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A Tale of Two Green Walls: A functional trait approach to assess vegetation establishment on restored steep slopes

Running head: Vegetation establishment on Green Walls

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Abstract

Green Walls (GWs) have been increasingly recognized as an important restoration technique for steep slopes resulting from quarrying activities or major infrastructure construction projects. In practice, GW irrigation is considered essential, although studies evaluating vegetation establishment under different irrigation regimes are lacking. Besides taxonomic metrics, functional diversity measures were used to compare the diversity and composition of plant communities of two hydroseeded GWs, with different irrigation regimes (irrigated vs. low-irrigated).

The studied GWs were installed in Peneda-Gerês National Park (NW Portugal) to minimize the visual impact of shotcrete walls, along a road infrastructure, and promote their ecological restoration. Species' cover was recorded three years after installation. Species were classified according to their growth-form, life-form, and life-strategy.

Despite hydroseeding c. 57 species, GW vegetation was dominated by spontaneous species, particularly acrocarpous mosses, regardless of irrigation regime. Species and functional richness were higher under irrigated conditions, while no differences were observed for species diversity and functional dispersion. Functional trait composition did not differ between GWs, indicating that both systems potentially provide the same ecosystem functions and services. Our results also suggest that spontaneous species colonizing GWs are highly adapted to local environmental conditions, given their dominance in both irrigated and low-irrigated communities. Overall, irrigation did not affect the structure and functioning of GW communities, only their redundancy, since

more species exhibiting similar traits were established in the irrigated GW. Therefore, our findings suggest that low-irrigated GWs, hydroseeded with native species, represent more cost-effective solution to reduce the ecological impacts of steep slopes.

Keywords: Bryophytes, Hydroseeding, Nature-based solutions, Trait-based approach, Steep slopes, Vertical greening system.

Implication for Practice

- Green wall irrigation promotes the establishment of plant communities with higher (species and functional) richness, without changes in functional composition.
- Practitioners should consider hydroseeding green walls with native species (both vascular plants and bryophytes), in order to promote the provision of multiple ecosystem services, and the conservation of local diversity.
- On green wall systems, spontaneous colonization is a key component of community assembly, especially in areas surrounded by natural vegetation. As such, under favorable environmental conditions, the use of hydroseeding can be minimized.
- Extensive, low-irrigated green walls represent an innovative solution for the ecological restoration of steep slopes.

Introduction

Ecological restoration of steep slopes resulting from human activities, as quarrying or major infrastructure construction, poses serious challenges due to extreme

environmental conditions that hinder vegetation establishment (Ballesteros et al. 2017; Tamura et al. 2017). In addition to drought and temperature stress, enhanced surface runoff and lack of suitable edaphic conditions are the most limiting factors for the establishment of vegetation on steep slopes (Beikircher et al. 2010). As such, given the long-time scales required, and the adverse microclimatic and substrate conditions characterizing these environments, natural colonization is usually not considered as a suitable restoration strategy (Cullen et al. 1998; García-Palacios et al. 2010). Common practices to improve slope stability and enhance vegetation establishment include hydroseeding procedures, the use of geotextiles, and topsoil spreading (Oliveira et al. 2013; Rivera et al. 2014). In recent years, vertical greening systems, more specifically Green Walls (GWs; sensu Medl et al. 2017a), have been increasingly recognized as an important restoration technique for steep slopes and vertical shotcrete walls (Medl et al. 2017b). Although most research on GWs has been conducted in urban areas (e.g. Collins et al. 2017), this greening system also represents a suitable solution for the integration of steep slopes into natural and semi-natural landscapes. Additionally, GW systems can promote landscape connectivity by reducing habitat fragmentation (Medl et al. 2017b) and potentially provide multiple ecosystem services essential for human well-being (Larcher et al. 2018).

In urban areas, vertical greening systems - green façades and, more recently, GWs - have been frequently used as an aesthetical feature in buildings (Manso & Castro-Gomes 2015; Medl et al. 2017a). GWs also contribute to the mitigation of the heat-island effect, improve air quality, promote stormwater retention, and act as a noise insulation barrier, with important environmental, social and economic benefits (Larcher et al. 2018). In natural and semi-natural areas, GWs should be designed to provide habitat for

biodiversity, in general, and even to potentially support species of conservation concern (Francis & Lorimer 2011). Indeed, a substantial advantage of this type of greening system comes from its capacity to act as habitat for colonizing species. However, the few studies focused on spontaneous vegetation and ecological succession on GWs were performed in urban environments (Mayrand & Clergeau 2018; Mayrand et al. 2018). In addition, the influence of GW greening through traditional hydroseeding procedures (with fast-growing, commercial species; Medl et al. 2017b; Medl et al. 2018) in natural colonization has not been assessed. In previous studies, several authors have reported the competitive exclusion of native species by introduced generalists, such as those present in standard seed mixtures (de la Riva et al. 2011; Gilardelli et al. 2013; Oliveira et al. 2013).

