Applying Ellenberg's indicator values to the study of green roofs installed with native plants

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Abstract

Horizon 2020 policies and objectives for urban management, including energy conservation and increase of biodiversity, growing interest, and cities need to build sustainable green roofs in urban spaces, have led to advanced scientific research in this area. This has also induced a more specific choice of plant species and nature-based solutions to be used. In North Europe, North America, and Asia, extensive green roofs are generally part of the new building design, while they are still uncommon in the Mediterranean area. Environmental conditions can be limiting for the expansion of green roofs in those areas. The use of native species, given their high diversity and adaptations to environmental stresses, can be a sustainable solution, both in terms of biodiversity and economics. This study seeks to examine the native plant survival rate results, flowering duration and intensity, and green cover areas of three green roof projects NativeScapeGR, apiWall, and apiMat conducted separately from 2016 to 2020 at the University of Lisbon. Furthermore, we used Ellenberg's indicator values for the plants chosen to propose a list of suitable natives for green roofs.

Among all species evaluated, only *Antirrhinum linkianum, Brachypodium phoenicoides, Briza maxima, Capsella bursa-pastoris, Chrysanthemum coronarium, Foeniculum vulgare, Lavandula stoechas, Rosmarinus officinalis*, and *Sedum sediforme* showed favorable results, based on the results of NativeScapeGR, apiWall, and apiMat projects and Ellenberg's indicator.

This research presents a reliable method for selecting wild plant species (non or less irrigated than the species more commonly available commercially) and design patterns for extensive green roofs based on ecological and nature-based characteristics.

Keywords: Native plants, Irrigation, Ecological indicators, Mediterranean Environment, Nature-based solution.

Resumo

As políticas e objetivos do programa Horizonte 2020 para a gestão urbana, incluindo a conservação de energia e o aumento da biodiversidade, a necessidade de as cidades construírem telhados verdes sustentáveis em espaços urbanos e o aumento do interesse nesta temática, levaram ao desenvolvimento da investigação nesta área. Tal também induziu uma escolha mais seletiva de espécies de plantas e de soluções baseadas na natureza a serem usadas. No Norte da Europa, América do Norte e Ásia, as coberturas verdes fazem frequentemente parte dos novos projetos de construção. No entanto, esta situação é menos vulgar na área do Mediterrâneo e do Sul da Europa. As condições ambientais podem ser limitantes para a expansão de coberturas verdes nessas áreas. O uso de espécies autóctones, dada a sua elevada diversidade e adaptações aos stresses ambientais, pode ser uma solução sustentável, tanto em termos de biodiversidade quanto em termos económicos. Este estudo visa examinar os resultados relativos à taxa de sobrevivência de plantas autóctones, à duração e intensidade do período de floração e à área de cobertura verde em três projetos conduzidos separadamente de 2014 a 2020 na Universidade de Lisboa. São também usados valores do indicador de Ellenberg para as plantas selecionadas, tendo em vista a elaboração de uma lista de plantas autóctones, com boa adaptação em coberturas verdes.

Das espécies avaliadas, apenas *Antirrhinum linkianum, Brachypodium phoenicoides, Briza maxima, Capsella bursa-pastoris, Chrysanthemum coronarium, Foeniculum vulgare, Lavandula stoechas, Rosmarinus officinalis* e *Sedum sediforme* apresentaram resultados favoráveis, com base nos resultados dos projetos NativeScapeGR, apiWall e apiMat e na aplicação do indicador de Ellenberg.

Este estudo apresenta um método confiável para selecionar espécies de plantas autóctones, com potencial resistência ao stress hídrico, e delinear orientações de projeto para coberturas verdes extensivas, com base em características ecológicas.

Palavras-chave: Plantas autóctones, Rega, Indicadores ecológicos, Mediterrâneo, Solução baseada na natureza.

Resumo Alargado

As políticas e objetivos do programa Horizonte 2020 para a gestão urbana, incluindo a conservação de energia e o aumento da biodiversidade, a necessidade das cidades construírem telhados verdes sustentáveis em espaços urbanos, enquanto uma das estratégias de sustentabilidade de gestão urbana,levaram ao desenvolvimento da investigação nesta área. Tal também induziu uma escolha mais seletiva de espécies de plantas e de soluções baseadas na natureza a serem usadas. No Norte da Europa, América do Norte e Ásia, as coberturas verdes fazem frequentemente parte dos novos projetos de construção. No entanto, esta situação é menos vulgar na área do Mediterrâneo e do Sul da Europa, as quais caraterizam-se por longos verões secos com radiação intensiva. As condições ambientais podem ser limitantes para a expansão de coberturas verdes nessas áreas. Contudo, as soluções baseadas na natureza, podem ser um caminho para superar as restrições climáticas do mediterrâneo para coberturas verdes. O uso de espécies autóctones, dada a sua elevada diversidade e adaptações aos stresses ambientais, pode ser uma solução sustentável, tanto em termos de biodiversidade quanto em termos económicos. Este estudo visa examinar os resultados relativos à taxa de sobrevivência de plantas autóctones, à duração e intensidade do período de floração e à área de cobertura verde em três projetos conduzidos separadamente de 2016 a 2020 na Universidade de Lisboa. São também usados valores do indicador de Ellenberg para as plantas selecionadas dos projetos NativeScapeGR, apiWall, e apiMat,. Depois através da comparação dos resultados dos três projetos e os três importantes indicadores ecológicos de cada espécie (incluindo luz, temperatura e humidade) tendo em vista a elaboração de uma lista de plantas autóctones, com boa adaptação em coberturas verdes. Estes indicadores ecológicos circunscrevem um conjunto de espécies que são as espécies de plantas mais tolerantes tendo como base as características ecológicas do Mediterrâneo.

Das espécies avaliadas, apenas Antirrhinum linkianum, Brachypodium phoenicoides, Briza maxima, Capsella bursa-pastoris, Chrysanthemum coronarium, Foeniculum vulgare, Lavandula stoechas, Rosmarinus officinalis e Sedum sediforme apresentaram resultados favoráveis, com base nos resultados dos projetos NativeScapeGR, apiWall e apiMat e na aplicação do indicador de Ellenberg.

Com este estudo, podemos afirmar que as coberturas verdes em Lisboa, Portugal, sob condições do clima mediterrânico, podem beneficiar com o contributo das plantas nativas.

Este estudo apresenta um método confiável para selecionar espécies de plantas autóctones, com potencial resistência ao stress hídrico, e delinear orientações de projeto para coberturas verdes extensivas, com base em características ecológicas.

O indicador de Ellenberg pode definir aspetos ecológicos das espécies de plantas, assim pode ser usado antes da seleção de plantas nativas para testar nas coberturas verdes. Estes indicadores podem poupar tempo e dinheiro na testagem de plantas.

Palavras-chave: Plantas autóctones, Rega, Indicadores ecológicos, Mediterrâneo, Solução baseada na natureza.

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1. INTRODUCTION

Urbanization is growing in several parts of the world; for instance, around 75% of the EU's population has chosen urban areas as their place to live (Caneva et al., 2015; *Urban Environment — European Environment Agency*, n.d.).

The densely populated space of the urban ecosystem has increased the requirement of a broad input of energy and materials. Population growth leads to an increase in dense construction patterns; the result is an overuse of energy and materials. These features create adverse environmental conditions in cities, including the heat island effect, waste, polluted water and air and poor air quality; they restrict the airflow of the lower-level and with a negative impact on biodiversity (Caneva et al., 2015; Paraskevopoulou et al., 2020).

According to the Horizon 2020 framework and Urban Green Labs Projects, cities must recur to smart and sustainable solutions to overcome climate and water-related challenges. There are multiple benefits in using nature-based solutions to face these challenges. Green roofs are one of the solutions inspired by, supported by, or copied from nature (*Nature-Based Solutions | European Commission*, n.d.) because of their benefits in terms of physical, environmental, and aesthetic characteristics (Caneva et al., 2015; *Home | UNaLab*, n.d.).

Green roofs are engineered ecosystems, including a vegetation layer, a growing medium over a series of root barriers and waterproofing membranes (MacIvor & Lundholm, 2011a).

Rooftop green space can relieve urbanization difficulties on an individual scale and contribute to a better city environment if applied broadly (Paraskevopoulou et al., 2020).

By minimizing flowing water volume in urban waterways, green roofs mitigate stormwater runoff and save energy (because of thermal insulation), improve sound insulation, and reduce urban pollution's adverse effects. Furthermore, green roofs have an aesthetic value, which can increase the economic value of buildings. The ecological function is another green roof ecosystem service. Through quality improvement and expansion of biodiversity, green roofs improve the urban ecosystem's quality since they can form wildlife habitats (Caneva et al., 2015).

Generally, Green roofs are classified into two main typologies, depending on the substrate layer depth, type of maintenance, variety of plants, irrigation use, and cost, i.e., intensive green roofs or extensive green roofs.

Intensive green roofs are characterized by a thick growing substrate (more than 25 cm) (Paulo & José Vila, 2019) with diverse and usable vegetation, which need regular maintenance.

Extensive green roofs have a thin and shallow growing substrate (depth of 8–15 cm) and, as a result, they have lightweight (from 80 to 180 kg/m^2); they need little maintenance, and the plants are chosen from a limited set of species (Caneva et al., 2015; Paraskevopoulou et al., 2020).

Over the last twenty years, extensive green roofs studies and projects have increased in North America, Northern Europe, and Asia. Furthermore, most of the extensive green roofs' research is based on the German standards defined by (Dachbegrunungen, 2018); However, many of these standards are not easily enforceable outside of those regions, when the climate is different (Caneva et al., 2015; Silva et al., 2015).

Semi-arid and long dry summer conditions in the Mediterranean area are limiting factors for plants growing on roofs. Thus, green roofs are still not significantly expanded in Mediterranean countries, and scientific literature associated with green roofs is still scarce (Caneva et al., 2015).

Therefore, there is much more to learn in the Mediterranean area about creating successful green roofs, specifically designed for its unique ecological condition (Vinson & Zheng, 2013).

According to extensive empirical evidence, ecological factors determine the composition and structure of plant communities. Based on a simple ordinal classification, Ellenberg's indicators determine the influence of each main environmental factor in the flora and vegetation changes (Bianco et al., 2001; Ellenberg, H. et al., 1992).

Rooftop conditions are not the same as conditions at ground level. They are challenging for plant survival and growth since plants on a green roof face elevated temperature, high light intensity, high wind speed, and additional moisture stress (Oberndorfer et al., 2007). These rooftop conditions may be severe in the Mediterranean area and quite challenging for the vegetation layer. Mediterranean climate conditions increase plant irrigation requirements, while in this area, water resource availability is a limit. Although it is possible to employ irrigation, the irrigation systems have implementation and management costs (Paço et al., 2019; Tassoula et al., 2015).

Green roofs without irrigation systems are quite common in temperate climates, providing an optimal design for such structures and depending only on rainfall for water supply. Supplemental irrigation is sometimes offered, but only in the early growth stages or during severe or prolonged droughts (Caneva et al., 2015). However, under Mediterranean conditions, irrigation is nearly unavoidable. The strategy to overcome the water-limitation of the environment can be based on natural solutions, and one of the proposed nature-based solutions is the use of native species (Paço et al., 2019). Accordingly, the use of plant species that are resistant to heat, drought, and water scarcity is crucial in green roof systems (Paraskevopoulou et al., 2020).

Green roof systems are being incorporated on buildings worldwide, and engineering, energy, and hydrology solutions for green roofs are abundant. Simultaneously, there is a lack of information about plant species in terms of the literature of green roof plant's ecology and their diversity (Caneva et al., 2015; Vinson & Zheng, 2013). Case studies and experiments are often based on only a few species, mostly of the genus sedum (Caneva et al., 2015).

The high biodiversity of plants in the Mediterranean region can be a significant resource to increase green roofs' plant diversity. Many Mediterranean region native plants are adapted to drought, high levels of radiation, and extreme heat stress while vegetating in shallow and low substrates, which coincide with the biological and environmental specifications required for the challenging environment of Mediterranean urban roof ecosystems (Caneva et al., 2015). The most suitable plants for green roofs environment are plants that can naturally tolerate cold, heat, drought, wind, high irradiation, diseases, and pests. Native plants are suggested because of the reduced costs in comparison to more traditional gardening. Usually, they do not require overly soil preparation, irrigation, fertilizers, or pruning. Possibly, elected native plant species from habitats with similar environmental conditions, which are naturally compatible with stress conditions, may improve green roof performance (Arabi et al., 2015; Farrell et al., 2013). Furthermore, native plants contribute to the increase in urban biodiversity since they bring native fauna to the Roofscape (Farrell et al., 2013).

Choosing convenient plants for green roofs, plant performance, stability, and plant survival eventually assure green roofs' effectiveness in restituting ecological services (Farrell et al., 2013; Papafotiou et al., 2013). The stability of green roofs over time can be enhanced by plant characteristics, including the potential to grow, height, blooming and blooming duration, green plant surface area, and a high survival rate, which operates urban functional advantages related to green roofs (Cáceres et al., 2018; Van Mechelen et al., 2014).

The green roof's initial challenge consists of choosing the right plants, based on ecological factors, which can survive in the vegetation layer. The vital phase in developing the appropriate plants for green roofs is to evaluate the plants under various development and growth conditions (Cáceres et al., 2018).

Given the benefits of green roofs, it is expected that this concept will become less foreign to the public and that its awareness will spread. For green roof installation's companies in the Mediterranean region to respond to customer requests and at the same time keep adherence to Horizon 2020 commitments in the field of sustainability, all parts, elements, native species, and conservation procedures of green roofs must be evaluated to improve success (Vinson & Zheng, 2013).

This study seeks to examine the adaptation of native plants species installed on green roofs, based on Ellenberg's indicator values (EIVs). The results of three projects, NativeScapeGR (Anico, 2016), apiWall (Martins, 2018), and apiMat (Catarina da Silva Figueiredo, 2020), which were conducted separately at the *Instituto Superior de Agronomia*, *Universidade de Lisboa*, (*the green roof lab* https://www.facebook.com/thegreenrooflab), were analyzed for this purpose.

A list of native plants was established, with plants, which are possible to collect from walls, and rocky environments in the Lisbon region and that can colonize green roofs in Mediterranean conditions, in order to select the most suitable. In this frame, native plants were investigated based on survival rate, flowering duration, intensity, and ground cover rate under different water availability levels. Furthermore, the plant species were evaluated based on Ellenberg indicator values (EIVs) to propose green roof solutions for potential commercial use, based on the knowledge gathered.

2. STATE OF THE ART

2.1. Green roof - Definition and Framework

According to the definition of (Asperin et al., 2011), a Green Roof is a roof that has permanently installed plant growth medium into the building, and plants grow purposefully in this area. Green Roofs are different from roof gardens with temporary plants that grow in pots or planters.

A green roof is designed and engineered to function as a green area in a challenging condition, with living and non-living compounds (Magill et al., 2011).

Although the use of vegetation on top of buildings is not a recent technique (remember, for example, the hanging gardens of Babylon), this is a fast-growing technique and has been improved and adapted to modern cities' needs. The green roof modernization movement started in Europe around 1980 and then spread to North America, and then to the rest of the world (Köhler, Manfred, 2005; Sutton & Lambrinos, 2015). Thus, the search and use of species better adapted to the extreme conditions to which we will expose the plant material is a priority, especially when installing extensive green roofs, since they require less maintenance. So, it will be possible to hypothesize that the selection of plant material adapted to rocky, walls, and other structures is advantageous because they are well-adapted to the local climatic conditions without requiring high maintenance (Heim & Lundholm, 2014).

2.2. Historical Background

Green roofs have been used since Antiquity, and the oldest ones were in Sumerian ziggurats in 2250 BC. Based on the bibliography, we found several examples spread worldwide in various climates (Figure 1). The Hanging Gardens of Babylon as one of the '7 Wonders of the Ancient World', in 600 BC, is one of the most famous examples (Figure 2). They were ordered to be built by King Nebuchadnezzar II and, according to archaeologists, consisted of large terraces supported by stone arches at about 20 m high (Costa, 2010; Magill et al., 2011; Theodore Osmundson, 1999).

Both of the previous examples were located in the Middle East, an area of warm climate with an alluvial plain, subjected to floods and scarce vegetation. In this context, the 'hanging gardens' intended to simulate oases, places rich in vegetation, shade, and water. However, when we think about colder climates, we observe that this type of facility was slow to reach in these areas because of the diversity of vegetation and the mountains characterizing a large part of the landscapes (Costa, 2010).

In medieval times (1384), in Italy (Lucca), construction began on the Torre del Guinigis, known for its roof garden of 36.5 m in height, where there are seven oak trees watered by an innovative system for underground irrigation (Costa, 2010; Magill et al., 2011) (Figure 3).

