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*Article*

# Selecting Potential Moss Species for Green Roofs in the Mediterranean Basin

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**Abstract:** Green roofs are important infrastructures to address the effects of climate change in urban areas. However, most studies and applications have been done in cooler and wetter regions of the northern hemisphere. Climate change will lead to more extreme weather events, such as increased drought and decreased precipitation with intense flash rain events. Increase desertification is expected especially in the Mediterranean Basin, where in summer, radiation and temperature are high and water is scarce. Therefore, while vascular plants increase water consumption in green roofs during warmer periods, mosses present themselves as potential candidates due to their poikilohydric nature, responding to the environmental availability of water, completely drying out and recovering upon rehydration. Although criteria for the selection of vascular plants adapted to the Mediterranean and suitable for green roofs have been developed, no information is available regarding the selection of mosses based on scientific criteria. Here we propose selection criteria for moss species based on ecological preferences according to Ellenberg's values and help to define moss traits suitable for a nonirrigated, nature-based green roof that tolerates the Mediterranean climate. The main result is a table of potential candidate mosses that can be either used as standalone or in conjunction with vascular plants to decrease water usage and/or manage stormwater through an easily applicable selection methodology. For green roof practitioners, we proposed that acrocarpous mosses exhibiting turf/cushion life forms and colonist or perennial life strategies best fit the requirements for such a green infrastructure in extreme climate regions with scarce water resources.

**Keywords:** mosses; sustainability; nature-based solutions; traits; urban ecology

## 1. Introduction

The Mediterranean climate is characterised by mild wet winters, autumns and springs with variable temperature and precipitation, and warm to hot, dry summers that are typical of semiarid climates [1]. However, nowadays, against a background of climate change with extreme temperatures (high and low) and precipitation (scarce or very intense flash rain events), drought periods occur in the whole Mediterranean Basin, not only in summer, but also in winter. The decrease in winter precipitation and the increase in air temperature have had a serious impact on the region [2], especially in cities, where urban heat islands further increase temperatures, reduce air humidity, and change local wind and precipitation patterns compared to peri-urban and rural areas [3]. Thus, there is growing interest in the development of green infrastructures mitigating climate change effects in urban areas [4].

Green roofs are plant-based spaces that mimic shallow substrate rock outcrops or meadow habitats. They are placed on a waterproof layer on top of houses, factories, offices and other buildings, and complement the ecosystem services provided by other types of green spaces in urban areas [5–8]. Moreover, at the building level, they help to improve thermal regulation by providing a shading increment and better insulation of the roof system, in addition to reducing noise pollution, increasing roof durability, hindering the spread of fires, and reducing energy consumption by mitigating heat loss from the building during winter [9,10]. Furthermore, green roofs with herbaceous and small shrubs can reflect 27% of solar radiation, absorb 60% through photosynthesis and transmit about 13% to the growing medium [11]. At the city level, the important contributions of green roofs include biodiversity conservation, improvement of urban aesthetics, increase in carbon sequestration to improve air quality, increased retention and delayed release of stormwater, and reduction of the urban heat island effect [12–15].

Given these benefits, green roofs constitute a highly valuable biological resource to be explored as a nature-based solution to mitigate the effects of climate change in urban areas. Among the plants with potential for green roof use are nonvascular plants, like mosses, as they are adapted to survive in extreme climate conditions (defined here as low and variable water availability and high radiation). Using the ISI Web of Knowledge database (February 2018) with the keywords “green roofs”, more than 1000 scientific studies of green roofs published in the last 10 years (January 2008 to December 2017) were identified; but when the search was narrowed including the keyword “moss” or “bryophyte”, only 14 studies on the use of mosses on rooftops remained, and only four of those focused on the Mediterranean. Moreover, most of the studies did not specify the species of investigated moss, referring to the plants simply as "mosses" or “bryophytes”. Mosses are poikilohydric, being able to completely desiccate under low relative humidity but quickly resuming metabolic activity upon rehydration [16]. The trade-off for the ability of moss species to survive such extreme conditions is a slow growth rate, which no doubt accounts for the lack of studies regarding their use in green infrastructures in this type of climate and thus the absence of a selection list for these plants. Yet, under controlled conditions of light, temperature and humidity, the growth rates can be increased [17].