The success of GWs as a restoration technique for steep slopes is usually considered high when species from the hydroseeding mixture achieve high cover values (Medl et al. 2017b). However, this type of quantification does not take into account the ecological characteristics of the emerging plant communities, neither their dynamics over time (Matesanz et al. 2006). Understanding the long-term dynamics of hydroseeded and spontaneous species, as well as their effects on ecosystem functioning, is therefore crucial to develop sustainable restoration strategies (García-Palacios et al. 2010).

Over the last decades, functional diversity, i.e., the value, range, and relative abundance of functional traits in a given ecosystem (Díaz et al. 2007), has emerged as a key concept in ecological research. Functional traits can be defined as the characteristics of organisms, considered relevant to their response to the environment and/or their effects on ecosystem functioning (Díaz & Cabido 2001). Trait-based approaches are, therefore, expected to provide a more mechanistic understanding of

species' responses to environmental factors, as well as their effects on ecosystem processes and/or services (de Bello et al. 2010). Nevertheless, few studies have used trait-based approaches to evaluate the outcome of ecological restorations (Zirbel et al. 2017). Indeed, restoration success has been traditionally evaluated by taxonomic metrics that provide little or no information on the processes and mechanisms that control species' recruitment and succession, in restored communities (D'Astous et al. 2013; Hedberg et al. 2013). In this sense, functional diversity measures have been increasingly recognized as a promising approach to identify ecological constraints of restoration projects (Laughlin 2014), for instance, through the assessment of species filtering during community reassembly (Funk et al. 2008).

One of the major issues regarding the implementation of GWs is their susceptibility to drought (Medl et al. 2017b). As the vertical arrangement limits the absorption of rainwater, artificial irrigation is usually considered essential in these kinds of systems (Pérez-Urrestarazu et al. 2013). Irrigation requirements of GWs are highly variable and depend on multiple factors such as local climatic conditions, light exposition, and the type of vegetation and substrate used (Manso & Castro-Gomes 2015). While many studies have evaluated the performance of green roof vegetation under different irrigation practices (Nagase & Dunnett 2010; Van Mechelen et al. 2015a; Van Mechelen et al. 2015b; Paço et al. 2019), only a few were performed in GW systems (Medl et al. 2018). Research focused on the irrigation needs of vertical greening systems is therefore crucial to improve water management practices and transform GWs into a more sustainable, nature-based solution, which is especially relevant given the current context of climate change and water scarcity.

The aims of this study were (i) to compare taxonomic and functional diversity and composition of plant communities among GWs with different irrigation levels; (ii) to evaluate vegetation establishment, considering both hydroseeding success and spontaneous colonization; and (iii) to assess the need for an integrated irrigation system in temperate zones with high rainfall. This was performed by sampling species diversity in two GWs located along a road infrastructure, in NW Portugal.

Methods

Green Wall systems and experimental set-up

This study was conducted on two GW systems located within or in the proximity of Peneda-Gerês National Park (PNPG), northwest Portugal (41°41'31.41"N, 8° 5'28.70"W; Fig. 1). The PNPG consists of a series of complex mountains - *Peneda*, *Soajo*, *Amarela* and *Gerês*, delimited by deep river valleys, with altitudes ranging from 50 to 1500 m a.s.l. In biogeographical terms, this protected area is included in the Eurosiberian region (Costa et al. 1998). The climate is Temperate/Atlantic to sub-Mediterranean, with one to two dry months in summer. Annual precipitation ranges from 1500 mm in lower regions, up to 3000 mm in mountainous areas; with mean annual temperatures ranging from 10 to 16 °C. As most of the northwestern territories, this National Park is mainly composed of Hercynian granite outcrops and small strips of shale (Honrado 2003). In Temperate/Atlantic areas, climatic vegetation consists of deciduous oak-forests (*Quercus robur* L. and *Quercus pyrenaica* L.) and mixed deciduous and coniferous forests, while evergreen oak-forests (*Quercus suber* L.) occupy areas influenced by the sub-Mediterranean climate (Honrado 2003). Nevertheless, seral scrublands of heather