Figure 1.Ziggurat drawing. The first reference of roof gardening (https://www.mozaweb.com/Extra-3D_scenes-Ziggurat_Ur_3rd_millennium_BC-12042).

Figure 2. The Hanging Gardens of Babylon (https://www.pinterest.com/pin/380694974728878643/).

Figure 3.Guinigi Tower, Lucca, Italy (https://travel.earth/why-lucca-tuscan-itinerary/)

Between 1950 and 1960, in Germany, the concept of green roofs was reconstructed. Along with political support, the interest of scientists drove their installation in the 1970s (Dachbegrunungen, 2018).

In Portugal, the recognized green roof functions are diverse; they consider building's aesthetics, a leisure space, or even making the building more sustainable. In Porto, in 2013, the *Passeio dos Clérigos* was opened (Figure 4). This garden has fifty live trees, covers a commercial area, and is not the only green roof in this city. The Trindade Metro Station also has a 'live roof' (Figure 5), and the case of several housing buildings and University facilities (Catarina da Silva Figueiredo, 2020).

Figure 4. Passeio dos clerigos, Port (https://www.pinterest.com/pin/221802350371309815/)

Figure 5. Metro Station Trindade (https://www.tripadvisor.com.ph/LocationPhotoDirectLink-g189180-d9705615-i182273981-Porto_Metro-Porto_Porto_District_Northern_Portugal.html)

In Lisbon, in 2013, the number and the total area of green roofs were twelve, with a total area of 52085 m^2, according to the municipality (Santos et al., 2016) Lisbon also presents several examples of these covers. Of note, the *Jardim das Oliveiras* at the CCB (*Centro Cultural de Belém*) (Figure 6), the roof of the WWTP (Wastewater Treatment Plant) in Alcântara (Figure 7) (Catarina da Silva Figueiredo, 2020).

Several studies stand out in this area, such as the NativeScapeGR project, which was based on native plants (Anico, 2016), the apiWall project that aimed at testing different installation techniques for green roofs and several plants that colonize walls and roofs (Martins, 2018), and the apiMat project, that investigated pre-vegetated mats production, with native species, for further installation in green roofs under Mediterranean climate (Catarina da Silva Figueiredo, 2020).

Figure 6. The Centro Cultural de Belém (https://www.lisboa.pt/atualidade/noticias/detalhe/ha-um-novo-jardim-no-centro-cultural-de-belem)

Figure 7. West water treatment station, Alcantara (http://www.ppa.pt/member-directory/portuguese-portfolio/?lang=en)

2.3. Typology of Green roofs

In general, green roofs are divided into two main categories, Intensive and Extensive green roofs. Sometimes, another group placed between these two groups is considered, the Semi-intensive green roofs (Figure 8). Generally, the classification depends on weight, substrate layer depth, maintenance, cost, plant community, and irrigation (Paraskevopoulou et al., 2020).

- Intensive - also called roof gardens, are typically planned for human enjoyment, comfort, and well-being while maintaining the ecological potential. They present a substrate with a depth greater than 15 cm, therefore, even with lighter substrates; the building must support a large load, and so its structure must be adapted. This substrate depth allows the choice of a wide range of plants, from the smallest to the trees, so they need an efficient irrigation system and extraordinary maintenance. This type of installation is the one that requires more planning, involving also higher costs (Varela, 2011).
- Semi-intensive - represents the middle ground of typologies, merging characteristics of intensive and extensive cover. It can go from 10 cm to 25 cm in-depth, allowing a wide choice of plant species, usually composed of herbaceous, sub-shrub, and bushy plants requiring moderate maintenance. Regarding use, these green roofs are not intended to be accessed by people but rather work as a landscape to be contemplated.
- Extensive - they are the most common type of green roof since they have reduced maintenance and low installation cost. Extensive green roofs have a substrate depth of 2 cm to 15 cm, are relatively light, and have some limits for species' choice. Although it is necessary to consider the structure's load capacity, they can be installed without much preparation in most roofs, including those existent. The vegetation in this green roof model must be able to regenerate easily and quickly; it must be resistant to radiation, waterlogging, wind, and very efficient in the use of water and nutrients (Catarina da Silva Figueiredo, 2020).

Figure 8. Different type of green roofs (https://www.buildup.eu/en/learn/ask-the-experts/which-are-different-types-green-roofs).

2.4. Constituents and Installation

Green roof system components can have more than one purpose, and each component's poor condition can jeopardize the performance of the entire system (Almeida Silva Castelo-Branco et al., 2012). These components are typically included when installing a green roof structure (Figure 9):

1. Vegetation - adequate selected plants, taking into account the climate and conditions of the cover;
2. Substrate - the substrate layer can have different depths depending on the type of cover; Currently, there are already specialized substrates for this type of system;
3. Filter - filter layer prevents the finer particles from being washed away with water;
4. Drainage element - draining layer allows water to drain, avoiding root asphyxia, thus ensuring root breathing; stores some water, guaranteeing reserves for the system;
5. Thermal insulation - controls the temperature changes of the system;
6. Protection blanket - works as the last 'reservoir,' retains water and nutrients, and protects the next layer against roots;
7. Anti-root blanket - protects the surface from perforation by the roots (Le Trung et al., 2018; Martins, 2018).

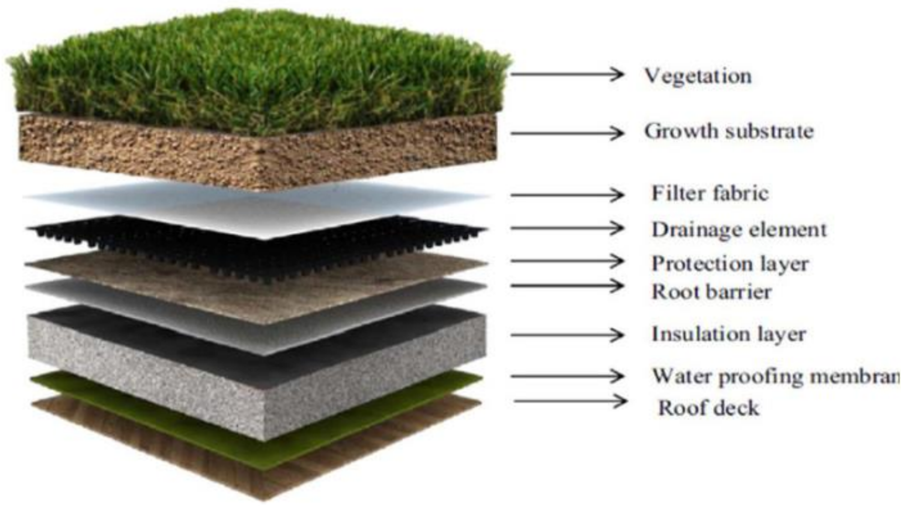

Figure 9. Components of the green roof structure (https://www.buildup.eu/en/learn/ask-the-experts/which-are-structural-components-form-green-roof).

2.5. Benefits and Limitations of Green roofs

Roofs make up about 40 to 50% of the impervious surfaces in cities, which is a factor in increasing the potential of green roofs as a sustainable option for urban drainage systems to reduce runoff. In cities, this option is even more economical than other means of pipe solutions in removing pollutants (Dunnett & Kingsbury, 2008).

Green roofs and green walls and the rest of urban vegetation are useful in capturing dust, Heavy metals, CO_2, and H_2O (Kingsbury & Oudolf, 2013).

Green roofs are justified in the long term due to green roof environmental benefits and the number of pollutants they remove from the air (Yang et al., 2008).A quantitative study of annual rainwater retention in Brussels showed extensive green roofs reduce 54% runoff for the individual buildings. In addition, these structures effectively reduce urban rainfall-runoff. Other green roof processes are also related to the water cycle: water evaporation, absorption, and transpiration done by the green roof vegetation or water-storing by the roof for later use (Mentens et al., 2006).

Green roofs not only act at the building insulation level and reduce its heat loss, especially during the winter, but they also help to cool the building by transpiration of vegetation. These features are optimized by increasing the complexity and variety of vegetation (Dunnett & Kingsbury, 2008).

In terms of tax benefits, there is a significant growing incentive to implement green roof systems. In 2020, various forms of sponsorship have been established by the government in Portugal to increase citizens' motivation to implement green roofs (*Environmental Fund, Ministry of the Environment*, n.d.). In some countries, there is some economic stimulus; for instance, in Germany, Homburg, up to 60% of installation costs are subsidized to the building owners; in the USA, Philadelphia, taxes on storm-water are reduced (Benjamin et al., 2013; Currie & Bass, 2008; Santos et al., 2016).

Regarding benefits associated with biodiversity, green roofs are ideal places to facilitate wild habitats since they are isolated from human interactions (in the limit with very few maintenance operations and not walkable) and urban traffic. Besides, the increase in invertebrate biodiversity on roofs can help support migratory birds and other animals. With attractive plants and flowers on the roofs, it is also possible to reduce bee populations on the ground level by relocating bees on the roof, with their needs being met and, simultaneously, allowing species conservation and pollination of plants, with less interference from the human population (Benjamin et al., 2013; Vijayaraghavan, 2016).

2.6. Selection of Plant Material for Green roofs

Literature refers to the genus sedum as a preferred candidate for green roofs due to its characteristics. Sedum is considered a very durable species with a shallow root; they can save water by having the CAM photosynthesis process (MacIvor & Lundholm, 2011a) and using less water than herbaceous plants.

Contrary to this opinion (Vaz Monteiro et al., 2017) suggest in their work that succulent plants, for example *Sedum spp.*, have no more benefits than other plants like *Stachys* spp. In fact, not for significant cooling of the environment during the summer, nor for the substrate's thermal insulation, which contradicts the current trend of using *Sedum* and other succulent plants for this purpose. They also specifically mention the importance of plants of the genus *Stachys* in the cooling of the surrounding environment, enabling the improvement of the thermal insulation of buildings during the day (especially at times of more significant heat, during the summer, moreover if they are not in conditions of water stress).

The literature review confirms the high importance of correctly choosing a plant in the climatic adaptation to the Portugal region.

Environmental conditions are severe in the Mediterranean area and make challenging situations for the vegetation layer. Therefore, it is essential to consider the adverse factors and the characteristics of the plant material chosen and all the different elements' reciprocal interactions. One must consider aspects such as the plants' stability in the face of wind, drought, high temperatures, resistance to pests, diseases and urban pollutants, low nutritional requirements, or the atmosphere's evaporative demand. Other elements mentioned are the intensity of solar radiation, influencing plants' transpiration, and the substrate's evaporation, which points to the need to consider the system's water storage capacity. Another factor to ponder is the lower competitiveness of the selected plant material towards invasive species, which may unpleasantly alter the cover's constitution. In this way, the plants' reseeding capacity must be valued to fill the coverings' gaps, mainly in the extensive ones (Sutton & Lambrinos, 2015).

Regarding plant choice (Sutton & Lambrinos, 2015) refer that, plants that present themselves as the best candidates for use in extensive ground cover (the situation we defined for our study) are those that have the best tolerance to water stress, wind exposure and high temperatures, associated with extensive coverings, thus resembling the grassland biome. These authors also stress the importance of considering vegetative growth with a limited substrate thickness and lack of nutrients and limited space. Invasive or high maintenance plants should be excluded, as well as plants that are difficult to obtain or of no interest to the beneficiaries of ground cover.

2.7. Native Plants

Native plants are best adapted to the local climate and soil conditions of the areas where they occur naturally and interact with other local plant communities in that region. Compared to lawns in hot and dry areas, they require less water, pesticides, and maintenance, and no fertilizers (*Native Gardening*, n.d.). They also provide integration into the existing landscape and environment, maintaining ecological balance and contributing to the development of ecosystems in which they occur. Aesthetically, native plants can compete with cultivated ornamental plants (Kendal et al., 2017; *Native Gardening*, n.d.; Threlfall et al., 2017; zyavuz et al., 2013). So, the particular characteristics of native plants make them fully compatible with the features of plants in landscaping, conservation, and restoration projects in cities (zyavuz et al., 2013).

(Madre et al., 2014), further, recommend using native species for ground cover and the reservation of some regions of the cover for natural colonization and other plant species' development. Also, the roofs must have a considerable size to support a stable plant population and thus move towards the objective of an autonomous and resistant roof. Besides, watering and maintenance of the vegetation cover should also be reduced to maintain or increase plant diversity. Herbicides should not be used, and unwanted plants (weeds) must be removed manually, keeping the cover's organic material.

Therefore, native plants in green roofs can transform green roofs' artificial nature into an integrated ecosystem in the urban landscape. They can also act as an ecosystem for conserving species in a protected state in urban environments.

2.8. Pre-Cultivated Mats

The installation of vegetation on green roofs can be done using three methods: planting, direct sowing, or using pre-cultivated mats. This last technique is more frequently used in extensive green roofs (Raposo, 2013).

Vegetation mats are mosaics of pre-cultivated vegetation in a nursery, on geotextile support, for example, coconut fiber. Plants are usually kept in a nursery from planting until they have developed enough and can be transplanted. The most common vegetation used in pre-cultivated mats are grasses, legumes, or other herbs. It is more convenient to use various species and cover about 75% of the surface, with a maximum height of 6 cm and about 8 to 10 species (Martins, 2018).

Several companies currently sell pre-cultivated mats to install on roofs in Portugal, the most common being mixtures of different types of sedum (Figure 10). Although the sedum genus has shown adaptability in coverings, having a wide variety of species, thus representing a safe choice, other mixtures can be commercialized, and there is space for the development of new ones (Catarina da Silva Figueiredo, 2020).

Figure 10, Sedum Mat (http://www.vegetalid.com/solutions/green-roofs/with-sedum-mats-id-mat/description.html)

According to (Sutton & Lambrinos, 2015), several types of mats with pre-cultivated plants are marketed for roofs application. Regardless of the selected vegetation, it is possible to find common characteristics in these products, namely the use of an erosion control mat (biodegradable or persistent) as support, with approximately 25 mm thickness, and the substrate and the plant material.

Pre-cultivated mats provide plants with favorable conditions, allowing plants to attain an adequate development stage before they are exposed to green roofs' stressful situations. They also have more resistance to wind and present more extensive surface cover when placed in the final place.

The main advantage of pre-cultivated mats is providing the final consumer the “instantaneous” effect of the cover, so there is no need to wait for seeds germination or plant growth until the green impact appears. However, this technique also has the particular advantage of helping conserve water in the green roof, reducing water evaporation from the substrate (Martins, 2018).

2.9. Climatic specificities of the Lisbon region

Climate can be an obstacle to implementing green roofs in Southern Europe, under Mediterranean conditions, as in Portugal. Long periods without precipitation during the summer, along with high temperatures, increase the need to install irrigation systems on green roofs, with all associated costs (Brandão et al., 2017).

Portugal's climate classification is characterized by having a temperate climate with mild winter and dry summer (*IPMA - Clima Normais*, n.d.). The Lisbon region falls under the Csa classification, with a hot, dry summer and a gentle (slightly cold) and rainy winter.

Regarding the temperature, it is possible to verify the incidence of average minimum temperatures in the order of 8/9 °C in the coldest months (December, January, and February) with minimums that excess of 0 °C.
The average maximum temperatures are around 28 °C in the summer months, namely July and August. Generally, the highest temperatures are observed in that season, with the maximum order of 41 °C between June and August.
According to temperature information and annual rainfall data, between 1981-2010, it is easy to confirm that the hottest months coincide with the months when water is less available.
The average precipitation is 710 mm/year. Rainfall pattern is abundant in autumn and winter, limit and less frequent in spring, and low in summer (Martins, 2018).

2.10. Ellenberg’s indicator Values (EIVs)

Ellenberg’s indicator values (EIVs) method can be used to describe the relationship between plants and the environment. Ellenberg’s indicator values evaluate the influence of main ecological elements in specific flora changes (Bartelheimer & Poschlod, 2016).
By using numerical indices referring to 7 main ecological factors, Ellenberg defined all vascular flora species' synecological preferences belonging to Central Europe.
These can be divided into two subgroups:
The first subgroup includes three indicators, which refer to climatic variables:

- Light conditions (L): The species' distribution about the relative light intensity, meaning the intensity in the species' natural environment in the season with the full leaf development.
- Temperatures (T): the value is obtained from the annual averages of the species' distribution areas' temperatures and, where possible, also from field measurements in the relative plant associations.
- Climatic continentality (C): the geographical distribution of each species is interpreted according to the continental gradient.

The second subgroup includes four indicators, which refer to edaphic conditions:

- Moisture (U): distribution of the species in the various environments according to the soil moisture gradient, from very arid to moderately humid, swampy environments and floating or submerged vegetation.
- Reaction (R): distribution of species along the soil pH gradient or limestone content
- Nutrient availability (N): Distribution of species concerning the availability of nutrients in the soil during the growing season.
- Salinity (S): distribution of the salt concentration in the soil or the water.