Biological soil crusts, a complex community of soil particles, mosses, cyanobacteria, fungi and bacteria, have multifunctional roles including soil stability, the fixation of basic nutrients such as carbon (C) and nitrogen (N), $CO_2$ flux, N mineralisation [18,19] and serving as a habitat for other organisms. In these communities, mosses can retain several times their weight in water, allowing their self-sustained growth for longer periods than it would be predicted [20].

According to [21], commercial green surfaces that include mosses such as *Tortula muralis* and *Bryum argenteum* are slowly gaining favour and the advantage of these plants as a desiccation-tolerant poikilohydric may contribute to sustainable water-use, especially in areas with Mediterranean-like climates. Moreover, they can grow directly on a flat surface, with no or very little soil content, allowing exploration of more sloped surfaces, although establishment might require some roughness. It might also allow existing sloped roofs to be retrofitted where vascular plants would normally only establish with difficulty. However, despite the many benefits of using mosses in green roofs [10,21,22], criteria for the selection of moss species suitable for green covers under this climate have yet to be elaborated.

A study of plant functional traits can facilitate the selection of the species best-adapted to the conditions of the study area besides being less time consuming. A trait-based analysis to select vegetation for Mediterranean green roofs was previously performed for vascular plants [23] and resulted in a list of species appropriate for use under these conditions. In contrast to vascular plants, for which several protocols and databases that include their traits have already been published (e.g., [24]; LEDA: [25]; BROT: [26]; TRY: [27,28]), similar information for mosses is scarce. One such study focused on mosses in Great Britain (BRYOATT: [29]) and another on those in the Azores (BryoTraits AZO: [30]). Brandão and co-workers [31] have already shown that the combined green roofs of shrubs, grasses and mosses proved to be the most effective vegetation cover to reduce water use. The presence of the moss layer under the canopy also contributes to increasing the amount of water retention [32]. Hence, the importance of selecting the moss species best suited to local conditions. In the present study we propose the development of a selection method for moss species exhibiting beneficial characteristics and relevant for the green roof industry.

## 2. Materials and Methods

We began our study with two moss checklists: the Mediterranean Basin moss checklist from Ros and co-workers [33], which cited 1168 species, and Hodgetts' bryophyte checklist and country status for European countries [34], which cited 1515 species, of which 1285 are present in the Mediterranean Basin. Afterwards, we inserted each moss genus in an online database for European vegetation [35] based on Ellenberg's ecological preference values [36]. The Ellenberg's ecological preference values are based on an ordinal classification of plants according to the position of their realised ecological niche along an environmental gradient, allowing to generate a list of species classified with respect to light, temperature, humidity, nitrogen fertility, etc. From this list, we selected only the species whose Eilenberg values were typical for a Mediterranean climate and that can be experienced in a green roof from this area: light (8–9: light-loving and full-light plants); temperature (8–9: Mediterranean and sub-Mediterranean plants); and humidity (1–3: extreme dryness to moderately dry sites) and analysed their life form, growth form and lifestyle [37,38]. We also noted confirmed moss occurrence along the countries of the Mediterranean Basin to determine the more cosmopolitan species [33,34].

## 3. Results and Discussion

The result was a list of the 43 most tolerant moss species (Table 1) of the extreme conditions selected, corresponding to 3% of the moss checklist within the countries of the Mediterranean Basin [33,34]. It is the first time that Ellenberg's values of ecological preferences are used in the selection of mosses for use on green roofs in the Mediterranean and, as we can see in Table 1, these preferences reflect perfectly their functional traits, as expected, since according to the literature, life form, growth form and life strategy are related to plant strategy, climatic factors and land use [24,28–30,37,39]. Likewise, different life forms can be arranged in sequences reflecting water availability and light intensity in different habitats [40].

In this selection method, the predominant life forms are turfs (56%), followed by cushions (23%) and mats (21%). Our method confirms the fact that turf and cushion forms predominate in dry and xeric habitats, presenting the perfect structure for retaining water through capillarity and reducing surface area during dry-out events [41], whereas mats are more common in humid, shady areas [42]. Regarding the growth form, acrocarpous mosses are dominant (about 84%). The plants with this growth type are smaller than pleurocarpous ones and their colonies are dense, and therefore they equilibrate more slowly with the relative humidity in their surroundings. As such, they tend to be either fully hydrated and metabolically active or desiccated and metabolically inactive [43]. For this, acrocarpous mosses are commonly found in open dry sites, while their pleurocarpous counterparts are more common in moist shady locations [44]. The predominant life strategy was colonist (58%), followed by perennial (35%) in its different manifestations (66% perennial, 27% stress-tolerant perennial and 7% competitive perennial) and only 7% long-lived shuttles (Table 1). As a life strategy, colonist is very common for plants on open naked or shallow surfaces because these species produce countless small spores that easily disperse and colonise large areas after germination [45]. During reported that moss species able to tolerate environmental stress are mostly perennial species or long-lived shuttles [38].