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(*Erica* spp.), furze (*Ulex europaeus* L. and *Ulex minor* Roth), Portuguese broom (*Cytisus striatus* (Hill) Rothm.), common juniper (*Juniperus communis* L.) and gorse (*Pterospartum tridentatum* (L.) Willk.) are usually dominant in the landscape (Amigo et al. 2017). Local herbaceous communities are characterized by (hygro-)nitrophilous species, typical of areas with moderate human influence, such as *Eupatorium cannabinum* L., *Echium rosulatum* Lange, *Hypericum perforatum* L., *Lamium maculatum* L., *Pentaglottis sempervirens* (L.) L.H.Bailey, *Picris hieracioides* L., and *Scrophularia scorodonia* L. (Honrado 2003; Honrado et al. 2004). The PNPG is also particularly rich in bryophytes, with more than 370 *taxa* recorded (Sérgio et al. 2012), owing to the presence of natural woodlands in sheltered and humid valleys, bogs, mires, streams, and rocky outcrops (Hespanhol et al. 2005).

The studied GW systems were installed on shotcrete walls along a road infrastructure, within the scope of the *Salamonde* Hydroelectric Power Plant (*Salamonde II*) repowering project. In order to minimize the visual impact resulting from the presence of excavation slopes reinforced with shotcrete, and promote their ecological restoration, a TEC-ROC GREEN solution (Projar, Agualva-Cacém, Lisbon, Portugal) was implemented to create GWs (Fig. 2). Overall, this bioengineering technique consists of the application of a substrate layer, with enough depth for plant root growth and establishment, over geotextiles designed for the purpose of soil containment. Specifically, a double layer of TRINTER mesh, a geotextile developed for erosion control, was secured to the shotcrete wall, followed by the installation of a triple torsion wire mesh, fixed with an expansion anchor system (Fig. 3). The substrate was then projected into the double layer of TRINTER mesh (final substrate thickness of 8 cm; see Table S1 in supporting information for details on the composition of the substrate material). Both GWs were

equipped with an automatic irrigation system. Green Wall 1 (GW1; southeast exposed) was installed in April 2015, while Green Wall 2 (GW2; northwest exposed) was installed in June 2015. GWs were automatically irrigated three times per day (15 minutes each, 4.6 L/h m²) from June to August, two times in May and September, and one time in April. No irrigation was supplied from October to March, given the historical high precipitation values registered in the *Salamonde* area during this period (precipitation of 190 mm, 1988-2017 monthly average; SNIRH 2019). GW2 has been supplied with the above mentioned irrigation scheme since its installation, while GW1 has been left without irrigation since the summer of 2016 (that is, it was irrigated only during the 1st year after installation).

In the spring of 2015, both GWs were hydroseeded with a seeding density of 45 g/m². In 2016, GWs were hydroseeded with a seeding density of 15 g/m², to promote the growth of a pre-selected mixture of annual and perennial species such as *Silene vulgaris* (Moench) Garcke and *Saponaria ocymoides* L., respectively. Due to poor vegetation development (species cover less than 20%), GW1 was re-seeded (15 g/m²) in May 2018. See Tables S2 and S3 in supporting information for more details regarding the composition of hydroseeding material and seed mixtures.

Vegetation sampling

Sampling was performed in August 2018, using the point-intercept method (Nunes et al. 2014). In GW1 and GW2, bryophyte and vascular species' cover was estimated as the proportion of points intercepted along three and four 20 m horizontal transects (41 points each, spaced every 50 cm), respectively. At each point, a rod of 5 mm in diameter was positioned on the wall surface with a 90° angle. All species touching the rod were

recorded, though the same species was recorded only once at each point. Species cover was calculated as the proportion of points intercepted per transect, and diversity was calculated using Simpson's Diversity Index. Bryophytes were identified following the nomenclature of Ros et al. (2007) for liverworts and Ros et al. (2013) for mosses; vascular plant species were identified following Castroviejo et al. (1986-2008) and Valdés et al. (1987).