Ellenberg’s indicator values application is not so problematic to use in Eastern and Central Europe, owing to many common species and the comparable latitudinal range. However, to adapt Ellenberg’s scales to warmer climatic conditions, they have to be re-calibrated at a regional scale, in order to make them coherent with local plant species' ecological behavior.
All EIVs are arranged in ordinal scales which were ranging between 1 and 9 (Guarino et al., 2012).
"If Ellenberg’s scales are left unchanged when moving to different latitudes, ecological comparisons with different regional floras become senseless." For this reason, those scales expanded from 9 to 12 values for L (light) and T (temperature) indicators for the Italian region by (Guarino et al., 2012; Pignatti, 2005), as depicted after.

L = Light value

1. Dense shade, up to 1% of the external light, but for short periods it can rise up to 30%
2. Intermediate conditions between those of 1 and 3
3. Shade plants, mostly on values around 5% of the external light
4. Intermediate conditions between those of 3 and 5
5. Half-shade plants, values above 10% and for short periods even in bright light
6. Intermediate conditions between those of 5 and 7
7. In general, in bright light, but often also in low light
8. Intermediate conditions between those of 7 and 9
9. Full sun exposure in a temperate climate with frequent nebulosity
10. In full sun in stations exposed to high radiation
11. In the full sun with high irradiation and low fog climate
12. As above, in stations where a reflection effect is added.

T = Temperature value

1. Cold environment indicators, only in high mountains or with arctic-alpine distribution
2. Intermediate conditions between those of 1 and 3
3. Indicators of a cool environment, in a mountain-upper or subalpine environment, in the temperate-cold zone
4. Intermediate conditions between those of 3 and 5
5. Species adapted to the average conditions of the temperate belt, mostly in the low mountains
6. Intermediate conditions between those of 5 and 7
7. In the Po Valley or arid Mediterranean-mountain environments: Euro-Mediterranean
8. Intermediate conditions between those of 7 and 9

9. Mediterranean species in the evergreen forest, scrubland, and relatively cool environments: steno Mediterranean
10. Mediterranean species of hot stations
11. South Mediterranean species of Mesic environments
12. South Mediterranean species of hot stations and sub desertic environments

H = humidity value

1. Indicators of intense aridity, able to live only in dry places and on arid soils
2. Intermediate conditions between those of 1 and 3
3. Indicators of dryness, more frequent in dry places than in those with a surface stratum; absent from moist soils
4. Intermediate conditions between those of 3 and 5
5. Mainly on well-watered soils, they lack on flooded or desiccated soils
6. Intermediate conditions between those of 5 and 7
7. Humidity indicators, live on moist, but not flooded, soils
8. Intermediate conditions between those of 7 and 9
9. Indicators of marsh conditions, distributed on frequently submerged soils (sometimes asphyxiated)
10. Transient submergence indicators, which can also live in subaerial conditions for ± long times
11. Aquatic plants, rooted on the bottom, but with parts of the plant in normal emerging conditions, or floating on the
12. Water surface
13. Submerged plants, continuously or at least for extended periods

R = Substrate reaction value (Ph)

1. Indicators of firm acidity do not occur on basic, neutral, or mildly acidic soils
2. Intermediate conditions between those of 1 and 3
3. Acidity indicators; they live on acid soils and only sporadically occur on neutral soils
4. Intermediate conditions between those of 3 and 5
5. Mesophilic species, which are lacking on decidedly acidic or basic soils
6. Intermediate conditions between those of 5 and 7
7. Indicators of mildly basic or neutral-basophilic environments, lacking on acid soils
8. Intermediate conditions between those of 7 and 9
9. Calcified species or other markedly basic substrates

N = Nutrient value

1. Species that grow in oligotrophic conditions, on soils low in phosphorus, nitrates, and organic matter
2. Intermediate conditions between those of 1 and 3
3. Species of nutrient-poor soils
4. Intermediate conditions between those of 3 and 5
5. Optimal growth on humified soil, well-supplied with nutrients
6. Intermediate conditions between those of 5 and 7
7. Occupy environments where there is a concentration of nutrients in the soil
8. Intermediate conditions between those of 7 and 9
9. Species of environments with excessive concentration of P and N, especially in landfills and where there is an accumulation of excrement animals

The literature review shows that, since plant species' ecology condition reflects the environmental conditions and factors of a site, Ellenberg's indicator values can be applied to enhance the plant's potential success rate for planting in green roofs.
EIVs was one method used to determine wild species for EGRs (Extensive Green Roofs) based on ecological characteristics in the Mediterranean area. They investigated 471 taxa by comparing Ellenberg's indicator values of all taxa and the relevant results of some species tested on the green roof; at the end, 83 species were successfully selected to growing on green roofs in the Mediterranean area (Caneva et al., 2015). To study the interactions between green roof plants and substrate, Ellenberg's indicator values were used to select plant species to ensure that these plants perform well in the Mediterranean region's dry conditions. They can grow and survive, although each species had a different reaction based on the type and depth of the substrate (Dusza et al., 2017). (Cruz de Carvalho et al., 2020) used Ellenberg's ecological preference to select moss species that most adequate for Mediterranean green roofs. Their results showed all selected species presented a high potential for use in the Mediterranean area, except one species.

3. MATERIALS & METHODS

The present study investigated the results of three experimental projects, including the NativeScapeGR project (Anico, 2016), the apiWall project (Martins, 2018), and the apiMat project (Catarina da Silva Figueiredo, 2020); based on the essential goal of developing a diverse list of recommended interesting native plants to use in green roofs, under Lisbon weather. Then, to select the right species to grow successfully on green roofs from the point of view of development and aesthetic function, we decided to use Ellenberg's ecological indicator values to support our studies in the Mediterranean region in green roofs. In the present thesis, Materials and methods include two sections:

- Materials and methods referring to the projects NativeScapeGR, apiWall, and apiMat and the green roof lab database;
- Material and methods referring to the application of Ellenberg Indicator values to the green roof lab database.

The author was responsible for gathering information and results from the three referred projects and then applying Ellenberg’s indicator values to the plant species associated with them and analyze the results ensemble based on ecological characteristics.

3.1. Projects NativeScapeGR, apiWall & apiMat – The green roof lab database

These studies were conducted at the green roof lab, *Instituto Superior de Agronomia* (ISA, University of Lisbon, Portugal) at the green roof testing facility located on the rooftop of the Herbarium building “Prof. João de Carvalho Vasconcellos” (38˚42´28.8”N, 9˚11´0.43”W) (Figure 11).

Figure 11. Photo of testbeds on the rooftop of the Herbarium building Prof. João de Carvalho Vasconcellos https://www.google.com/maps/place/Herbario+%22Joao+de+Carvalho+e+Vasconceloa%22,+Lisboa/@38.7080501,9.1851488,145m/data=!3m2!1e3!4b1!4m5!3m4!1s0xd1934aa26a25e6b:0x68d857d77f9c72c1!8m2!3d38.7080491!4d-9.1846016

3.1.1. Test beds, Substrates & Mats

The experimental device consisted of 12 testbeds with 2.5 m long by 1 m wide, 20 cm deep, and 2.5% slope to enhance the received water drainage in three projects. Each deck had a metallic structure with 1 m high from the building's roof surface (Figure 12), avoiding shadowing the wall around it. The standard components internally covered all testbeds, as in commercial green roofing installations. The installation was carried out with the participation of the company Neoturf, specialized in this type of activity. Each tray was covered with protection and retention mat (Figure 13) (SSM45 - Neoturf) drainage element (alvéolos Floradrain® FD 25E), drainage filter SF and drop pipe for draining water resulting from drainage (Figure 14).

Figure 12. The framework of testbeds NativeScapeGR project

Figure 13. The protection and retention mat NativeScapeGR project

Figure 14. Drainage elements NativeScapeGR project

There is a drop pipe in each of the trays to drain the water resulting from the drainage. To prevent the pipes from clogging, all the constituent plates present inside the board were cut. In the NativeScapeGR project, all trays were filled with different substrates, S_1, S_2, and S_3, provided by Neoturf (Figure 15). All testbeds had a depth of 15 cm of a substrate (Anico, 2016).

Figure 15. Commercial substrate NativeScapeGR project

In the apiWall project, the substrate Siro Roof, specially designed for use on green roofs, based on hummus and blonde peat moss, was placed on all trays, uniformly covering a height of 11 cm (Figure 16).

In the apiMat project, pre-cultivated vegetation mats were transplanted and installed. For that, a 100% coconut fiber geotextile blanket was used as a base, reinforced with a synthetic net, marketed by the company Ecosalix®. The mat was cut into rectangles with dimensions 1 m × 2.5 m and was arranged, as shown in (Figure 17).

Figure 16. The substrate of apiWall project

Figure 17. Pre-cultivated mats of apiMat project (Catarina da Silva Figueiredo, 2020)

Subsequently, the substrate was placed about 1 cm high, covering the mat, leaving a margin on the sides, to avoid losses in the mats' transfer. The substrate used was the same as in apiWall project (Catarina da Silva Figueiredo, 2020).

3.1.2. Irrigation

In the NativeScapeGR and apiWall projects (Figure 18), irrigation was carried out by a drip system, programmed to water every day during the summer period. The amount of annual water allocated to each test bed in the apiWall project, in 2018, was 1.6 m3/year when 100% of the ETo value was used, and 1.1 m3/year for 60% of the ETo value and slightly lower than this for the NativeScapeGR project in 2014-2015.

Figure 18. Drip system at apiWall project

In apiMat project, a sprinkler system for four months was used during the pre-cultivation mats preparation (Figure 19). After transplantation, however, the irrigation practiced was carried out by a drip system at 2019. The amount of total water allocated to making irrigation was around 1.3 m^3/year corresponding to about 60% of evapotranspiration (ETo) according to previous experimental results (Anico, 2016; Martins, 2018).

Figure 19. Sprinkler system at apiMat project

The estimation of actual evapotranspiration (ET) (ETact) was performed using a widely generalized approach, consisting on the use of ETo (reference evapotranspiration) and coefficients related to the use of water by vegetation, generally referred to as crop coefficients, in the case of agricultural crops (Allen et al., 1998), and landscape coefficients in the case of green spaces (Snyder et al., 2015).

The reference evapotranspiration was initially calculated using data from the climatological normals (1971 and 2000) of the Tapada da Ajuda weather station. Afterward, the established target values for irrigation allocations were adjusted and using real-time data from the same station with meteorological data from the EMA (automatic weather station). The estimated real ET (ETact) was calculated according to (Snyder et al., 2015).

$$ET_{act} = ET_o \times K_L$$

ETo being the reference evapotranspiration and K_L, the landscape coefficient. Two irrigation allocations were used: a higher one (100% ETo,) and a lower one (60% ETo).

In the apiWall project, the irrigation allocation used was the same as previously used by (Anico, 2016), using reference evapotranspiration (ETo) (Allen et al., 1998), whit 100% ETo value in the case of the higher irrigation level and 60% ETo in the case of reduced irrigation.

In the apiMat project, watering was controlled by the ‘Rainbird WPX Battery-Operated Controller’ programmer.

3.1.3. Plants Used in Experimental Trials

Regarding plant material choice for the green roof, the option was the Portuguese flora, more specifically native plants of the Lisbon region. The objective was to select plants that have the advantage of being initially adapted to the climate, facing only the difficulty of the cover's hostile conditions. Besides, the projects also searched for aesthetically attractive species that had some flowering or visual appeal. An attempt was further made in apiWall project to use plants of rocky environments, such as walls, roofs, roadsides, and paths (*Flora-On | Interactive Portugal Flora*, n.d.).

The native species chosen in NativeScapeGR project were: *Brachypodium phoenicoides* (L.) Roem. & Schult*, Lavandula stoechas* L. subsp. *luisieri*, and *Rosmarinus officinalis* L. (Table 1).

The native species chosen for the apiWall project were: *Antirrhinum linkianum* Boiss. & Reut, *Asphodelus fistulosus* L., *Centranthus ruber* L., *Sedum sediforme* (Jacq.) Pau. (Table 1) which were collected from roofs and walls in the Lisbon region.

Plants used in the apiMat project were *Achillea ageratum* L.*, Anagallis arvensis* L.*, Anthyllis vulneraria* L.*, Briza maxima* L.*, Capsella bursa-pastoris* L.*, Centranthus ruber* L.*, Cerinthe* *major* L*., Cichorium intybus* L., *Chrysanthemum coronarium* L*., Ecballium elaterium* L. A. Rich. *Euphorbia segetalis L. var., Foeniculum vulgare* L*., Lavandula stoechas* L., *Lavatera trimestris, Nigella damascene, Papaver rhoeas* L*., Plantago lanceolate* L*., Sedum sediforme (Jacq.) Pau., Sanguisorba verrucose (Link ex G. Don) Ces., Scabiosa atropurpurea* L*., Stachys germanica* L*.,Teucrium scorodonia* L., *Trifolium incarnatum* L. (Table 1).

All seeds were purchased from the company "Sementes de Portugal." Four mixtures were obtained, with the following characteristics:

Mix 1: *Briza maxima, Sedum sediforme, Stachys germanica, Teucrium scorodonia, Trifolium incarnatum,* white, green, purple, yellow and red*,*flowers; flowering can range from Jan to Sept;

Mix 2: *Capsella bursa-pastoris, Centranthus ruber, Papaver rhoeas, Sanguisorba verrucose, Sedum sediforme*; pink, red, yellow and white flowers; flowering can run from Jan to Sep;

Mix 3: *Achillea ageratum, Anagallis arvensis, Cerinthe major, Cichorium intybus, Chrysanthemum coronarium, Euphorbia segetalis, Foeniculum vulgare, Lavandula stoechas, Nigella damascene, Sedum sediforme;* blue, purple, yellow, green, and white flowers; flowering Jan to Sept;

Mix 4: *Achillea ageratum, Anthyllis vulneraria, Ecballium elaterium, Foeniculum vulgare, Lavandula stoechas, Lavatera trimestris, Plantago lanceolate, Scabiosa atropurpurea, Sedum sediforme;* purple, pink, white, and yellow flowers; flowering from Jan to Sept.

Each mixture was sown on three mats, making a total of twelve mats. Seed germination was two weeks after sowing, and the development of roots was about two months after it showed that the plants could access soil resources when they were transferred. The mats transplanted to the experimental trays on the 24th of May on the roof of the Herbário Professor João Carvalho Vasconcelos, at the Instituto Superior de Agronomia. An interesting fact about apiMat experiment was the spontaneous presence of *Serratula* spp., in all the mats mixtures, without being planted. Since this plant demonstrated great ability to colonize (Catarina da Silva Figueiredo, 2020), it was decided to consider the result of *Serratula* spp., and compared to other species.

Table 1. The list of plants species at NativeScapeGr, apiWall & apiMat projects

Species	Family	Projects					
		NativeScapeGR	apiWall	apiMat			
				Mix 1	Mix 2	Mix 3	Mix 4
Achillea ageratum	Asteraceae					X	X
Anagallis arvensis	Primulaceae					X	
Antirrhinum linkianum	Scrophulariaceae		X				
Anthyllis vulneraria	Fabaceae						X
Asphodelus fistulosus	Asphodelaceae		X				
Brachypodium phoenicoides	Poaceae	X					
Briza maxima	Poaceae			X	X		
Capsella bursa-pastoris	Brassicaceae				X		
Centranthus ruber	Caprifoliaceae		X				
Cerinthe major	Boraginaceae					X	
Cichorium intybus	Asteraceae					X	
Chrysanthemum coronarium	Asteraceae					X	
Ecballium elaterium	Cucurbitaceae						X
Euphorbia segetalis	Euphorbiaceae					X	
Foeniculum vulgare	Apiaceae					X	X
Lavandula stoechas	Lamiaceae	X				X	X
Lavatera trimestris	Malvaceae						X
Nigella damascene	Ranunculaceae					X	
Papaver rhoeas	Papaveraceae				X		
Plantago lanceolate	Plantaginaceae						X
Rosmarinus officinalis	Lamiaceae	X					
Sanguisorba verrucose	Rosaceae		X	X	X	X	X
Scabiosa atropurpurea	Caprifoliaceae				X		
Sedum sediforme	Crassulaceae						X
Stachys germanica	Lamiaceae			X			
Teucrium scorodonia	Lamiaceae			X			
Trifolium incarnatum	Fabaceae			X			

3.1.3.1. *Achillea ageratum*

Achillea ageratum belonging to the Asteraceae family and a perennial species. It is usually found in sunny places, such as on the edges of forests and woods, on the edges of paths and agricultural fields. It does not require much watering and adapts to different types of soil. The flowering season starts in April and lasts until September, the flower being a bright yellow shade, working as an attraction for pollinating insects. This species, also known as Marcela-real, has medicinal properties and is aromatic (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 20).