**Table 1.** List of potential moss 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) [36]. (x—no specific ecological preference). Life form (Cu, cushion; Ma, mats; Tf, tuft), growth form (Acr, acrocarpous; Pl, pleurocarpous) and lifestyle (C, colonist; CP, competitive perennial; LS, long-lived shuttle; P, perennial; STP, stress-tolerant perennial) are also noted [37,38].

| Species | L | T | H | Life Form | Growth Form | Lifestyle |
|---|---|---|---|---|---|---|
| *Abietinella abietina* (Hedw.) M.Fleisch | 8 | x | 3 | Ma | Pl | P |
| *Barbula convoluta* Hedw. | 8 | x | 3 | Tf | Acr | C |
| *Bryum argenteum* Hedw. | 8 | x | x | Tf | Acr | C |
| *Bryum canariense* Brid. | 9 | x | 2 | Tf | Acr | C |
| *Campylopus oerstedianus* (Müll.Hal.) Mitt. | 8 | 9 | 2 | Tf | Acr | P |
| *Campylopus pilifer* Brid. | 9 | 8 | 2 | Cu | Acr | LS |
| *Ceratodon purpureus* (Hedw.) Brid. | 8 | x | 2 | Tf | Acr | C |
| *Cheilothela chloropus* (Brid.) Broth. | 9 | x | 2 | Tf | Acr | C |
| *Crossidium crassinerve* (De Not.) Jur. | 9 | 8 | 2 | Tf | Acr | C |
| *Crossidium squamiferum* (Viv.) Jur. | 9 | 8 | 1 | Tf | Acr | C |
| *Didymodon cordatus* Jur. | 9 | 8 | 1 | Tf | Acr | P |
| *Didymodon fallax* (Hedw.) R.H.Zander | 8 | x | 2 | Tf | Acr | P |
| *Fabronia ciliaris* (Brid.) Brid. | 8 | 8 | 2 | Ma | Pl | P |
| *Fabronia pusilla* Raddi | 8 | 9 | 3 | Ma | Pl | P |
| *Grimmia anodon* Bruch & Schimp. | 9 | x | 1 | Cu | Acr | STP |
| *Grimmia crinita* Brid. | 9 | 8 | 1 | Tf | Acr | C |
| *Grimmia donniana* Sm. | 8 | x | 2 | Cu | Acr | C |
| *Grimmia lisae* De Not. | 8 | 9 | 1 | Cu | Acr | C |
| *Grimmia tergestina* Tomm. ex Bruch & Schimp. | 9 | 8 | 1 | Cu | Acr | C |
| *Haplocladium virginianum* (Brid.) Broth. | 8 | 8 | 3 | Ma | Pl | P |
| *Hedwigia ciliata* (Hedw.) P.Beauv. | 9 | x | 2 | Ma | Acr | LS |
| *Hedwigia stellata* Hedenäs | 8 | 9 | 1 | Ma | Acr | LS |
| *Homalothecium aureum* (Spruce) H.Rob. | 8 | 9 | 2 | Ma | Pl | P |
| *Leptobarbula berica* (De Not.) Schimp. | 8 | 8 | 2 | Tf | Acr | C |
| *Orthotrichum cupulatum* Hoffm. ex Brid. | 9 | 8 | 1 | Cu | Acr | C |
| *Pleurochaete squarrosa* (Brid.) Lindb. | 9 | 8 | 2 | Tf | Acr | CP |
| *Pottiopsis caespitosa* (Bruch ex Brid.) Blockeel & A.J.E.Sm. | 8 | 8 | 2 | Tf | Acr | C |
| *Pseudoleskeella tectorum* (Funck ex Brid.) Kindb. ex Broth. | 8 | x | 2 | Ma | Pl | STP |
| *Pterygoneurum sampaianum* (Machado-Guim.) Machado-Guim. | 9 | 8 | 3 | Tf | Acr | C |
| *Racomitrium lanuginosum* (Hedw.) Brid. | 9 | x | 3 | Tf | Acr | STP |
| *Rhytidium rugosum* (Hedw.) Kindb. | 9 | x | 3 | Ma | Pl | P |
| *Schistidium confertum* (Funck) Bruch & Schimp. | 9 | x | 1 | Cu | Acr | C |
| *Schistidium flaccidum* (De Not.) Ochyra | 9 | x | 1 | Cu | Acr | P |
| *Syntrichia caninervis* Mitt. | 9 | 9 | 1 | Tf | Acr | C |
| *Syntrichia laevipila* Brid. | 8 | 8 | 2 | Tf | Acr | C |
| *Syntrichia ruralis* (Hedw.) F.Weber & D.Mohr | 9 | x | 2 | Tf | Acr | C |
| *Tortella nitida* (Lindb.) Broth. | 8 | 8 | 2 | Cu | Acr | STP |
| *Tortula acaulon* (With.) R.H.Zander | 9 | 9 | 3 | Tf | Acr | C |
| *Tortula brevissima* Schiffn. | 9 | 8 | 2 | Tf | Acr | C |
| *Tortula inermis* (Brid.) Mont. | 8 | 8 | 2 | Cu | Acr | C |
| *Tortula muralis* Hedw. | 9 | 8 | 1 | Tf | Acr | C |
| *Tortula revolvens* (Schimp.) G.Roth | 9 | 8 | 1 | Tf | Acr | C |
| *Trichostomum crispulum* Bruch | 8 | 8 | 2 | Tf | Acr | C |