Trait data and functional diversity measures

Species were classified according to their growth-form (morphological term, expressing the architecture of a plant), life-form (related to the structural form that a plant assumes under the conditions of its habitat), and life-strategy (i.e., life-history traits related to reproductive strategies and life cycles). Functional traits were assigned to each species using several sources, including the BRYOATT (Hill et al. 2007) and BRYOTRAIT-AZO (Henriques et al. 2017) databases for bryophytes; the TRY database (www.try-db.org) and LEDA Traitbase for vascular plants (Kleyer et al. 2008); regional floras, expert knowledge, and field observations (Table 1). The trait matrix had no missing values.

To quantify the functional diversity of plant communities, two distinct measures were calculated: Functional Richness (FRic) and Rao's quadratic entropy (RaoQ) (Mason et al. 2013). FRic represents the amount of niche space filled by species in the community (Villéger et al. 2008). It was measured as the convex hull volume of the individual species in multidimensional trait space (Cornwell et al. 2006). Low values indicate that some of the resources potentially available to the community are unused (Mason et al. 2005).

RaoQ estimates the dispersion of species in functional trait space (Laliberté & Legendre 2010). It was measured as the sum of the pairwise distances between species in multidimensional trait space, weighted by their relative abundance (Botta-Dukát 2005). RaoQ values will increase as the most abundant species have increasingly extreme traits. To investigate the functional trait composition of plant communities, the community-weighted mean (CWM; Violle et al. 2007) was calculated for each trait. This measure quantifies the dominant trait values in a community and represents the average trait value weighted by the relative abundance of the species carrying each value (Díaz et al. 2007). For categorical traits, CWM values correspond to the proportion of each category in the community (i.e., their relative abundance). All calculations were performed using the “dbFD” function from the “FD” package (Laliberté et al. 2014) in R (R Core Team 2017).

Data analysis

Prior to statistical analysis, species abundance data were square-root transformed to increase the weight of rare species. Differences in taxonomic and trait composition of plant communities among GWs were assessed using Permutational Multivariate Analysis of Variance (PERMANOVA), based on Bray-Curtis dissimilarities. PERMANOVA was also performed to test for differences among sown and spontaneous species composition. This method partitions the variation in multivariate data between one or more *a priori* groups. Tests of significance are produced by calculating a distance-based pseudo-*F* statistic for each term in the model, based on expected mean squares (Anderson 2017). *P*-values were obtained using a permutation procedure for each term (9999 permutations). PERMANOVA was performed using the “vegan” package

(Oksanen et al. 2013) in R. The nonparametric Mann-Whitney U test was used to compare taxonomic and functional diversity measures of total, sown and spontaneous species (i) between GWs, and (ii) considering both GWs simultaneously. This analysis was carried out using the software STATISTICA 12.0 (Statsoft 2012).

Results

A total of 42 species (22 vascular plants, 19 mosses, and one thalloid liverwort) were recorded, comprising 24 families and 37 genera (see Table S4 in supporting information for the complete species list). Three years after GW installation, a clear dominance of spontaneous species was found (76.2%), whereas only 23.8% of the observed species had been previously sown. Abundance of sown and spontaneous species was similar among GWs (GW1: 25.8% and 74.2%, respectively; GW2: 22.5% and 77.5%, respectively). The mosses *Bryum argenteum* Hedw, *Ceratodon purpureus* (Hedw.) Brid., *Philonotis rigida* Brid., the liverwort *Marchantia polymorpha* L., and the grass *Festuca arundinacea* Schreb. were the most abundant species. Overall, the surveyed communities were dominated by acrocarpous mosses (52.4%), graminoids (18.5%), and herbaceous plants (14.1%). Regarding life-form, moss species forming turfs (44.5%) and hemicryptophytes (28.2%) were the most abundant. Species presenting a perennial life-strategy (38%), followed by colonist bryophytes (37.8%), dominated GW communities.

Species composition significantly differed between GWs (GW1, low-irrigated; GW2, irrigated; PERMANOVA, $R^2 = 0.49$, $p = 0.028$). However, no significant differences were observed for trait composition ($R^2 = 0.19$, $p = 0.339$). The same pattern was found when comparing the composition of spontaneous species. More specifically, spontaneous

species composition significantly differed between GWs ($R^2 = 0.50$, $p = 0.029$), but the same was not observed for their trait composition ($R^2 = 0.34$, $p = 0.10$). In contrast, no significant differences were found when comparing species ($R^2 = 0.27$, $p = 0.06$) and trait composition of sown plants among GWs ($R^2 = 0.18$, $p = 0.42$).