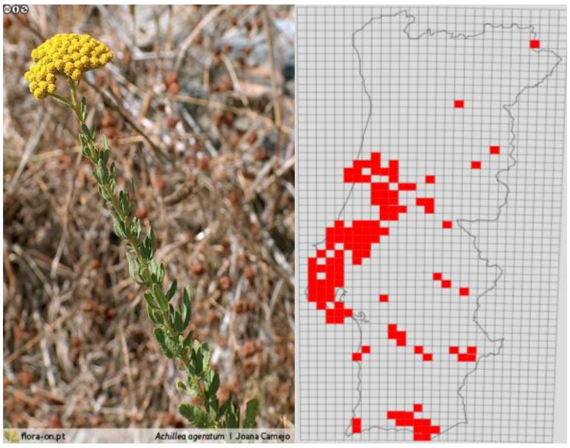

Figure 20. Achillea ageratum and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.2. *Anagallis arvensis*

Anagallis arvensis is also known as 'Morrião,' which belongs to the family Primulaceae. It is an annual herbaceous with a wide distribution throughout the country, common in cultivated or vacant lots, humanized zones, and borders of thickets and forests. It is not specific to any type of soil; that is, it presents edaphic indifference. These plants are of the therophyte type. Flowering from January to September peaked in March, April, and May (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 21).

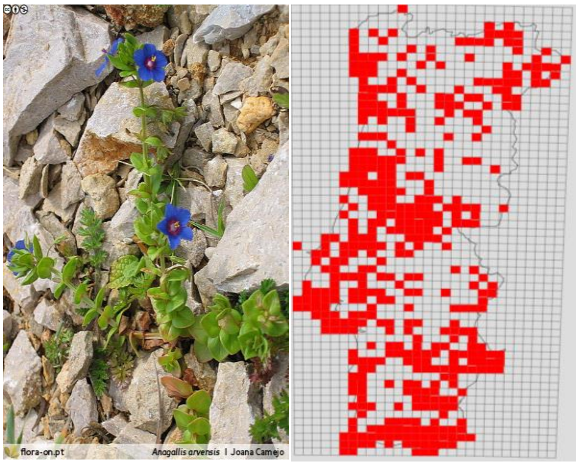

Figure 21. Angallis arvensis and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.3. *Antirrhinum linkianum*

Antirrhinum linkianum is a perennial plant (hemicryptophyte and caméfito - buds above the ground), also known as 'bocas-de-lobo'. It belongs to the Plantaginaceae family. It is indigenous to mainland Portugal. It appears in cracks in rocks, gravel, rocky outcrops, rocky terrain, roadsides. The flowering season is from April to July, but flowering is reported yearly (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 22).

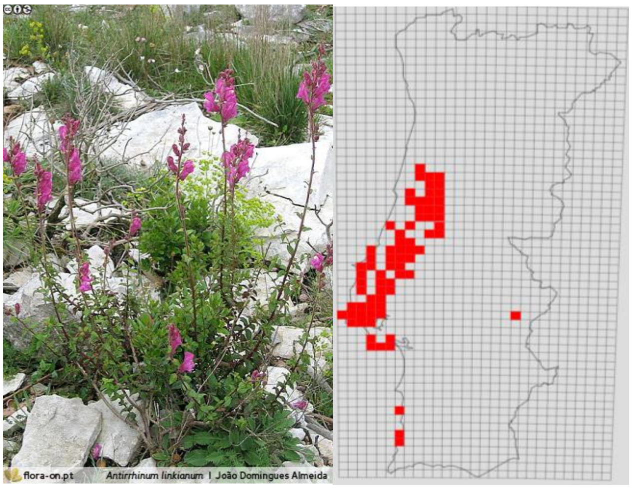

Figure 22. Antirrhinum linkianum and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.4. *Anthyllis vulneraria*

Anthyllis vulneraria is a hemicryptophyte species belonging to the Fabaceae family, colonizes clearings of undergrowth, wasteland, and dry and stony places. It presents flowers devoid of the pedicel, arranged in chapters, flowering from January to August, the peak being in April and May. It is a perennial plant and can also behave as an annual (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 23).

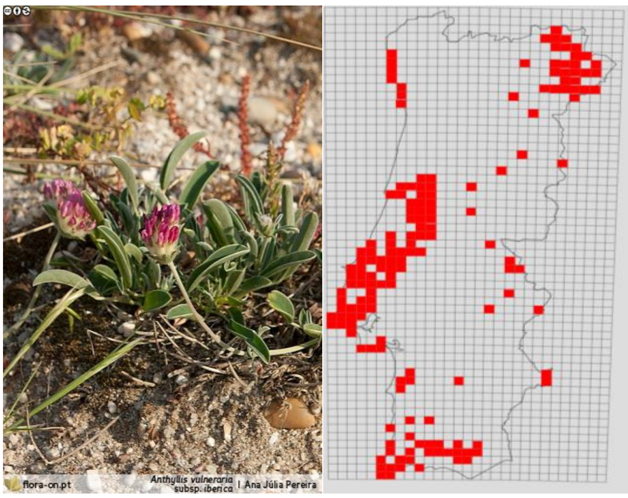

Figure 23. Anthyllis vulneraria and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.5. *Asphodelus fistulosus*

Asphodelus fistulosus is an annual (therophyte) or perennial (hemicryptophyte) plant. It is also known as 'fistulous backgammon.' It belongs to the family Xanthorrhoeaceae, which is native to mainland Portugal and the Madeira archipelago. It appears on roadsides, agricultural borders, fallows, vacant and uneducated. It has been reported to occur in somewhat disturbed locations and on different types of substrate. Coastal sands are included. The flowering season is described as from January to June, with a peak in March (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 24).

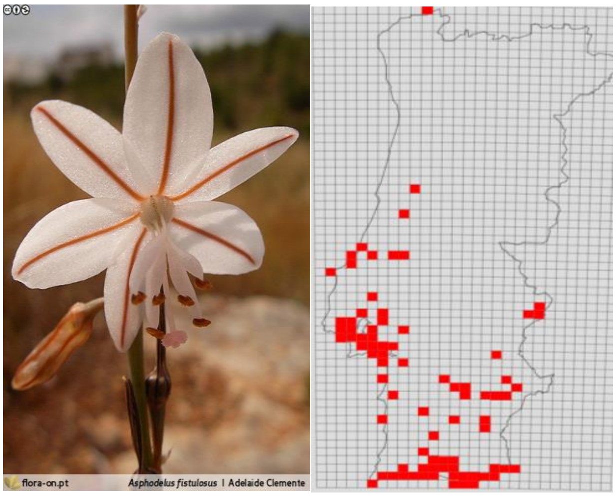

Figure 24. Asphodelus fistulosus and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.6. *Brachypodium phoenicoides*

Brachypodium phoenicoides is quite common in the Mediterranean region. This species is a perennial, cespitose, tall grass (up to 1 m) with alternating spikelet ears. It blooms between May and August. This species is found mainly in bush and uncultivated land, being found all over the country (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 25).

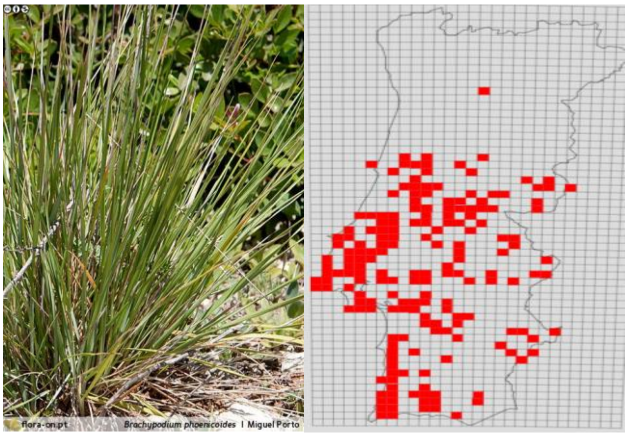

Figure 25. Brachypodium phoenicoides and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.7. *Briza maxima*

Briza maxima from the Poaceae family, known as 'Abelhinha,' is a widespread grass in Portugal, with a homogeneous distribution from north to south. It is a plant with a tremendous ecological range; however, it has some dry places. It is an annual species; it is a therophyte. It presents an inflorescence, a panicle, with few spikelets on thin peduncles and hanging ends, with the flowering season from January to September. Still, the peak is from April to June (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 26).

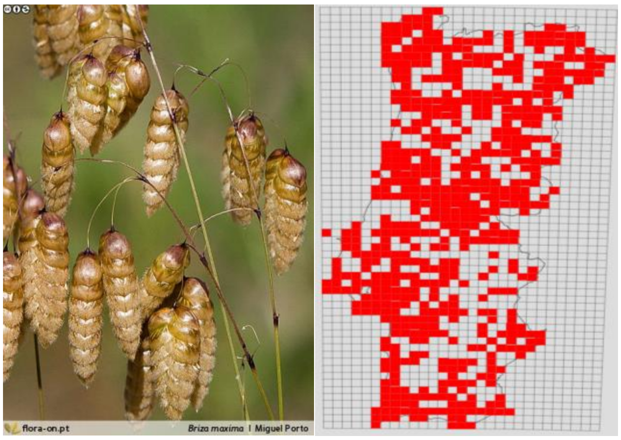

Figure 26. Briza maxima and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.8. *Capsella bursa-pastoris*

Capsella bursa-pastoris Medik. It is an annual plant or therophyte, which belongs to the family Brassicaceae. This is also known as 'Bolsa-de-pastor'; it presents a tremendous ecological amplitude in cultivated fields, pastures, fallows, wastelands, borders, paths, and roadsides. The flowering season is generally from January to July; however, it can flower all year round (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 27).

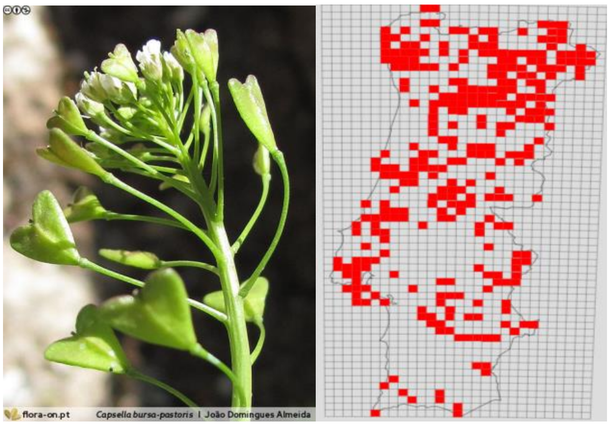

Figure 27. Capsella bursa- bursa-pastoris and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.9. *Centranthus ruber*

Centranthus ruber is a perennial plant (hemicryptophyte), also known as 'pins' or 'care-formen.' It belongs to the family Valerianaceae. It is indigenous to Portugal, except for the autonomous regions. It appears in walls and rock cracks, nitrified places, roadsides, embankments, heaps, walls, cliffs, and rocks, usually on calcareous substrates. Its flowering season is from March to July; however, there are reports where it blooms in March until the end of July, with occasional flowering reports also dispersed in September, December, and January (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 28).

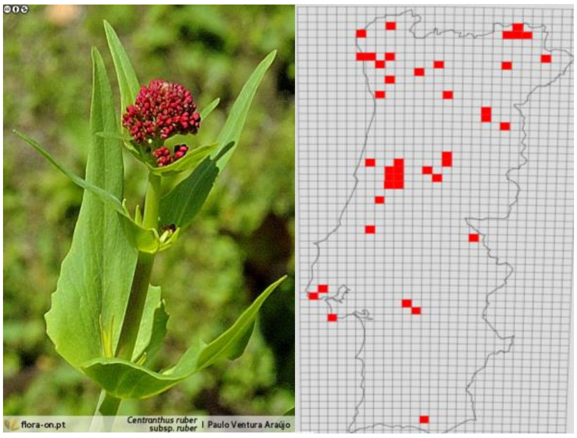

Figure 28. Cetranthus ruber and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.10. *Cerinthe major*

Cerinthe major is an annual herbaceous species of the therophyte type of the Boraginaceae family. Also known as 'Flôr honey,' this plant can be found in cultivated or vacant land; on slopes and rocks, it prefers bare and nitrified soils; however, it also survives on acidic and sandy soils. Flowering is from February to May, peaking in April, presenting a purple flower (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 29).

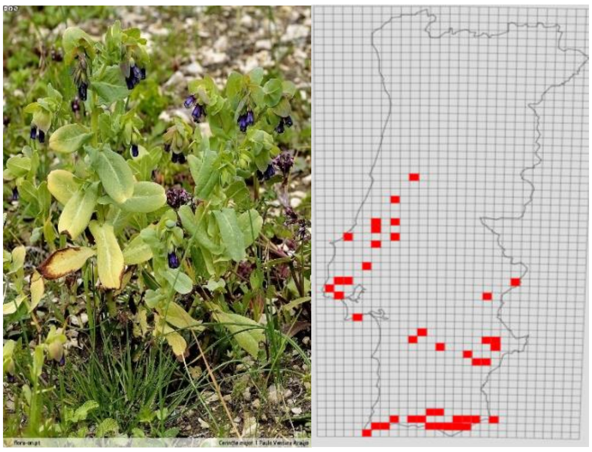

Figure 29. Cerinthe major major and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.11. *Cichorium intybus*

Cichorium intybus is a perennial (sometimes biennial) plant of the hemicryptophyte type, belonging to the Asteraceae family. It produces lilac or blue flowers from May to July, and the flowering season can start earlier in January and continue until September. This plant, commonly called 'Chicory' or 'Almeirão,' appears in ruderal environments, usually in vacant lots, roadside, and cultivated or uncultivated land. It is a plant with reduced water needs (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 30).

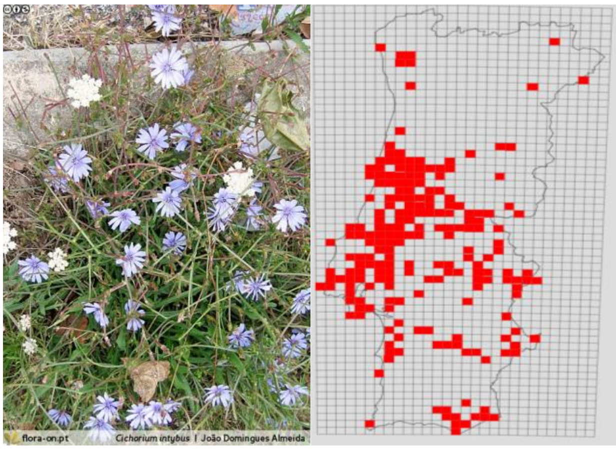

Figure 30. Cichorium intybus and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.12*. Chrysanthemum coronarium*

Chrysanthemum coronarium, common name 'Pampilho', is an annual herbaceous or therophyte species belonging to the Asteraceae family. These plants can reach up to 1.5 meters in height, with white or yellow flowers, which are arranged in chapters. Inflorescences appear from February to July, but they are more common in spring, that is, from March to June, these are very attractive for insects. It is a ruderal species that adapts to different soil types, has a preference for areas with good sun exposure, is commonly found on roadsides, vacant lots, or agricultural fields. It also has the particularity of functioning as a repellent for some less desired insects (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 31).

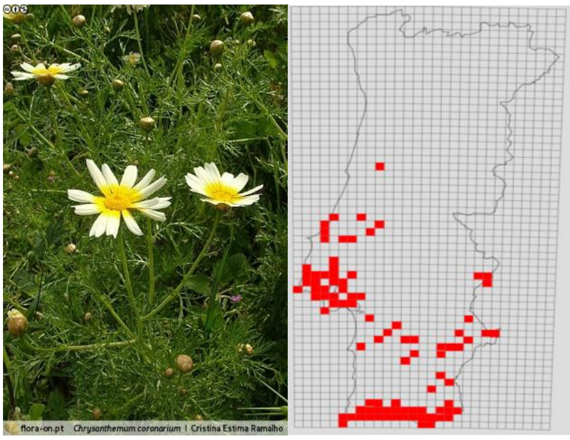

Figure 31. Chrysanthemum coronarium and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.13. *Ecballium elaterium*

Ecballium elaterium belongs to the family Cucurbitaceae; It is known as 'Pepino-de-São-Gregório' or 'Pepineiro-bravo.' a ruderal species, which appears in vacant lots, walls, ruins, and debris. It is a hemicryptophyte type, blooming from January to September, peaking in March and April. The flowers are characteristic of the family, are white with a yellow or green center, and can be male or female. The female flowers originate from the fruit, and the male flowers end up degenerating. These plants have an impressive form of seed dispersion, since when the fruit is ripe and touched by some animal, it stands out and explodes, projecting the seeds (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 32).