For all the above, it makes sense that the 10 most widely distributed species in the 34 countries of Mediterranean Basin are all acrocarpous and with a tuft life form and a colonist strategy (70% respectively, Table 2): *Bryum argenteum*, *Tortella nitida* and *Trichostomum crispulum* (32 countries); *Tortula muralis* (31 countries); *Didymodon fallax* (30 countries); *Grimmia lisae* and *Syntrichia laevipila* (29 countries); and *Ceratodon purpureus*, *Pleurochaete squarrosa* and *Tortula inermis* (27 countries). However, care needs to be taken over the choice of provenance of the propagation material used, in order to minimise risk of disruption to the distribution patterns of local genetic variation within species. Compared with vascular plants, where intraspecific variation has been well-studied in many species, there have been very few investigations of bryophyte species, but the precautionary principle suggest that we assume, in the absence of contrary evidence, that bryophyte species will also be genetically variable. Nevertheless, the establishment of companies to grow these mosses from local populations has a potential for economic development, once the standard growing protocols are established, something that we are currently testing.

**Table 2.** Countries or regions according to Ros and co-workers [33]. The most common moss species are highlighted in grey (present in more than 27 countries [80%]). (Countries abbreviation AD: Andorra; AL: Albania; AZ: Azores; BA: Bosnia-Herzegovina; BG: Bulgaria; BL: Baleares; CN: Canary Islands; CO: Corsica; CT: Crete; CY: Cyprus; DZ: Algeria; EG: Egypt; ES: Spain; FR: France; GR: Greece; HR: Croatia; IL: Israel; IT: Italia; JO: Jordan; LB: Lebanon; LY: Libya; MA: Morocco; MD: Madeira; ME: Montenegro; MK: Macedonia; MT: Malta; PT: Portugal; RS: Serbia; SA: Sardinia; SC: Sicily; SI: Slovenia; SY: Syria; TN: Tunisia; TR: Turkey.)

