>. [Accessed: 11st of January 2024]
- [2] Webster E., Cameron R., and Culham A. *Gardening in a Changing Climate*. London: Royal Horticultural Society, 2017.

- [3] Xarepe D. A reinvenção dos jardins xerófilos no Algarve com recurso às suculentas xeromórficas. Dissertação para a obtenção do grau de mestre. Faro: Universidade do Algarve, 2023.
- [4] Girot C. *The Course of Landscape Architecture*. London: Thames & Hudson, 2016.
- [5] Çetin N., Mansuroğlu S. and Önaç A. Xeriscaping Feasibility as an Urban Adaptation Method for Global Warming: A Case Study from Turkey», *Pol. J. Environ. Stud.*, vol. 27, n.º 3, pp. 1009–1018, mar. 2018, doi: 10.15244/pjoes/76678. Available in: <http://www.pjoes.com/doi/10.15244/pjoes/76678>. [Accessed: 15th of October 2022]
- [6] Rivas-Martínez S. Mapa de series, geoseries y geopermaseries de vegetación de España. *Itinera Geobotanica. AEFA*, vol. 17, n.º 5–436, 2007.
- [7] Rivas-Martínez S., Sáenz S. R. and Penas A. Worldwide bioclimatic classification system. 2011.
- [8] Fernández-Cañero R., Ordovás J. and Herrera Machuca M. Á. Domestic Gardens as Water-wise Landscapes: A Case Study in Southwestern Europe», *hortte*, vol. 21, n.º 5, pp. 616–623, out. 2011, doi: 10.21273/HORTTECH.21.5.616. Available in: <https://journals.ashs.org/view/journals/horttech/21/5/article-p616.xml>. [Accessed: 7th of October 2022]
- [9] Lake J. *Gardening in a Hot Climate*. Australia: Lothian books, 1996.
- [10] Ringleb J., Sallwey J. and Stefan C. Assessment of Managed Aquifer Recharge through Modeling — A Review. *Water*, vol. 8, n.º 12, p. 579, dez. 2016, doi: 10.3390/w8120579. Available in: <http://www.mdpi.com/2073-4441/8/12/579>. [Accessed in: 8th of October 2022]
- [11] Gildemeister H. *Gardening the Mediterranean way*. New York, N.Y.: H.N. Abrams, 2004.
- [12] da Costa J. *Caracterização e constituição do solo*. Lisbon: Fundação Calouste Gulbenkian, 2011.
- [13] Hartshorne H. *Dry Gardens*. UK: Allen & Unwin, 1995.
- [14] Xarepe D. *Sucus mei - uma viagem pelo universo das suculentas*. Porto: Quântica Editora - Conteúdos Especializados, Lda., 2021.
- [15] Modaihsh A. S., Horton R. and Kirkham D. Soil Water Evaporation Suppression by Sand Mulches. *Soil Sci.*, vol. 139, pp. 357–361, 1985.
- [16] Valera D. L., Belmonte, L. J., Molina-Aiz F. D., López A. and Camacho F. The greenhouses of Almería, Spain: technological analysis and profitability, *Acta Hort.*, n.º 1170, pp. 219–226, jul. 2017, doi: 10.17660/ActaHortic.2017.1170.25. Available in: [https://www.actahort.org/books/1170/1170\\_25.htm](https://www.actahort.org/books/1170/1170_25.htm). [Accessed in: 16th of April 2024]
- [17] Lightfoot D. R. and Eddy F. W. The agricultural utility of lithic-mulch gardens: Past and present. *GeoJournal*, vol. 34, n.º 4, pp. 425–437, dez. 1994, doi: 10.1007/BF00813138. Available in: <https://link.springer.com/10.1007/BF00813138>. [Accessed: 16th of April 2024]
- [18] Schmithals A. and Kühn N. To mulch or not to mulch? Effects of gravel mulch toppings on plant establishment and development in ornamental prairie plantings. *PLoS ONE*, vol. 12, n.º 2, p. e0171533, fev. 2017, doi: 10.1371/journal.pone.0171533. Available in: <https://dx.plos.org/10.1371/journal.pone.0171533>. [Accessed: 16th of April 2024]
- [19] Cudell G. *Manual de Instalação de Rega*. Lisbon: Gustavo Cudell, 2000.
- [20] Van Mechelen C., Dutoit T. and Hermy M. Adapting green roof irrigation practices for a sustainable future: A review. *Sustainable Cities and Society*, vol. 19, pp. 74–90, dez. 2015, doi: 10.1016/j.scs.2015.07.007. Available in: <https://linkinghub.elsevier.com/retrieve/pii/S2210670715300081>. [Accessed: 12th of October 2022]
- [21] Hewitt T. *The Complete Book of Cacti and Succulents*. UK: Dorling Kindersley Publishing, Incorporated, 1993.