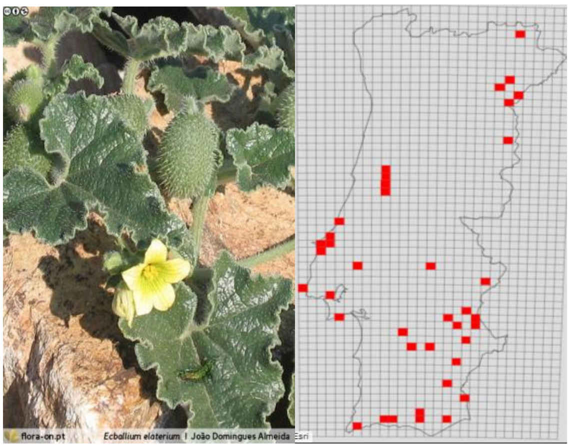

Figure 32. Ecballium elaterium and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.14. *Euphrobia segetalis*

Euphrobia segetalis is an annual species belonging to the Euphorbiaceae family, which appears in thickets, meadows, pastures, rocky and disturbed places, such as roadsides and uncultivated agricultural fields. It is indifferent to the substrate type and may appear in dune sands or even in soils affected by fires. These plants, also known as 'Alforba-brava,' are annual or therophytes. They flower from January to August, with a peak from March to May (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 33).

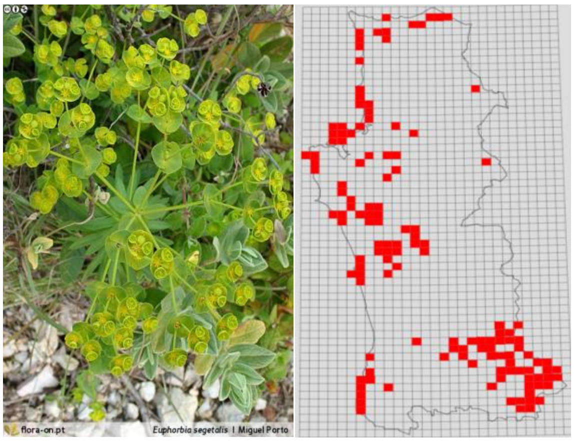

Figure 33. Euphorbia segetalis and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.15. *Foeniculum vulgare*

Foeniculum vulgare is a perennial herb, belongs to the Apiaceae family and is of the hemicryptophyte type. Commonly known as 'Fennel' or 'Fennel' is a widespread plant in Portugal. It can be found with a wide distribution in vacant and uncultivated land, in dry places, in clearings of scrub, on the edges of paths and cultivated fields. It is a ruderal species that adapts to different soil types; its population can reach large densities forming functional areas. In addition to the yellow inflorescences, which are very attractive to bees, which can appear almost all year round but are more common from June to September, their leaves are very aromatic. They can be used in food (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 34).

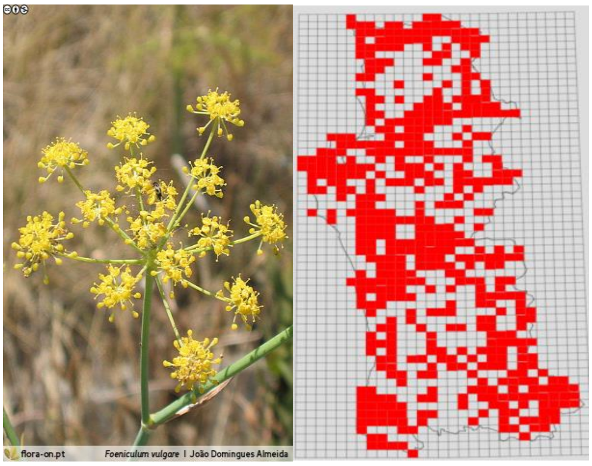

Figure 34. Foeniculum vulgare L. and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.16. *Lavandula stoechas*

Lavandula stoechas (subsp. Luisieri) is typical of the Mediterranean climate. It is a small shrub (20-40 cm) aromatic, evergreen, with a straight, ascending, or prostrate stem. Flowers are grouped in a compact and angular ear, violet in color, occurring between March and

September. It occurs mainly in exposed and dry places, preferring low substrates. Its conservation is important because it has a very restricted geographical area (Iberian Peninsula) despite being shared in our country. In Portugal, it only occurs in the center and south of the country. Its presence is relevant because it is part of several habitats. It is also a plant with medicinal and aromatic properties (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 35).

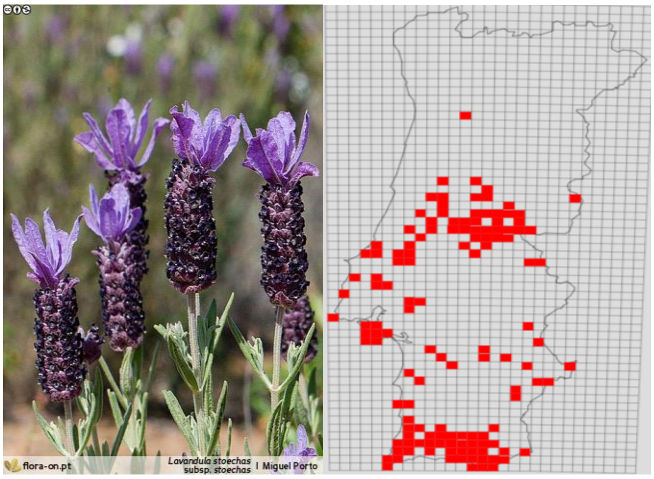

Figure 35. Lavandula stoechas and its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.17. *Lavatera trimestris*

Lavatera trimestris is an annual herbaceous member of the Malvaceae family, of the therophyte type. It has a relatively short life cycle and fast growth, reaching about 1.5 m. In the months from March to June, it presents a pinkish flowering beautiful for pollinating insects. The 'Malva-de-three-meses' adapts to different soil types, mainly clayey, sandy, or limestone, and is easily found in agricultural land, fallow, meadows, clearings of scrub, or roadsides. These species prefer sunny places (*Flora-On | Interactive Portugal Flora*, n.d.) (**Error! Reference source not found.**).

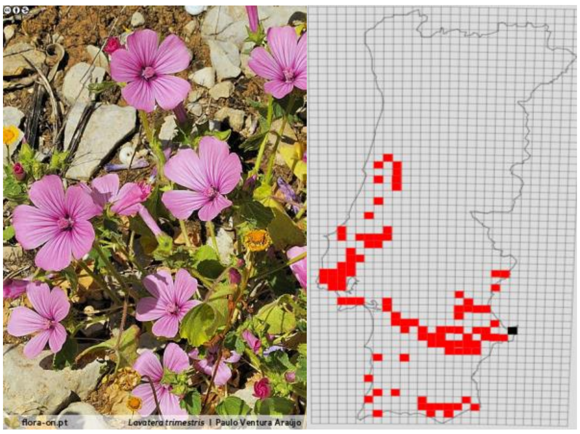

Figure 36. Lavatera tirmestris and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.18. *Nigella damascena*

Nigella damascena is an annual species in the Ranunculaceae family, known as 'Flower-of-the-lady.' It blooms between March and June, the flower being blue and white. It is found in agricultural fields, crops, rainfed orchards, and rocky places. It adapts to different types of soil and does not require frequent watering. The seeds are contained in capsules when they burst to make their sowed(*Flora-On* | *Interactive Portugal Flora*, n.d.) (**Error! Reference source not found.**).

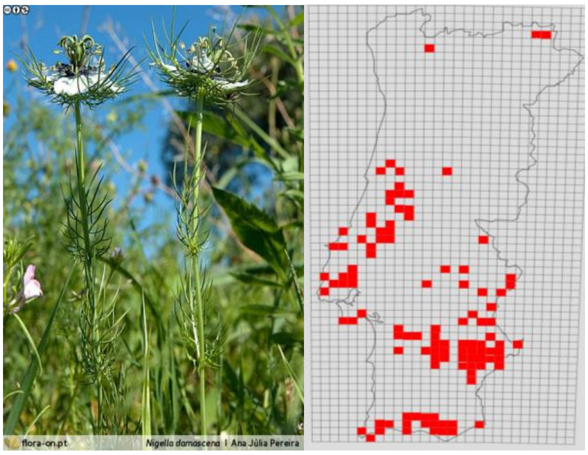

Figure 37. Nigella damascena and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.19. *Papaver rhoeas*

Papaver rhoeas is an annual herbaceous plant of the therophyte type. It is commonly called 'Red poppy' or 'Poppy vulgaris'. This Papaveraceae family species are found in crops, fallows, pastures, meadows, montados, olive groves, roadsides, wastelands, and debris. From April to July, the flowering season may vary, with its flower red and satiny, usually showing a black spot at the base. This species has been widely combated, treated as a weed in wheat fields, yet it continues to appear spontaneously (*Flora-On* | *Interactive Portugal Flora*, n.d.) (**Error! Reference source not found.**).

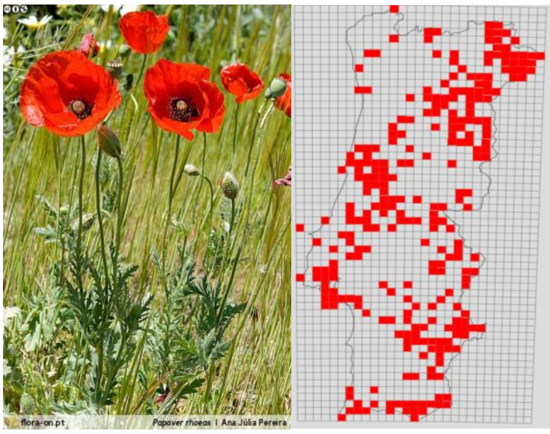

Figure 38. Papaver rhoeas and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.20*. Plantago lanceolata*

Plantago lanceolate belongs to the Plantaginaceae family. It is known as ‘Sheep herb.’ It is a perennial species of the hemicriptófito type that appears in meadows, paths, wastelands, humanized zones, or urban environments. It shows inflorescence in the ear from March to September. The lanceolate leaves are one of the points that help identify this species. They are available in a basal rosette and are of an intense green tone (*Flora-On | Interactive Portugal Flora*, n.d.) (**Error! Reference source not found.**).

Figure 39. Plantago lanceolata and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.21. *Rosmarinus officinalis*

Rosmarinus officinalis is a common shrub which widely used as an ornamental plant in the Mediterranean region. It is a shrub that reaches up to 2 m in height, flowering occurring almost all year but mainly between January and May. It is found primarily in thermophilous scrub, in uncultivated land, and watercourses. It tolerates drought and marine exposure, needing plenty of light. It takes pruning well and regenerates from old branches. It is an attractive plant for bees, which attracts wildlife (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 40).

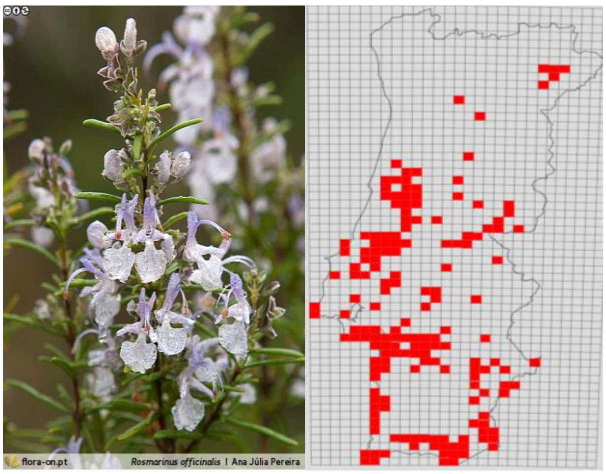

Figure 40. Rosmarinus officinalis and its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.22. *Sanguisorba verrucosa*

Sanguisorba verrucosa is a perennial plant of the hemicryptophyte type, also called 'Pimpinela,' which belongs to the Rosaceae family. It appears on embankments, vacant lots, in clearings of scrub and woods; in short, it seems on disturbed stony substrates, being relatively indifferent to the other soil characteristics. It presents flowers grouped in glomeruli, which appear between April and July, to anticipate and appear in February, with the peak of flowering in April (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 41).

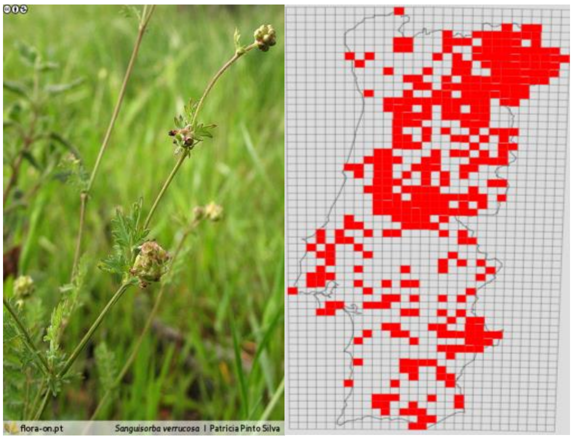

Figure 41. Sanguisorba verrucosa and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.23. *Scabiosa atropurpurea*

Scabiosa atropurpurea is a perennial species of the hemicriptófito type, commonly called 'Saudade', which belongs to the family Dipsacaceae. It appears in pastures, fallows or open fields, dams, and shoulders. It is not very selective in terms of soil. This plant has some morphological diversity. The leaves can have different shapes and flowers in different colors. Flowering is from January to September, mainly from April to June (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 42).

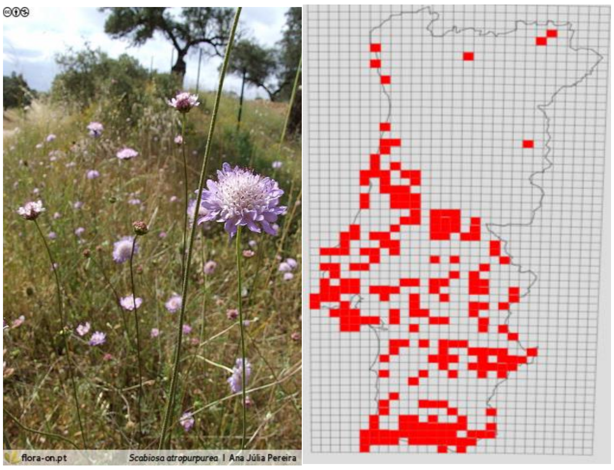

Figure 42. Scabiosa atropurpurea L. and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.24. *Sedum sediforme*

Sedum sediforme is a perennial subshrub plant, also known as ‘pine-weed. ' It belongs to the family Crassulaceae. It is indigenous to mainland Portugal. It appears in dunes, pine forests, clearings of scrub, rocks, bluffs, and walls. It colonizes poor, sandy, or stony soils, usually basic or, less often, acidic. The flowering season is from June to September, but there are reports of flowering starting in April. The peak of flowering is in July (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 43).

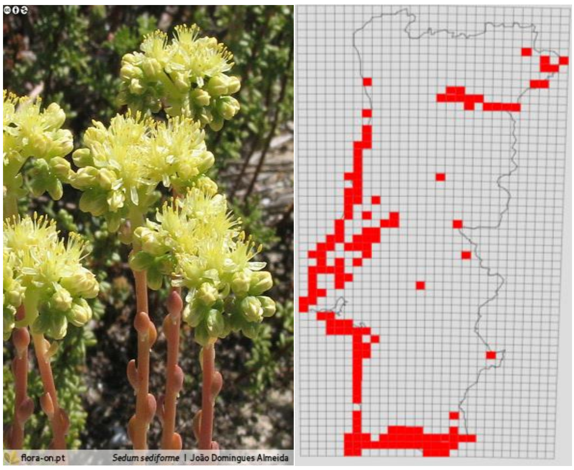

Figure 43. Sedum sediforme and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.25. *Stachys germanica*

Stachys germanica is a perennial herbaceous plant (hemicryptophyte), which belongs to the Lamiaceae family. It often appears on calcareous soils, edges, and undergrowth clearings. It blooms from March to June and pollinating insects visit its flowers, mainly bees (*Flora-On | Interactive Portugal Flora*, n.d.) (Figure 44).

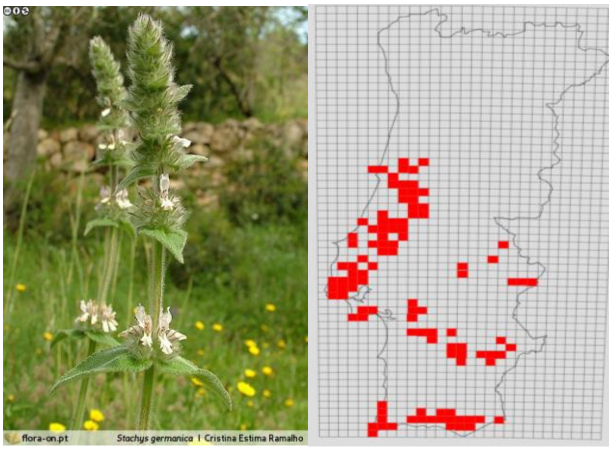

Figure 44. Stachys germanica L. and Its distribution map in Portugal (*Flora-On | Interactive Portugal Flora*, n.d.)