Results from pairwise comparisons (Mann-Whitney U tests) are shown in Table 2. Total species richness was significantly lower in GW1 when compared with GW2. However, no significant differences were observed for species diversity. Functional richness was also significantly higher in GW2, for all the studied traits. RaoQ values among GWs were deemed non-significant. No significant differences were observed when comparing taxonomic and functional diversity measures of sown species, among GWs, whereas species and functional richness of spontaneous plants were significantly higher in GW2, for all the studied traits. The same was also observed when comparing sown species from GW1 with spontaneous species from GW2. In contrast, spontaneous species from GW1 presented higher functional richness and dispersion values (measured as RaoQ) for the trait life-strategy, when compared with sown species from GW2. Considering both GWs, species richness and diversity were significantly different among sown and spontaneous plants. Functional richness values (life-form and life-strategy) were significantly higher for spontaneous species, while dispersion values for growth-form were higher for sown species.

Discussion

Taxonomic diversity and composition of GW communities

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In general, our results indicate that under different irrigation regimes, distinct plant communities are established, as a result of sowing and natural processes of species colonization, establishment, and succession. Although both communities were dominated by spontaneous plants (up to 78% cover), species richness and composition differed between GWs. Indeed, GWs were spontaneously colonized by species with different ecological requirements, reflecting a clear influence of irrigation regime. For instance, the mosses *Bryum argenteum* and *Ceratodon purpureus*, two of the most abundant species in GW1, are desiccation tolerant (Proctor et al. 2007), and common in disturbed habitats. In contrast, the liverwort *Marchantia polymorpha* and the moss *Philonotis rigida*, found in higher abundances in GW2, are typical of habitats with high moisture availability.

Nevertheless, the observed differences in species richness and composition among GWs cannot be entirely disentangled from other factors, namely GW aspect. GW1 is southeast-facing, while GW2 is northwest-facing, which may influence several microclimatic factors and consequently the structure and composition of plant communities. Indeed, higher values of solar radiation and temperature, and lower soil moisture are usually associated with south-facing slopes, therefore characterized by harsher environmental conditions (Cano et al. 2002; Martínez-Ruiz et al. 2007; Bochet & García-Fayos 2015). Several authors have reported differences in vegetation cover and species diversity in revegetated road slopes along gradients of aspect (Bochet et al. 2007; Bochet et al. 2009). However, since most of these studies were performed in semi-arid Mediterranean regions, further research is needed to better understand the influence of GW aspect on vegetation structure and floristic composition in temperate zones. On the other hand, GW1 was subjected to an additional hydroseeding application in May

2018 (low seeding density, 15 g/m²). Nonetheless, field observations revealed poor plant establishment and development, which indicates that differences in hydroseeding amount between GWs did not substantially affect the observed differences in species richness and composition.

Functional diversity and composition of GW communities

In contrast to species composition, trait composition did not differ between GWs, for both sown and spontaneous species. This finding is consistent with previous studies on experimental plant community assembly (Fukami et al. 2005; Li & Shipley 2018; Veen et al. 2018) that reported an increasing dissimilarity in species composition (divergence) and an increasing similarity in mean trait composition (convergence) among sites, with increasing restoration age. In fact, in both GWs, vegetation was generally dominated by acrocarpous, turf-forming mosses. These results are indicative of a directional development at the niche level, that is, as limited niches occur in the studied systems, only species having the appropriate traits are established (Helsen et al. 2012). Nevertheless, and although in low abundance, bryophyte functional groups associated with higher moisture levels, as the perennial wefts and mats, were found colonizing GW2. The presence of such life-forms suggests a possible successional trend towards the hygrophilous herbaceous communities typical of the studied PNPG area. From an ecosystem services perspective, both GWs potentially provide the same ecosystem functions, given their similarity in functional composition. Indeed, as stated by Mouillot et al. (2011) and de Bello et al. (2010), ecosystem processes and services are strongly influenced by the functional composition of biotic communities.