| Species | AD | AL | AZ | BA | BG | BL | CN | CO | CT | CY | DZ | EG | ES | FR | GR | HR | IL | IT | JO | LB | LY | MA | MD | ME | MK | MT | PT | RS | SA | SC | SI | SY | TN | TR | N° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Abietinella abietina* (Hedw.) M.Fleisch | X | X | | X | X | | | | | | | | X | X | X | X | | X | | | | | | X | X | | | X | | | X | | | | 13 |
| *Barbula convoluta* Hedw. | | | X | | X | X | X | X | X | X | X | X | X | X | X | | X | | | | | X | X | | | X | X | | | X | | | | | 18 |
| *Bryum argenteum* Hedw. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | | X | X | 32 |
| *Bryum canariense* Brid. | | X | X | | X | X | X | X | X | | X | | X | X | X | X | X | X | | | | X | X | X | | | X | | X | X | | X | | X | 22 |
| *Campylopus oerstedianus* (Müll.Hal.) Mitt. | | | | | | | | X | | | | | X | X | X | | | X | | | | | | | | | | | | X | | | | | 6 |
| *Campylopus pilifer* Brid. | | | X | | | X | X | X | | | | | X | X | X | | | X | | | | | X | | | | X | | X | X | | | | X | 13 |
| *Ceratodon purpureus* (Hedw.) Brid. | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | | X | | | | X | X | X | X | | X | X | X | X | X | X | | X | 27 |
| *Cheilothela chloropus* (Brid.) Broth. | | X | X | X | X | X | X | X | X | X | | | X | X | X | X | X | X | | | | | | X | X | | X | X | X | X | X | | | X | 23 |
| *Crossidium crassinerve* (De Not.) Jur. | | | | | X | X | X | | X | X | X | X | X | X | X | | X | X | X | | | X | X | | | X | X | X | X | X | X | | X | X | 23 |
| *Crossidium squamiferum* (Viv.) Jur. | | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | | | | X | X | X | X | | X | X | X | X | X | | X | | 25 |
| *Didymodon cordatus* Jur. | X | | | X | X | | | | | | | | X | X | X | X | | X | | X | | | | X | | | | X | | X | X | X | | X | 15 |
| *Didymodon fallax* (Hedw.) R.H.Zander | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | | X | X | X | X | X | X | X | X | X | X | | X | X | 30 |
| *Fabronia ciliaris* (Brid.) Brid. | | | | | X | | | | | | | | X | X | | | X | X | X | | | | | | | | | | X | | | | | | 7 |
| *Fabronia pusilla* Raddi | | X | | | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | | X | X | X | X | | | X | | X | X | X | | X | X | 25 |
| *Grimmia anodon* Bruch & Schimp. | | X | | | X | | X | X | X | | X | X | X | X | X | | X | X | X | | | X | | X | X | | | X | X | X | X | | X | X | 22 |
| *Grimmia crinita* Brid. | | X | | | X | X | X | | | | X | X | X | X | | | X | X | X | | | | | | | | | X | X | X | X | | X | | 16 |
| *Grimmia donniana* Sm. | | | | | X | | | | | | | | X | X | | X | | X | | | | | X | | X | | X | X | X | X | X | | | X | 13 |
| *Grimmia lisae* De Not. | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | | X | X | X | X | | X | X | | X | | X | X | X | X | X | X | X | X | 29 |
| *Grimmia tergestina* Tomm. ex Bruch & Schimp. | X | X | | X | X | X | X | X | X | X | | | X | X | X | X | | X | | X | | X | | X | X | | X | X | X | X | X | | X | X | 25 |
| *Haplocladium virginianum* (Brid.) Broth. | | | | X | | | | | | | | | | | | | | X | | | | | | | | | | | | | X | | | | 3 |
| *Hedwigia ciliata* (Hedw.) P.Beauv. | X | X | | X | X | | X | X | | X | | | X | X | X | X | | X | | | | | X | X | X | | X | X | X | X | X | | | X | 21 |
| *Hedwigia stellata* Hedenäs | X | | | | X | | X | X | | X | | | X | X | X | | | X | | | | X | X | | X | | X | | X | X | | | | X | 16 |
| *Homalothecium aureum* (Spruce) H.Rob. | | X | | | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | | | X | X | | X | | X | X | X | X | | | X | X | 24 |
| *Leptobarbula berica* (De Not.) Schimp. | | | X | | | X | | | X | X | | X | X | X | X | X | X | X | | X | | X | X | | | X | X | | | X | | | X | X | 19 |
| *Orthotrichum cupulatum* Hoffm. ex Brid. | | X | | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | | | | X | X | X | X | | X | X | X | X | X | | | X | 25 |
| *Pleurochaete squarrosa* (Brid.) Lindb. | X | | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | | | | X | X | X | X | | X | X | X | X | X | X | | X | 27 |
| *Pottiopsis caespitosa* (Bruch ex Brid.) Blockeel & A.J.E.Sm. | | | X | | | X | | | X | | X | | X | X | X | X | X | X | X | | | | X | X | | | X | X | X | X | | | X | X | 19 |
| *Pseudoleskeella tectorum* (Funck ex Brid.) Kindb. ex Broth. | X | | | | X | | | | | | | | X | X | X | | | X | | | | X | | | | | | X | | | X | | | X | 10 |