3.1.3.26. *Teucrium scorodonia*

Teucrium scorodonia is a perennial herbaceous plant (hemicryptophyte), belongs to the Lamiaceae family. It appears on the edges of deciduous or evergreen forests, mountain meadows, side roads, banks of water lines, rocky slopes, or cracks in rocks. It prefers siliceous, sandy, or limestone substrate. It blooms from June to September, peaking in May, presenting simple or branched inflorescences (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 45).

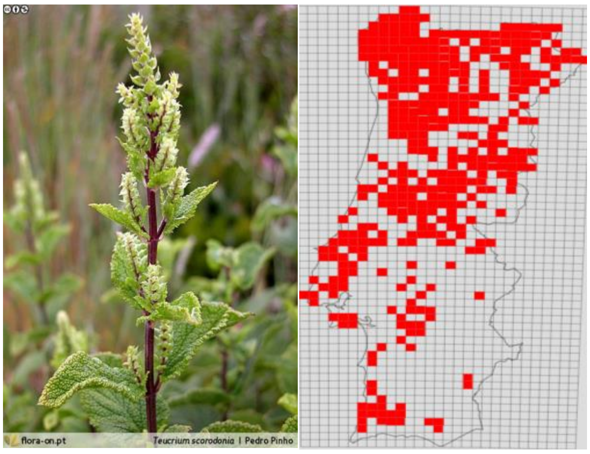

Figure 45. Teucrium scorodonia L. and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.3.27. *Trifolium incarnatum*

Trifolium incarnatum or 'Red clover' is an annual species (terophyte), from the Fabaceae family. Found in annual meadows, on nitrified soils. It is widely used in plant mixtures to plant road slopes and green manure (sideration). It has a vigorous and fast life cycle. As the name suggests, its flower is red and appear from January to August, with the most intense flowering in April and May. In addition to the advantages of the soil and aesthetic interest, these plants are also beautiful to pollinators (*Flora-On* | *Interactive Portugal Flora*, n.d.) (Figure 46).

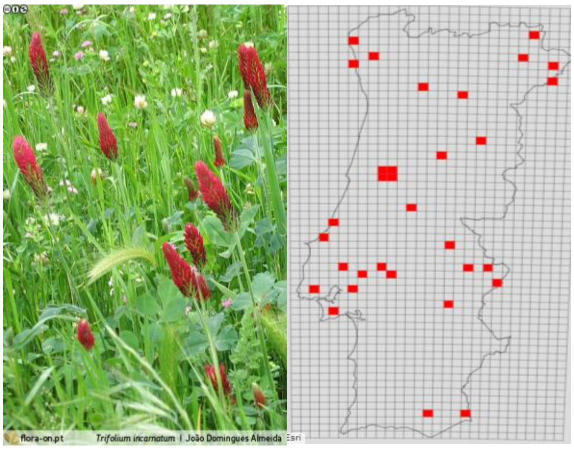

Figure 46. Trifolium incarnatum and Its distribution map in Portugal (*Flora-On* | *Interactive Portugal Flora*, n.d.)

3.1.4. Data analysis method

At the NativeScapeGR project, species were planted directly after prepared testbeds, then irrigate under two different levels. For approximately one year photographed to evaluate plant growth and its aesthetic value over time through digital image analysis with Adobe Photoshop CC 2015 software (Anico, 2016). In apiWall project, species adaptation and survival were evaluated for five months in the nurseries of the company Sigmetum (https://www.sigmetum.com/). In the next step, species were planted after preparing the testbed and irrigated under two different levels. Plants we digitally photographed for several months to be possible to evaluate its growth as well as its aesthetic value over time; all data were processed in Excel.

The percentage survival of the planted species was assessed across the NativeScapeGR, apiWall and apiMat projects. According to (MacIvor & Lundholm, 2011b), each species' values must be summed and divided by the total to calculate each species' survival rate.

Each plant's number of flowers (directly correlated with the plant's aesthetic value) in each test beds was counted during the test period in NativeScapeGR and apiWall projects.

The percentage of ground coverage each plant species was counted through a grid's superimposition, with fixed dimensions of 2 cm x 2 cm, to compare the plants' dimensions.

3.2. Application of EIVs to the green roof lab database

The mortality and persistence results, ground cover area, time, and intensity of flowering data collected were analyzed and interpreted to assess each species' development and aesthetic value.

In this project, Ellenberg's ecological indicator values, an ordinal numerical classification system, were used to select the Mediterranean green roof's adequate plant species.

While the cultivation tests were carried out in different experimental sets, Ellenberg's ecological indicator values were used for the whole data to increase the potential success rate of plants selected (Caneva et al., 2015) and identify which species are more suitable for green roof conditions.

Unfortunately, there is not any information about Ellenberg indicators adapted to the Portuguese flora. Therefore, due to almost identical weather conditions between Portugal and Italy, we used Ellenberg indicators adapted to the Italian flora (Pignatti, 2005), which expanded to 12 values for Light and Temperature indicators (refer to 2.10. Ellenberg's indicator Values (EIVs)).

Base on the method (Caneva et al., 2015), in this study, species which consider for the Lisbon climate are based on the following Ellenberg's values : L ≥7 (from well-lit to full light conditions), T ≥7 (adapted to heat stress), H ≤5 (adapted to the extreme to average dryness).

4. RESULTS & DISCUSSION

4.1. Species survival rate

The survival of a plant on a green roof is partly due to its ability to sustain itself, whether by seed or transplantation (Hawke, 2015).

The survival rate of species included *Brachypodium phoenicoides*, *Lavandula stoechas*, and *Rosmarinus officinalis,* in the NativeScapeGR project was close to 100% until the end of the experience (Table 2) (Figure 47). It became clear that those species survive well under the Mediterranean climate (Csa and Csb base on Koppen-Geiger classification) and in green roof microclimate conditions.

In the apiWall project, during the eight-month trial period, *Sedum sediforme* had a 100% survival rate, while *Antirrhinum linkianum* and *Centranthus ruber* had 90% and 80%, respectively. At the same time, the results for *Asphodelus fistulosus* were quite different since only 15% of the plants remained (Figure 48).

In the apiMat project, in April after seeds planted on mats and then carpet transplant to the testbeds, only the following survival rates were investigated in June: 0.5%, 1.4%, 1.5%, 1.6%, 1.8%, 4.6%, 7.4%, 28.3%, 36.1%, 37.4%, 65.5%, and 100%, for *Capsella bursa-pastoris, Stachys germanica, Plantago lanceolata, Trifolium incarnatum, Teucrium scorodonia, Lavatera trimestris, Briza maxima, Scabiosa atropurpurea, Cichorium intybus, Papaver rhoeas, Foeniculum vulgare,* and *Chrysanthemum coronarium respectively* (Figure 49). However, other apiMat project species include: *Achillea ageratum, Anagallis arvensis, Anthyllis vulneraria, Centranthus ruber, Cerinthe major, Ecballium elaterium, Euphorbia segetalis, Lavandula stoechas, Nigella damascena, Sedum sediforme, and Sanguisorba verrucosa, which did not survive until the end of the experience. The species Lavandula stoechas, Centranthus ruber*, and *Sedum sediforme* used in NativeScapeGR and apiWall project (Anico, 2016; Martins, 2018) showed promising results. The same was not right for the apiMat project, as detailed in Figueiredo (2020). Figueiredo (2020) reports that, the reasons why some species did not survive could be the following: 1) in some areas, the substrate was dragged, creating spaces where the coconut fiber was exposed; consequently, no vegetation developed; 2) the presence of small birds, that may have consumed the seeds; 3) the mats were rolled over themselves to allow transfer and, in this process, some of the plants with more upright roots had the root injured, whereas this was not the case for plants with fasciculate root.

The plant's survival rate influences the aesthetic value of the green roof and, by maximizing plants' survival by selecting appropriate species we can improve that aesthetic value. Aesthetic value is an essential aspect of green roofs performance that could influence their long-term acceptance by human populations (MacIvor & Lundholm, 2011a).

The species transplanted from nursery to test beds on the roof had a higher survival rate than species planted by seed on mats. In NativeScapeGR and apiWall project, the best survival rate belongs to *Brachypodium phoenicoides* (100%), *Lavandula stoechas* (100%), *Rosmarinus Officinalis* (100%), *Antirrhinum linkianum* (90%), *Sedum sediforme* (100%), *Centranthus rubber* (90%), and in the apiMat project belongs to *Chrysanthemum coronarium* (100%), *Foeniculum vulgare* (65%), *Papaver rhoes* (37%), *Cichorium intybus* (36%), and *Scabiosa atropurpurea* (28%) (Table 2).

Figure 47. Survival species at NativeScapeGR project

Figure 48. Survival species at apiWall project (Martins, 2018)

Figure 49. Survival species at apiMar project (Catarina da Silva Figueiredo, 2020)

Table 2. Survival rate of species in each project.

Species	Application	Survival rate
Brachypodium phoenicoides	Planted	100%
Chrysanthemum coronarium	Sowed	100%
Lavandula stoechas	Planted	100%
Rosmarinus officinalis L.	Planted	100%
Sedum sediforme	Planted	100%
Antirrhinum linkianum	Planted	90%
Centranthus ruber	Planted	90%
Foeniculum vulgare	Sowed	65.5%
Papaver rhoes	Sowed	37.4%
Cichorium intybus	Sowed	36.1%
Scabiosa atropurpurea	Sowed	28.3%
Asphodelus fistulosus	Planted	15%
Briza maxima	Sowed	7.4%
Lavatera trimestris	Sowed	4.6%
Teucrium scorodonia	Sowed	1.8%
Trifolium incarnatum	Sowed	1.6%
Plantago lanceolata	Sowed	1.5%
Stachys germanica	Sowed	1.4%
Capsella bursa-pastoris	Sowed	0.5%

4.2. Intensity & Duration of flowering

Like any permanent garden, floral displays are important on green roofs to enhance the green roof's aesthetic value. An assessment of floral traits includes the bloom period and flowering (Caneva et al., 2015).

In the NativeScapeGR project, the duration of flowering under reduced watering (60% ET_o) for *Lavandula stoechas* and *Rosmarinus officinalis* was approximately two months. Under higher irrigation level (100% ET_o), flowering occurred for one month for the same species, while in *Brachypodium phoenicoides* the period of flowering in both watering conditions was the same and occurred only during one month (Figure 52) . This indicates that the different irrigation levels did not drastically affect the duration of the flowering of *Lavandula stoechas*, *Rosmarinus officinalis*, and *Brachypodium phoenicoides* (Anico, 2016).

In the NativeScapeGR project, flowering was slightly higher in the condition of low irrigation levels. However, there was no significant difference compared to the conditions of high irrigation levels (Figure 50).

April and July were the flowering seasons for *Lavandula stoechas*, under 60% ETo. Flowering season under 60% ETo for *Rosmarinus officinalis*, was in January and February, and for *Brachypodium phoenicoides*, it occurred in September. Under 100% ETo, the flowering season for *Lavandula stoechas* was in April, for *Rosmarinus officinalis* was in February, and for *Brachypodium phoenicoides* was in July (Figure 50).

In the apiWall project, the duration of flowering under reduced watering in *Antirrhinum linkianum, Asphodelus fistulosus, and Sedum sediforme* were four, three, and four months, respectively, which represents more considerably extended periods than in higher irrigation level conditions. These results were consistent with *Lavandula stoechas* and *Rosmarinus officinalis*, in the first stage of the experiment. Besides, the flowering intensity of those species was higher in reduced irrigation conditions. However, the results of *Centranthus ruber* showed a different pattern from other species; for this species, the reduction of irrigation minimizes the intensity and duration of flowering (Figure 53). The flowering season in *Antirrhinum linkianum, Asphodelus fistulosus, Sedum sediforme, and Centranthus ruber* (under 60% ET_o irrigation) occurred from May to September, May to August, May to July, and May to June, respectively. Under higher level irrigation conditions, the flowering season in *Antirrhinum linkianum* and *Sedum sediforme* took place from May to August and in *Centranthus ruber* from May to September (Figure 51).

After analyzing the results, it is possible to verify that, in general, the data obtained suggest a quantitative increase in flowering with a decrease in the watering supplied to the system. It supports the previous study's idea, where the reduction in the watering level does not compromise the aesthetic value of plant material (Anico, 2016).

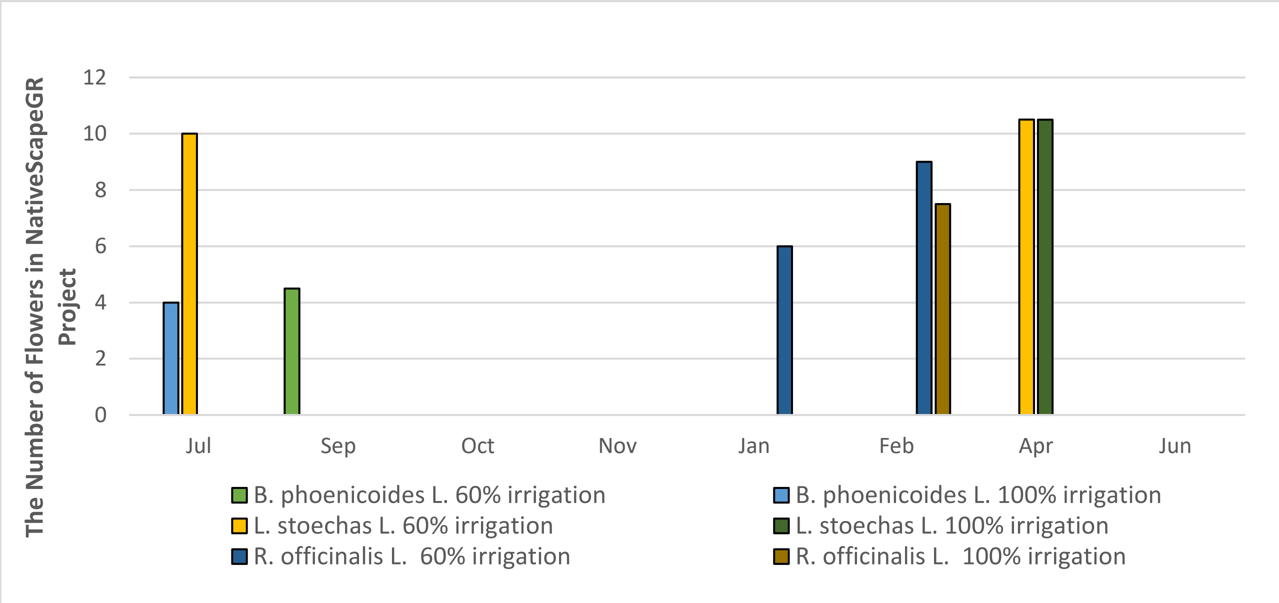

Figure 50. Intensity and Duration of Flowering in *Lavandula stoechas* L., *Brachypodium phoenicoides* L., *Rosmarinus officinalis.* L. in NativeScapEGR project

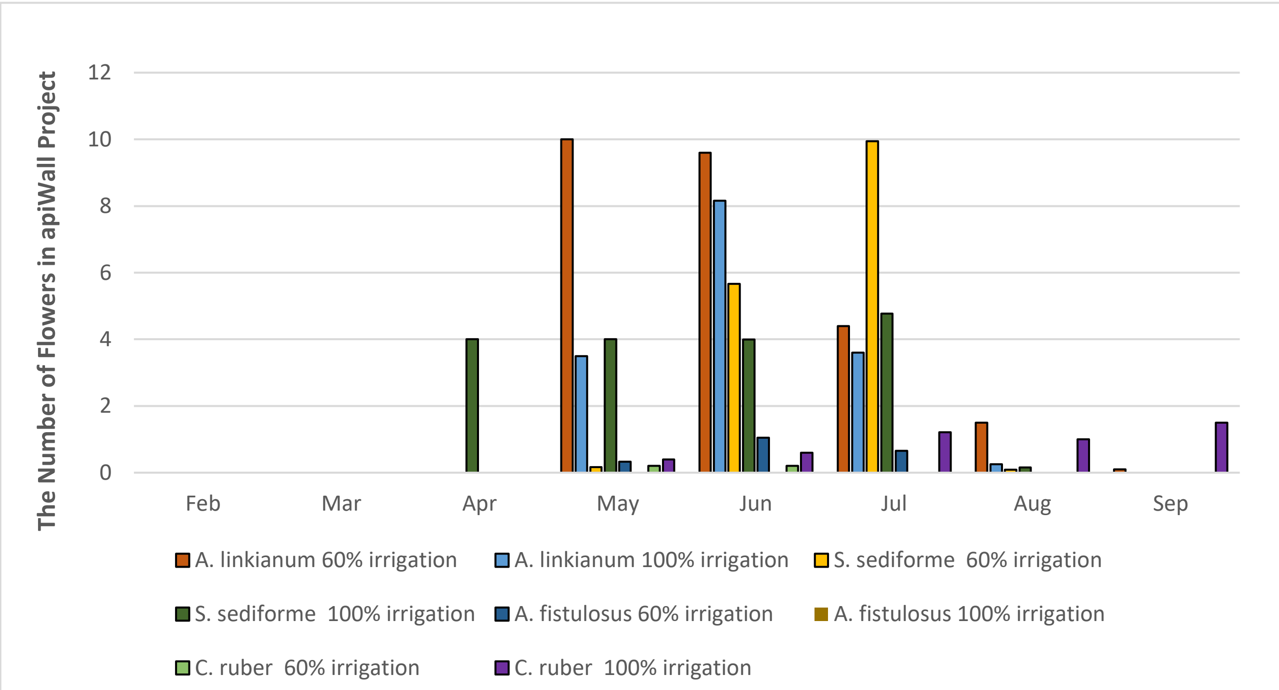

Figure 51. Intensity and Duration of Flowering *Antirrhinum linkianum, Asphodelus fistulosus, Sedum sediforme,* and *Centranthus ruber* in apiWall project.