- [22] Lee S. D., Kim S. J., Jung S. I., Son K. C. and Kays S. J. Diurnal CO<sub>2</sub> Assimilation Patterns in Nine Species of CAM-Type Succulent Plants», *HortSci*, vol. 41, n.º 6, pp. 1373–1376, out. 2006, doi: 10.21273/HORTSCI.41.6.1373. Available in: <https://journals.ashs.org/view/journals/hortsci/41/6/article-p1373.xml>. [Accessed: 15th of November 2022]
- [23] Males J. Secrets of succulence. *Journal of Experimental Botany*, vol. 68, n.º 9, pp. 2121–2134, abr. 2017, doi: 10.1093/jxb/erx096. Available in: <https://academic.oup.com/jxb/article-lookup/doi/10.1093/jxb/erx096>. [Accessed: 12th of October 2022]
- [24] Speirs D. C. The Evolution of Succulent Xerophytes. *The National Cactus and Succulent Journal*, vol. 35, n.º 3, pp. 56–59, 1980, Available in: <http://www.jstor.org/stable/42790941>. [Accessed: 12<sup>th</sup> of October 2022]
- [25] Grace O. M. Succulent plant diversity as natural capital. *Plants People Planet*, vol. 1, n.º 4, pp. 336–345, out. 2019, doi: 10.1002/ppp3.25. Available in: <https://onlinelibrary.wiley.com/doi/10.1002/ppp3.25>. [Accessed: 28th of September 2022]
- [26] Mahr D. L. *Some Major Families and Genera of Succulent Plants*. 2017.
- [27] Edwards E. *Succulent plants waited for cool, dry Earth to make their mark*. USA: Brown University, 2011.
- [28] Landrum J. V. Four Succulent Families and 40 Million Years of Evolution and Adaptation to Xeric Environments: What Can Stem and Leaf Anatomical Characters Tell Us about Their Phylogeny?. *Taxon*, vol. 51, n.º 3, p. 463, ago. 2002, doi: 10.2307/1554859. Available in: <https://www.jstor.org/stable/1554859?origin=crossref>. [Accessed: 21st of October 2022]
- [29] Griffiths H. and Males J. Succulent plants. *Current Biology*, vol. 27, n.º 17, pp. R890–R896, set. 2017, doi: 10.1016/j.cub.2017.03.021. Available in: <https://linkinghub.elsevier.com/retrieve/pii/S0960982217302907>. [Accessed: 12th of October 2022]
- [30] Heyduk K. The genetic control of succulent leaf development. *Current Opinion in Plant Biology*, vol. 59, p. 101978, fev. 2021, doi: 10.1016/j.pbi.2020.11.003. Available in: <https://linkinghub.elsevier.com/retrieve/pii/S136952662030128X>. [Accessed: 12th of October 2022]
- [31] Oldfield S. *Cactus and Succulent Plants*. Cambridge: International Union for Conservation of Nature and Natural Resources, 1997.
- [32] EU Regulation n.º 1143/2014 of the European Parliament and of the Council, from 22nd of October 2014, on the prevention and management of the introduction and spread of invasive alien species. Official Journal of the EU, 2014.

- 
- [33] Capuano A. and Caruso G. New records for the alien vascular flora of Calabria (S-Italy). *Research Journal of Ecology and Environmental Sciences*, n.º 3(2), pp. 1–35, 2023.
- [34] Kettunen M., Genovesi P., Gollasch S., Pagad S. and Starfinger U. Technical support to EU strategy on invasive species (IAS) - Assessment of the impacts of IAS in Europe and the EU IEEP. Brussels, 2008.
- [35] Marchante M., Morais M., Freitas H. and Marchante E. *Guia prático para a identificação de plantas invasoras em Portugal*, 1.ª ed. Imprensa da Universidade de Coimbra, 2014. doi: 10.14195/978-989-26-0786-3. Available in: <https://ucdigitalis.uc.pt/pombalina/item/53887>. [Accessed: 22nd of October 2022]
- [36] *Decreto-Lei n.º 92/2019, de 10 de julho*. 2019.
- [37] Pörtner H. O and Roberts D. C. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. London: CDP, 2022.
- [38] Leal F. et al. *Elaboração dos Estudos de Base, Documentos para Consulta Pública e Relatórios Finais*. Lisbon: APA, 2020.
- [39] Miranda, P. M. A., Valente M. A., Tomé A. and Trigo R. Alterações Climáticas em Portugal - Cenários, Impactos e Medidas de Adaptação - Projecto SIAM\_II, Gradiva. Lisboa, 2006. Available in: <https://www.researchgate.net/publication/258839031>. [Accessed: 22nd of October 2022]
- [40] AMAL, *Plano Intermunicipal de Adaptação às Alterações Climáticas da CI-AMAL*. Faro: AMAL, 2019.
- [41] Santos E., Paulino J., dos Santos M. J., Canaveira P., Baptista P. and Lourenço T. C. ENAAC - Estratégia Nacional de Adaptação às Alterações Climáticas». Lisbon: APA, 2015.