**Table 2.** *Cont.*

| Species | AD | AL | AZ | BA | BG | BL | CN | CO | CT | CY | DZ | EG | ES | FR | GR | HR | IL | IT | JO | LB | LY | MA | MD | ME | MK | MT | PT | RS | SA | SC | SI | SY | TN | TR | N° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pterygoneurum sampaianum* (Machado-Guim.) Machado-Guim. | | | | | | X | | | | | | | X | | | | | | | | | | | | | | X | | | | | | | | 3 |
| *Racomitrium lanuginosum* (Hedw.) Brid. | | | X | X | X | | X | X | | | | | X | X | X | | | X | | | | | X | X | | | X | X | X | X | X | | | X | 17 |
| *Rhytidium rugosum* (Hedw.) Kindb. | X | X | | X | X | | | | | | | | X | X | X | X | | X | | | | | | X | X | | | X | | | X | | | X | 14 |
| *Schistidium confertum* (Funck) Bruch & Schimp. | X | X | | X | X | X | X | X | | X | X | | X | X | X | X | | X | | | | X | | X | X | | X | X | X | X | X | | | X | 23 |
| *Schistidium flaccidum* (De Not.) Ochyra | | X | | X | X | | X | | | X | X | | X | X | X | | | X | | | | X | | | X | | X | X | | X | X | X | | X | 18 |
| *Syntrichia caninervis* Mitt. | | | | | | | | | | | | | X | X | X | | | X | | | | X | | | | | | | | | | | | | 5 |
| *Syntrichia laevipila* Brid. | X | X | X | | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | | X | X | X | X | | X | X | X | X | X | | X | X | 29 |
| *Syntrichia ruralis* (Hedw.) F.Weber & D.Mohr | X | | X | X | | X | X | X | X | X | X | | X | X | X | X | X | | | | | X | X | X | X | | X | X | | X | X | | | | 22 |
| *Tortella nitida* (Lindb.) Broth. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | | X | X | 32 |
| *Tortula acaulon* (With.) R.H.Zander | | X | | X | X | X | X | X | X | | X | | X | X | X | | X | X | | | | X | X | X | X | X | X | X | X | X | X | | | X | 24 |
| *Tortula brevissima* Schiffn. | | | | | | | X | X | | | | X | X | X | X | | X | X | X | | | | | | | | X | X | X | X | | | | X | 14 |
| *Tortula inermis* (Brid.) Mont. | | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | | X | X | | X | X | X | X | X | | | X | 27 |
| *Tortula muralis* Hedw. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | | | X | 31 |
| *Tortula revolvens* (Schimp.) G.Roth | | | X | | | X | X | | X | | X | | X | | X | | X | X | X | | | X | | | | | | | | X | | X | X | X | 15 |
| *Trichostomum crispulum* Bruch | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | | X | X | 32 |

## 4. Conclusions

Even though the poikilohydric nature of mosses and their desiccation tolerance makes them suitable candidates for green roofs in Mediterranean climates, studies are still scarce [31,32]. For this reason, our approach serves as an important tool for the standardisation of this type of vegetation, confirming that functional traits are a perfect tool for the selection of mosses for future use on nonirrigated green roofs in the Mediterranean. Moreover, given the extreme climatic conditions of the Mediterranean Basin, the generated list of moss species provides a valuable resource for the green roof industry. They have the potential to be incorporated directly on top of construction materials that could be tested in the future. Observation of the urban areas shows that they can grow almost on any substrate, with some particular preferences (e.g., calcicole or calcifuge). Many rooftops can present a dark colour that absorbs solar radiation, increasing the temperature inside buildings. This could be attenuated by this green infrastructure. Some bryophytes turn its colour from green to brown, which changes its albedo to absorb more solar radiation so the temperature under the moss will increase. However, the minimum daily and range of humidity is always lower under the moss, meaning that the small amount of water that reaches the moss is well absorbed and can be released in the form of humidity during drier periods (Varela et al., unpublished results). Acrocarpic growth form, turf life form, and a colonist life strategy fit the required profile to survive in extreme climatic conditions, such as the long dryness period typical of Mediterranean climate. It would be necessary to optimise the cultivation of different species of mosses and to assure that the laboratory transplants will not dry out/die and adapt well under green roof conditions. There are already works on moss cultivation in the laboratory for ecological restoration projects, but all of them done in drylands with sandy substrate that would not suit the green roof substrate materials. Therefore, future work will address the selection of mosses from this list, testing their growth rates under controlled conditions and afterwards under green roof conditions.

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