Contrary to functional trait composition, functional diversity measures showed different patterns between GWs. For all the studied traits, functional richness was higher in GW2, which indicates reduced environmental filtering (Mouchet et al. 2010). The same was observed when comparing spontaneous plants between GWs. Overall, these findings are in accordance with recent trait-based studies claiming that functional measures decrease with increasing environmental filter intensity (Funk et al. 2008; Hedberg et al. 2013; Bruno et al. 2016). In the present study, low water availability acts as a strong environmental filter, limiting the establishment of species with traits poorly adapted to desiccation, as observed in GW1. Interestingly, spontaneous species from GW1 presented higher functional richness and dispersion values, particularly for the trait life-strategy, in comparison with sown species from GW2. Functional richness increases when niche complementarity enhances probabilities of species occurrence while functional dispersion increases when niche complementarity enhances either, or both, species' occurrence probabilities and abundances (Mason & de Bello 2013; Mason et al. 2013). As such, and in accordance with Tilman et al. (1997), these results are indicative of a more complete use of resources by spontaneous species from GW1, although subjected to increased environmental stress. Taxonomic and functional measures of spontaneous species were, in general, higher than for sown species, regardless of irrigation regime. These findings suggest that spontaneous species colonizing GWs are highly adapted to local environmental conditions, given their dominance in both irrigated and low-irrigated communities. Indeed, the benefits of including native species in restoration projects, either through natural colonization or artificial introduction, have been increasingly recognized, especially under adverse climatic and soil conditions

(Gilardelli et al. 2013; Ballesteros et al. 2017). This solution is in general more cost-effective.

Vegetation establishment and irrigation requirements

One of the most interesting results of this study was the spontaneous colonization of GWs by bryophytes, despite the application of seed mixtures by means of hydroseeding. To a lesser extent, several native vascular plants were also established, namely *Hypericum perforatum* and *Scrophularia scorodonia*, common in the PNPG area. Recently, Van Mechelen et al. (2015b) also reported spontaneous bryophyte establishment in unirrigated extensive green roofs (up to 60% cover) located in Mediterranean and temperate maritime climates. Owing to their high dispersal capacities, the ability to colonize substrates that are not yet suitable for other species, and high-water retention capacity, bryophytes have been suggested for use in greening systems (Lambrinos 2015; Van Mechelen et al. 2015a). Additionally, these poikilohydric organisms are capable of surviving long dry periods in a desiccated state without suffering damage and can facilitate the establishment and survival of vascular plants by buffering environmental extremes (Heim et al. 2014). In this sense, Anderson et al. (2010) proposed the use of moss spores in hydroseeding mixtures, or alternatively to broadcast spraying suspended vegetative moss fragments, in order to successfully establish bryophyte species over large areas of greening systems.

The success of hydroseeding was therefore limited, as sown species only represented a small fraction of the total plant cover (except for *Festuca arundinacea*). The use of native rather than fast-growing, commercial species has been encouraged

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for the restoration of degraded areas, although some authors have reported limitations to the recruitment of native species in hydroseeding mixtures (Oliveira et al. 2013; Clemente et al. 2016). Nevertheless, from an ecological point of view, the use of native species in restoration projects presents numerous advantages, such as the preservation of genetic integrity, conservation of local diversity, and the enhancement of natural colonization (Bochet et al. 2010; García-Palacios et al. 2010).

Overall, our results highlighted the importance of integrated irrigation systems, especially when GW greening is based on standard seed mixtures (Medl et al. 2018). Nevertheless, hydroseeding with native species (both vascular plants and bryophytes) adapted to local environmental conditions, could represent a suitable approach to overcome the need for constant irrigation, promote biodiversity conservation, and increase the provision of ecosystem services. These findings are particularly relevant in the context of quarry restoration, where steep slopes and low-quality substrates constitute major challenges for vegetation establishment (Clemente et al. 2004; Ballesteros et al. 2017). Therefore, extensive GWs colonized by native species that require little or no maintenance and irrigation, represent an innovative technical solution for quarry restoration.

In conclusion, the studied GWs substantially reduced the visual and ecological impacts of shotcrete walls. This technique has potential applications in the ecological restoration of other types of steep slopes, like the ones created by quarrying activities. Overall, trait-based approaches provided new insights into the process of vegetation establishment in GWs. Moreover, functional diversity analyzes allow comparisons between similar greening systems among regions and communities with different species composition, with great value for restoration ecology.

Functional richness increased with increasing water availability, which indicates reduced environmental filtering. This is probably due to a higher degree of niche differentiation under more humid conditions. Nevertheless, both communities had similar functional trait composition. This finding suggests that both GWs essentially provide the same ecosystem functions and services, although subjected to different irrigation levels. Therefore, the installation of low-irrigated, extensive GWs should be supported, at least in temperate zones with high rainfall. Natural colonization processes also played a significant role in community assembly, as GW vegetation was dominated by acrocarpous moss species. Future research should be focused on the development of hydroseeding mixtures based on native species, in order to ensure the ecological integration of the target areas. Additionally, the assessment of spontaneous colonization as an alternative to sowing should be explored, as part of a sustainable restoration strategy.