One of the specifications that can elevate vegetated roofs' stability over time is the flowering and flowering period (Cáceres et al., 2018). Thus, we obtained the flowering and flowering period determined partly by vegetated roofs' stability over time. Generally, Top-ranking taxa flowered in spring, summer, and fall, creating elegant floral displays on a diversity of plants (Hawke, 2015). Therefore, in this study, early bloomers such as *Antirrhinum linkianum*, *Lavandula stoechas* and *Sedum sediforme* brought the green roof to life beginning in late April and early May. Summer-flowering perennials provided the most extended bloom periods, from June through September. Among the best shows of the summer-flowering taxa were *Antirrhinum linkianum*, *Lavandula stoechas,* and *Sedum sediforme,* and the best late-season species were *Brachypodium phoenicoides*, *Centranthus ruber*, and *Rosmarinus officinalis.*

Figure 52. Rosmarinus officinalis. L. in NativeScapEGR project

Figure 53. Centranthus ruber flowering at apiWall project

4.3. Ground cover

According to (Anico, 2016), the highest ground cover area was achieved in the case of ground cover by *Lavandula stoechas*, in April, under 60% ET_o irrigation, and *Brachypodium phoenicoides* under 100% irrigation conditions. However, in general, various irrigation levels did not significantly induce differences in species' green cover (Figure 54).

As reported by (Martins, 2018) (Figure 57), *Antirrhinum linkianum* and *Sedum sediforme* showed better results under high irrigation conditions. The results were different for *Asphodelus fistulosus* and *Centranthus ruber* so that the green area in both species was higher under low irrigation conditions.

A remarkable point is that all *Asphodelus fistulosus* plants died in comfortable irrigation conditions after two months. Mainly, it should be noted that there was no significant difference between the green area levels of *Antirrhinum linkianum, Sedum sediforme, Asphodelus fistulosus*, and *Centranthus ruber* in both irrigation conditions (Figure 55).

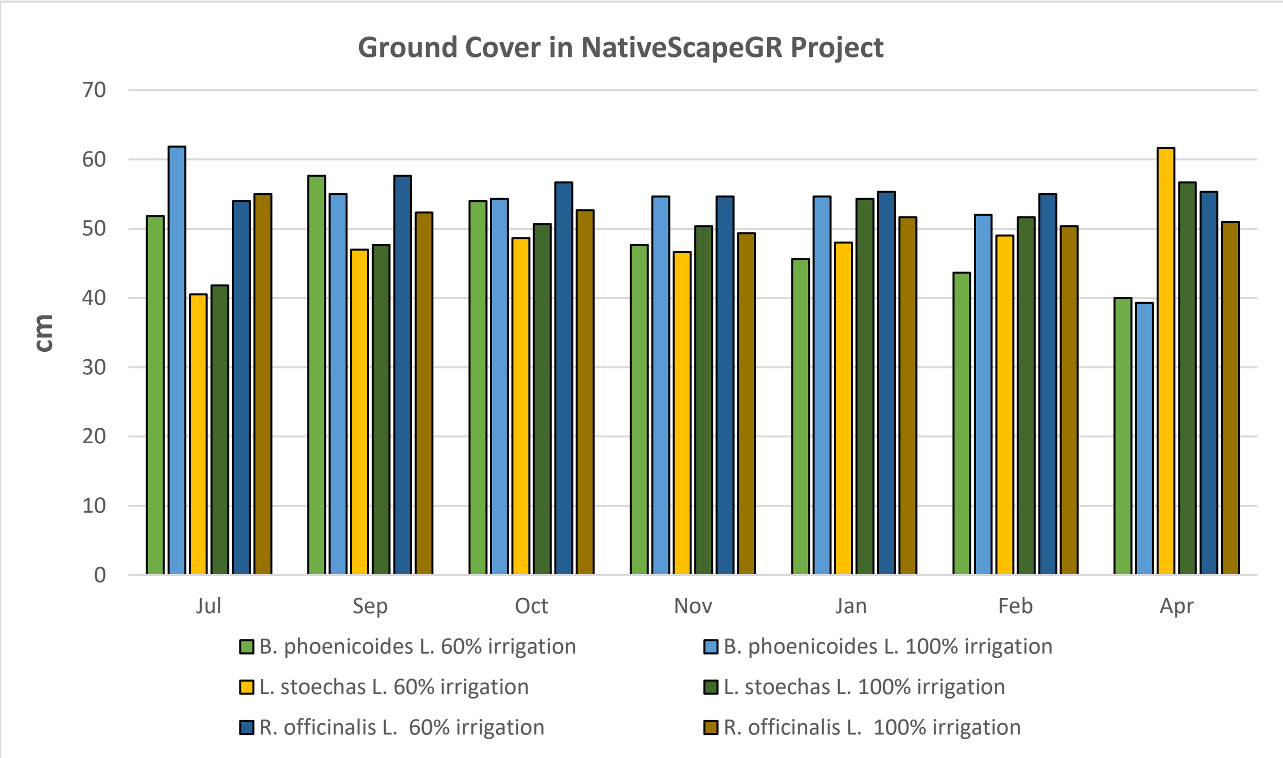

Figure 54. Ground Cover Species *Lavandula stoechas*, *Brachypodium phoenicoides, Rosmarinus officinalis (*The total area is 250 cm per each bed) in NativeScapeGR Project.

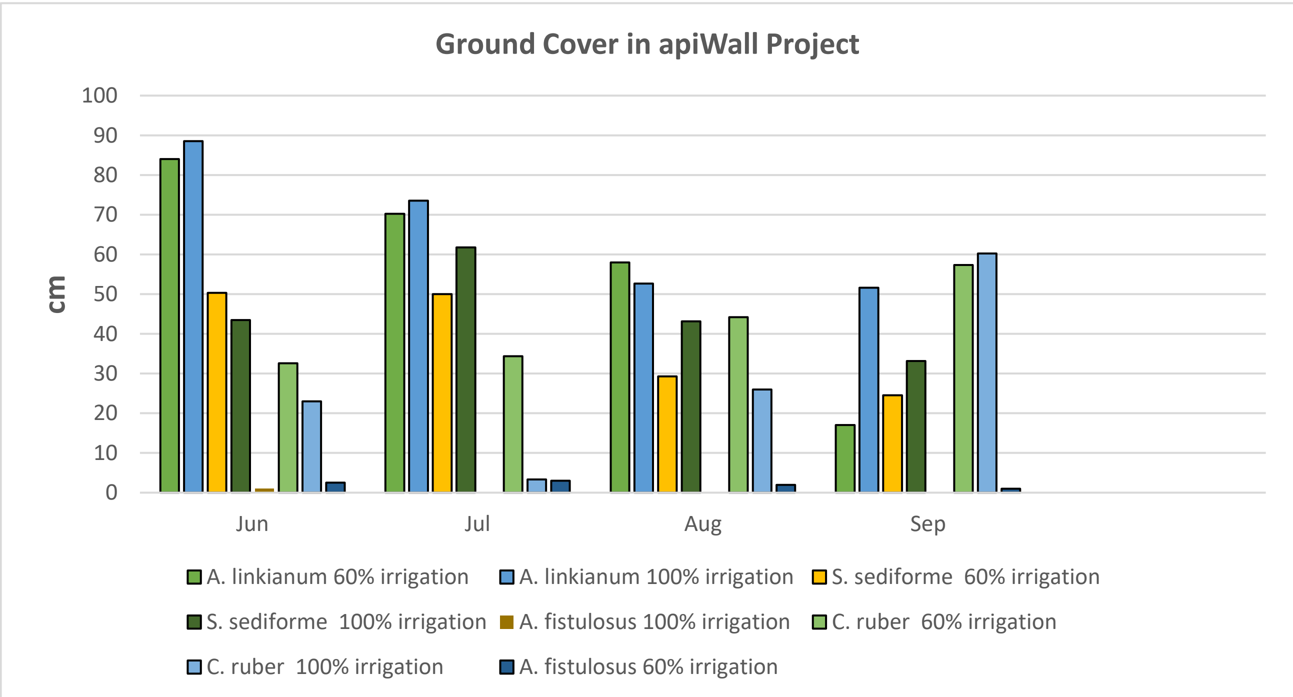

Figure 55. Ground Cover species in *Antirrhinum linkianum* and *Sedum sediforme, Asphodelus fistulosus* and *Centranthus ruber* (The total area is 250 cm per each bed) in apiWall Project.

In the apiMat project (Figure 58), all species were planted by seed on pre-cultivated mats under 60% irrigation. Generally, it was found that *Serratula* spp., *Chrysanthemum coronarium, Cichorium intybus, Papaver rhoes, Capsella bursa-pastoris*, and *Scabiosa atropurpurea* showed the maximum green area, compared to other species (Figure 56). Bear in mind that *Serratula* spp. were colonized in all the mats mixtures without being planted.

In Mixture 1 mats, 100% of their area was covered by vegetation *Serratula* spp.*, Briza maxima*, and *Trifolium incarnatum*. Most of the green stain on mats was due to *Serratula* spp.

In mixture 2, *Serratula* spp. represent a large percentage of the area, then *Papaver rhoes* and *Capsella bursa-pastoris*.

In Mixture 3 Green areas were covered almost the entire mat (94%). *Chrysanthemum coronarium* occupies 54% of the area, part of which is occupied by developed plants. *Cichorium intybus* occupies a vast area, its long and broad leaves increasing the area occupied by each plant. However, other species germinated in terms of the occupied area do not present a significant percentage of occupation.

Mixture 4 has the lowest degree of coverage, most of which is guaranteed by *Serratula* spp. It is important to emphasize that the sum of the percentages can be higher than 100% (Figure 56) since the vegetation develops in strata and may overlap.

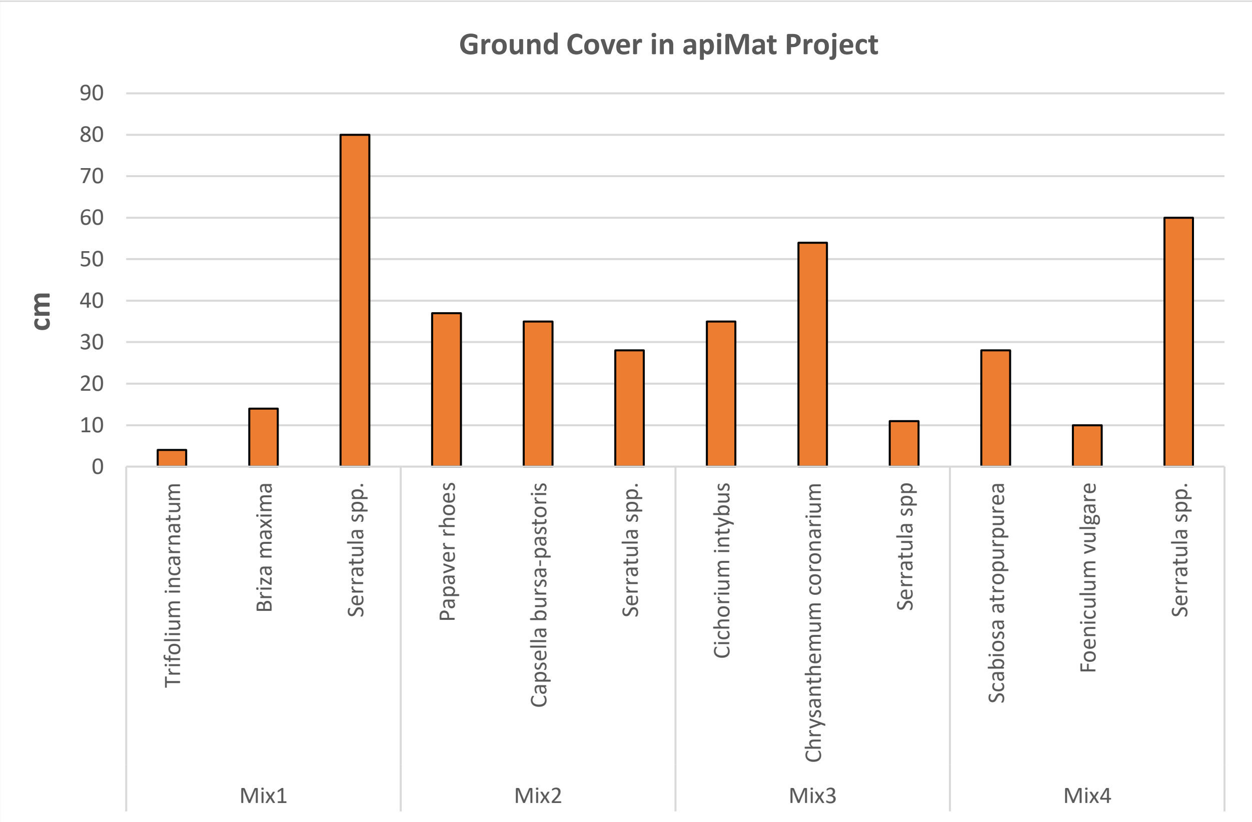

Figure 56. Ground cover Species *Serratula* spp.*, Chrysanthemum coronarium, Cichorium intybus, Papaver rhoes, Capsella bursa-pastoris, Scabiosa atropurpurea*, *Briza maxima, Foeniculum vulgare,* and *Trifolium incarnatum* (The total area is 250 CM per each bed) in apiMat Project

Under the conditions studied, the direct planting technique showed the best results for the analyzed period. In comparison, sowing on mats and transplanting would require more time to reach further detailed conclusions. Therefore, according to the appropriate species production on a mat, one should be aware that a species must grow successfully on the mats from the beginning of sowing to the green roof's re-installation. Species that complete this process quickly are most eligible to growers since this decreases the period required to produce a marketable mat (Vinson & Zheng, 2013).

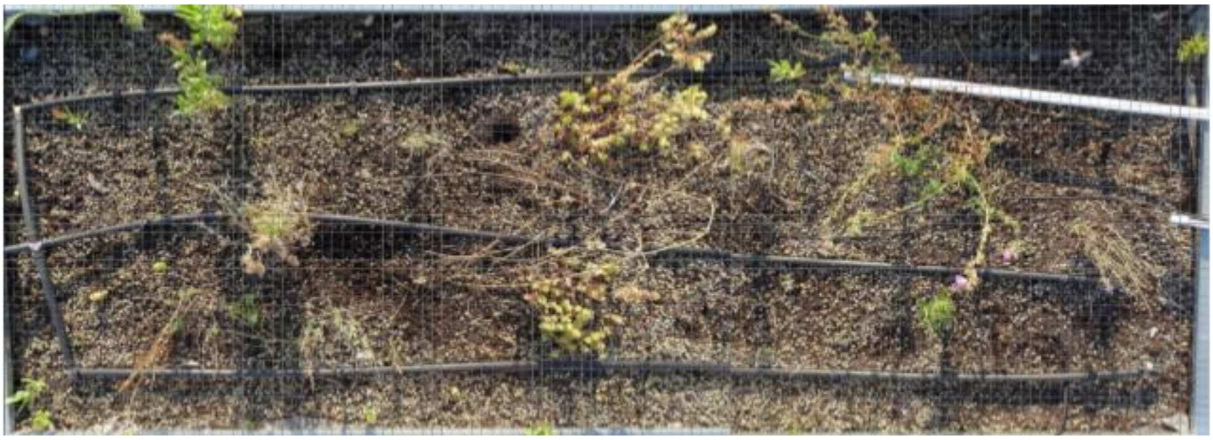

Figure 57. Example picture board for counting square (Martins, 2018)

Figure 58. Example picture as Ground coverage pre-cultivated mats at apiMat project

4.4. The Suitable Plant Native Species: The Results of NativeScapeGR, apiWall, and apiMat Projects

According to the results of the survival rate, intensity, duration of flowering, and cover area of native species obtained from NativeScapeGR, apiWall, and apiMat projects, we can conclude that: *Antirrhinum linkianum, Brachypodium phoenicoides, Briza maxima, Capsella bursa-pastoris, Centranthus ruber, Chrysanthemum coronarium, Cichorium intybus, Foeniculum vulgare, Lavandula stoechas, Papaver rhoes, Rosmarinus officinalis, Scabiosa atropurpurea, Sedum sediforme, Serratula spp*., species are suitable for cultivation in green roofs in the Lisbon region, and they can show acceptable results (Table 3).

Table 3.The results of Survival rate, Intensity of flowering, Ground cover, Duration of a flowering suitable native species NativeScapeGR, apiWall and apiMat projects

Species	A	S	IF	DF	GC
Antirrhinum linkianum	Planted	90%	10N r	4M h,r	88.5cm h
Brachypodium phoenicoides	Planted	100%	4.5N r	1M h,r	61.83cm h
Briza maxima	Sowing	7.20%	-	-	35cm r
Capsella bursa-pastoris	Sowing	0.5%	-	-	87.5cm r
Centranthus ruber	Planted	90%	1.5N h	5M h	60.25cm h
Cichorium intybus	Sowing	36.1%	-	-	87.5cm r
Chrysanthemum coronarium	Sowing	100%	-	-	135cm r
Foeniculum vulgare	Sowing	65%	-	-	25cm r
Lavandula stoechas	Planted	100%	10.5N h,r	2M h	61.66cm r
Papaver rhoes	Sowing	37%	-	-	92.5cm r
Rosmarinus officinalis L.	Planted	100%	9N r	2M h	57.66cm r
Scabiosa atropurpurea	Sowing	28%	-	-	70cm r
Sedum sediforme	Planted	100%	9.94N r	5M h	61.75cm h
Serratula spp.	Sowing	100%	-	-	200cm r

Legend				
	A	**Application**	**N**	**Number**
	S	**Survival**	**M**	**Month**
	IF	**Intensity of flowering**	**h**	**High irrigation**
	GC	**Green covering**	**r**	**Reduction irrigation**
	DF	**Duration of flowering**		

4.5. Ellenberg’s Indicator Values for all Species in NativeScapeGR, apiWall & apiMat projects

Ellenberg’s indicator values were examined for all species used in NativeScapeGR, apiWall, and apiMat project (Table 4) (Figure 59).

Table 4. Ellengerg's Numerical indicators all species

	Ellenberg's indicators					
Species	**A**	**L**	**T**	**H**	**R**	**N**
Antirrhinum linkianum	Planted	11	8	2	x	1
Asphodelus fistulosus	Planted	11	8	2	4	2
Brachypodium phoenicoides	Planted	8	8	3	8	4
Briza maxima	Sowed	8	10	2	4	1
Capsella bursa-pastoris	Sowed	7	x	5	5	4
Centranthus ruber	Planted	6	8	2	x	1
Chrysanthemum coronarium	Sowed	7	9	3	4	4
Cichorium intybus	Sowed	9	6	3	8	5
Foeniculum vulgare	Sowed	9	8	3	7	7
Lavandula stoechas	Planted	11	9	2	1	1
Lavatera trimestris	Sowed	8	9	2	5	4
Papaver rhoes	Sowed	6	6	5	7	x
Plantago lanceolata	Sowed	6	7	x	x	x
Rosmarinus officinalis	Planted	11	8	2	6	1
Scabiosa atropurpurea	Sowed	0	0	0	0	0
Sedum sediforme	Planted	11	10	2	4	2
Serratula spp.	Sowed	7	6	x	8	5
Stachys germanica	Sowed	7	6	3	8	8
Teucrium scorodonia	Sowed	6	5	4	2	3
Trifolium incarnatum	Sowed	11	8	4	5	7

Legend				
	L	**Light**		
	T	**Temperature**		
	H	**Humidity**		
	R	**Reaction**		
	N	**Nitrogen**		
	L	**From 1 to 12**	**X**	**broad-spectrum species**
	T	**From 1 to 12**		
	H	**From 1 to 12**	**0**	**insufficient information**
	R	**From 1 to 9**		
	N	**From 1 to 9**		

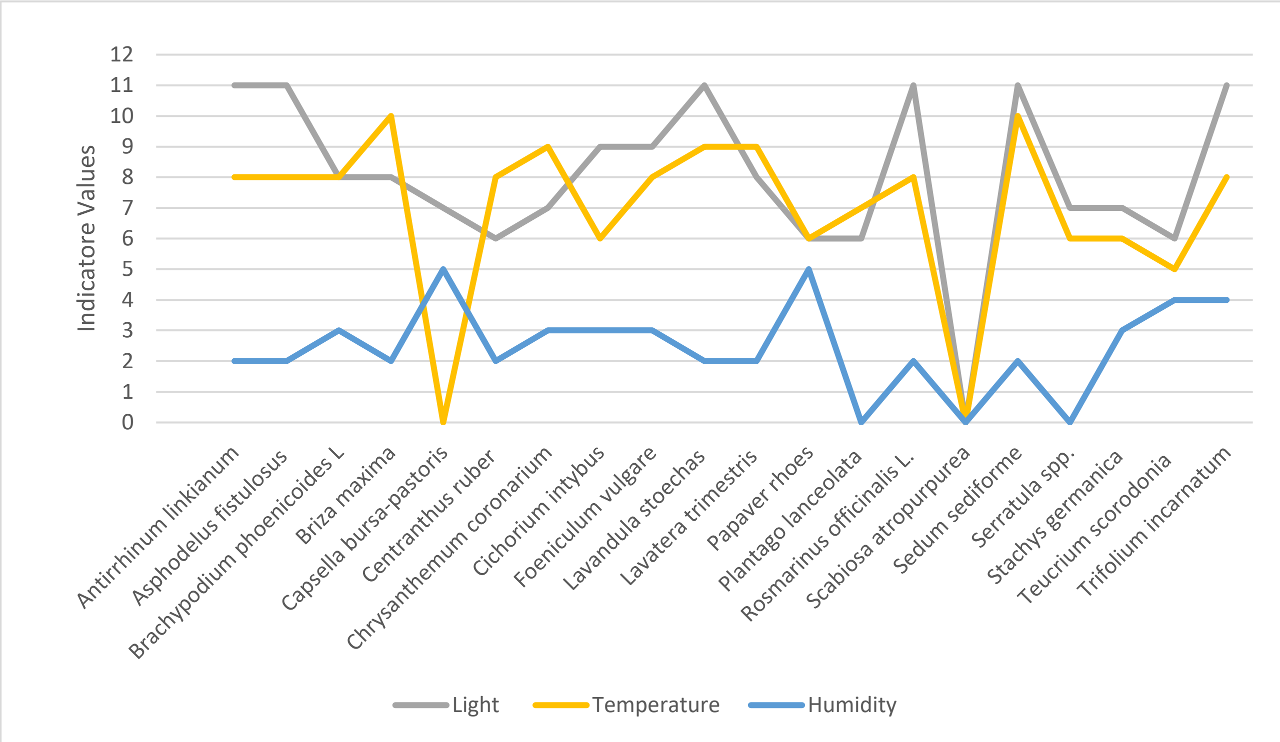

Figure 59. Comparison of Ellenberg's indicators of light, temperature, and humidity among all species

Among all species, studied, only twelve species introduced according to the following characteristics: L ≥7 (from bright and low light to full light), T≥7 (adapted to heat stress), and H ≤ 5 (from intense aridity to well-watered soils) in order to increase the potential success rate of plants selected.

These indicators ecologically circumscribe a set of species that are the most tolerant plant species based on the Mediterranean's ecological features.

Species include *Brachypodium phoenicoides, Lavandula stoechas, Rosmarinus officinalis, Antirrhinum linkianum, Asphodelus fistulosus, Sedum sediforme, Trifolium incarnatum, Briza maxima, Foeniculum vulgare, Lavatera trimestris, Chrysanthemum coronarium, Capsella bursa-pastoris* (Figure 60). In general, these species' results indicate that they do not require repetitive irrigation or other constant maintenance interventions and that they are adapted to the Mediterranean area (Caneva et al., 2015).

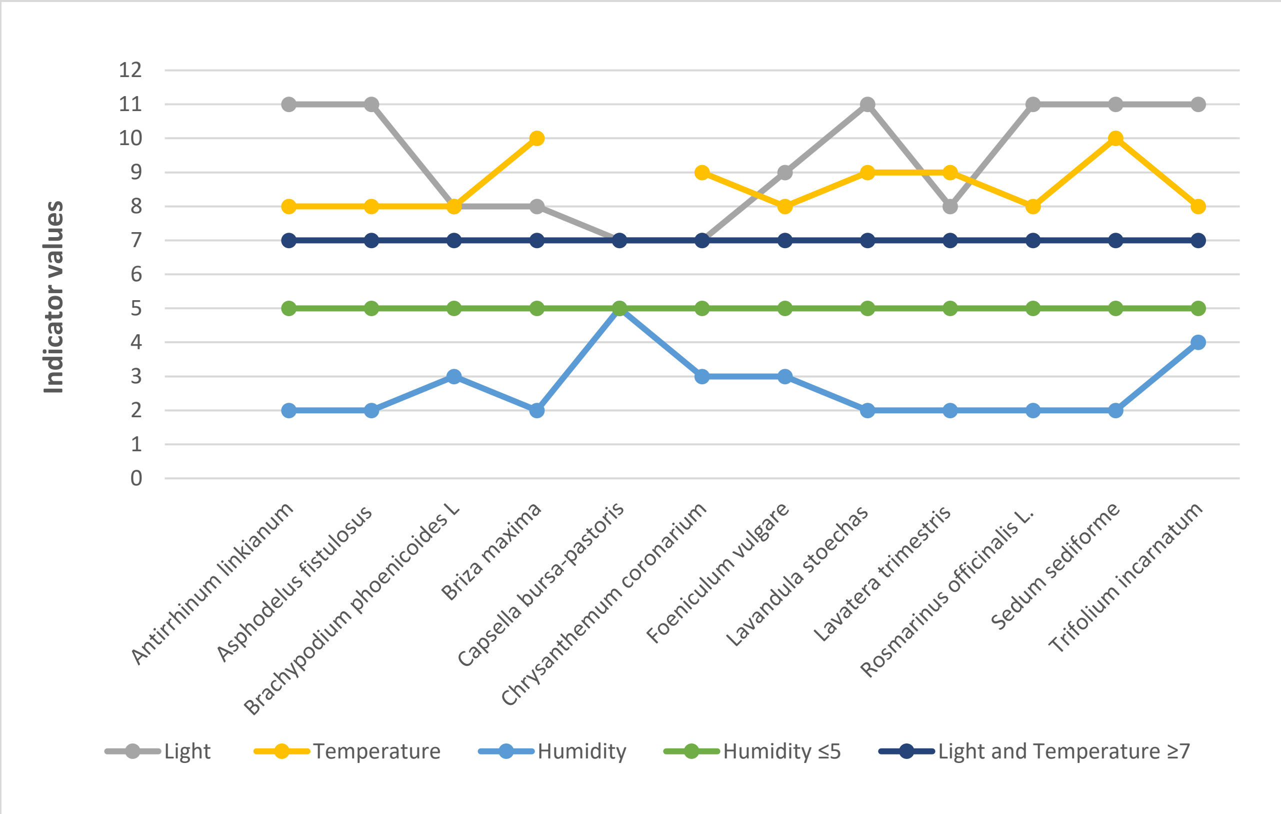

*Figure 60. List of potential plant species to be used in Mediterranean green roofs according to the selection method proposed in the current work using Ellenberg's values for light (L), temperature (T), and humidity (H). *So far, no values have been introduced for the temperature indicator Capsella bursa-pastoris.*

By comparing the results of suitable native species from NativeScapeGR, apiWall, and apiMat projects and the most tolerant plant species according to the following Ellenberg's indicators L ≥7, T≥7 and H ≤ 5, we can confidently introduce *Antirrhinum linkianum, Brachypodium phoenicoides L., Briza maxima, Capsella bursa-pastoris, Chrysanthemum coronariumm Foeniculum vulgare, Lavandula stoechas, Rosmarinus officinalis L., and Sedum sediforme,* as suitable native plant species for green roofs in the Lisbon area.

These species could be adapted to limiting factors like semi-arid and long dry summers conditions in the Mediterranean area. Therefore, the combined methods of plant biodiversity and the plant's ecological indicators can be used to guarantee high levels of green roofs' success rate in the Mediterranean region and increase urban biodiversity, based on the assumption that natural ecosystems can be used as green models roof design.

4.6. Suggestions for Potential Commercial Use

Green roof details

- Extensive Green roof with 20 cm deep
- A substrate with Commercial organic material
- Lighting with full sun (1 m high from the building's roof surface to remove shadow)
- Irrigation with drip system with 60% ETo (reference evapotranspiration)

Recommended plant species

Antirrhinum linkianum, Brachypodium phoenicoides L., Briza maxima, Capsella bursa-pastoris, Chrysanthemum coronarium, Foeniculum vulgare, *Lavandula stoechas, Rosmarinus officinalis L.,* and *Sedum sediforme.*

- The selected species can be planted side by side according to the flowering of one species. When the flowering of one species is over, the flowering of another species begins. It can help to the aesthetic aspect of a green roof.
- Direct plantation should be preferred over sowing.
- Based on these species' ability to ground cover, it is suggested that in the first year, planting occurs more densely and in larger quantities. In the following year, pruning and thinning operations can be done to increase the action's aesthetic aspects and quality.
- It is suggested that 60% ETo irrigation during cultivation and maintaining.

5. CONCLUSION

In the present study, the results of NativeScapeGR, apiWall, and apiMat projects were investigated under two different irrigation levels in Lisbon, Portugal; then, there was an intersection between these projects' results and Ellenberg's indicator values of native plant species' in green roofs conditions. Afterward, suitable species were identified for planting on green roofs in the Lisbon area and the following aspects were analyzed:

- **Survival rate:** *Antirrhinum linkianum Brachypodium phoenicoides*, *Centranthus ruber Lavandula stoechas*, *Rosmarinus officinalis*, and *Sedum sediforme*, that planted directly had a high rate of survival, which means that different levels of irrigation did not change the survival rate of the plants. Since climate change threats make water conservation a priority, lower irrigation levels are preferable. Among 24 species sowed by seeds only *Cichorium intybus, Chrysanthemum coronarium, Foeniculum vulgare, Papaver rhoeas, Scabiosa atropurpurea, and Serratula* spp*.,* had high survival level. Therefore, by comparing the two methods of planting, it can see species with direct planting are more likely to survive than species sown by seed.
- **Flowering** was favored in the situation of reduced watering in species *Antirrhinum linkianum, Asphodelus fistulosus, Brachypodium phoenicoides, Lavandula stoechas, Rosmarinus officinalis,* and *Sedum sediforme*, which showed greater intensity and longer duration for this stage. Therefore, 60% ETo is a suitable irrigation option to plant and maintain these green roof species.
- Concerning **ground cover**, species *Brachypodium phoenicoides, Centranthus ruber* and *Rosmarinus officinalis* under reducing watering showed larger coverage areas. In contrast, *Antirrhinum linkianum, Lavandula stoechas* and *Sedum sediforme*, under a higher watering level developed a larger coverage. However, there was no perceptible difference in the amount of green coverage for those species, under two irrigation conditions, in general. *Briza maxima, Capsella bursa-pastoris, Chrysanthemum coronarium*, *Cichorium intybus Papaver rhoes,* and *Serratula* spp*.,* occupied almost the entire area. Those species were under 60%ETo irrigation and showed an apreciable ground cover of the respective area. Thus, it is possible to confirm that the use of 60% irrigation can be suitable to allow adequate coverage of the ground by those species, and native plants collected in inhospitable places may present good adaptation to this situation.
- According to the irrigation water levels used in this study, using 60% ETo irrigation level in comparison to 100%ETo did not perceptible differ in species growth and

development. Still, in some species, the effect of a low irrigation rate originated better results.

- The Ellenberg’s indicator values, as a methodological approach, can be used as a comprehensive and reliable guide. The framework of Ellenberg indicator values can define the ecological aspects of plant species, so it can be used before selecting native plants to test in green roofs. These indicators can prevent wasting time and money on testing plant species.
- Finally, based on the results of the NativeScapeGR, apiWall, and apiMat projects and the Ellenberg indicators, it can be concluded that, the species *Antirrhinum linkianum, Brachypodium phoenicoides*, *Briza maxima, Capsella bursa-pastoris, Chrysanthemum coronarium*, *Foeniculum vulgare*, *Lavandula stoechas, Rosmarinus officinalis*, and *Sedum sediforme,* are the most suited species for the implementation of green roofs in the Lisbon area, with an irrigation level around 60%ETo.

With this study, we can affirm that green roofs in Lisbon, Portugal, under Mediterranean conditions, may benefit with the contribution of native plants. Especially native plants found naturally on roofs and walls, roadsides or bluffs, given their adequate adaptation to green roofs, with the maintenance of the aesthetic value, when the irrigation level is reduced.

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