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LITERATURE CITED

- Amigo J, Rodríguez-Gutián M, Honrado J, Alves P (2017) The lowlands and midlands of Northwestern Atlantic Iberia. Pages 191-250 In: Loidi J, (ed) The vegetation of the Iberian Peninsula. Springer International Publishing, Basel
- Anderson M, Lambrinos J, Schroll E (2010) The potential value of mosses for stormwater management in urban environments. *Urban ecosystems* 13:319-332
- Anderson MJ (2017) Permutational Multivariate Analysis of Variance (PERMANOVA) In: Wiley StatsRef: Statistics Reference Online. (eds N. Balakrishnan, T. Colton, B. Everitt, W. Piegorisch, F. Ruggeri and J. L. Teugels)
- Ballesteros M, Cañadas EM, Marrs RH, Foronda A, Martín-Peinado FJ, Lorite J (2017) Restoration of Gypsicolous Vegetation on Quarry Slopes: Guidance for Hydroseeding under Contrasting Inclination and Aspect. *Land Degradation & Development* 28:2146-2154
- Beikircher B, Florineth F, Mayr S (2010) Restoration of rocky slopes based on planted gabions and use of drought-preconditioned woody species. *Ecological Engineering* 36:421-426
- Bochet E, García-Fayos P (2015) Identifying plant traits: A key aspect for species selection in restoration of eroded roadsides in semiarid environments. *Ecological Engineering* 83:444-451
- Bochet E, García-Fayos P, Poesen J (2009) Topographic thresholds for plant colonization on semi-arid eroded slopes. *Earth Surface Processes and Landforms* 34:1758-1771
- Bochet E, García-Fayos P, Tormo J (2007) Road Slope Revegetation in Semiarid Mediterranean Environments. Part I: Seed Dispersal and Spontaneous Colonization. *Restoration Ecology* 15:88-96
- Bochet E, Tormo J, García-Fayos P (2010) Native Species for Roadslope Revegetation: Selection, Validation, and Cost Effectiveness. *Restoration Ecology* 18:656-663
- Botta-Dukát Z (2005) Rao's quadratic entropy as a measure of functional diversity based on multiple traits. *Journal of vegetation science* 16:533-540
- Bruno D, Gutiérrez-Cánovas C, Sánchez-Fernández D, Velasco J, Nilsson C (2016) Impacts of environmental filters on functional redundancy in riparian vegetation. *Journal of Applied Ecology* 53:846-855
- Cano A, Navia R, Amezaga I, Montalvo J (2002) Local topoclimate effect on short-term cutslope reclamation success. *Ecological Engineering* 18:489-498
- Castroviejo S, Lainz M, López G, Montserrat P, Muñoz F, Paiva J, Villar LE. (1986-2008) *Flora Iberica. Plantas Vasculares de la Península Ibérica e Islas Baleares*. Vol. 1–6, 7(I,II), 8, 10, 13, 14, 21. Real Jardín Botánico, CSIC, Madrid., Madrid

- Clemente AS, Moedas AR, Oliveira G, Martins-Loução MA, Correia O (2016) Effect of hydroseeding components on the germination of Mediterranean native plant species. *Journal of Arid Environments* 125:68-72
- Clemente AS, Werner C, Máguas C, Cabral MS, Martins-Loução MA, Correia O (2004) Restoration of a Limestone Quarry: Effect of Soil Amendments on the Establishment of Native Mediterranean Sclerophyllous Shrubs. *Restoration Ecology* 12:20-28
- Collins R, Schaafsma M, Hudson MD (2017) The value of green walls to urban biodiversity. *Land Use Policy* 64:114-123
- Cornwell WK, Schilke DW, Ackerly DD (2006) A trait-based test for habitat filtering: convex hull volume. *Ecology* 87:1465-1471
- Costa JC, Aguiar C, Capelo JH, Lousã M, Neto C (1998) Biogeografia de Portugal Continental. *Quercetea* 0:5-56
- Cullen WR, Wheeler CP, Dunleavy PJ (1998) Establishment of species-rich vegetation on reclaimed limestone quarry faces in Derbyshire, UK. *Biological Conservation* 84:25-33
- D'Astous A, Poulin M, Aubin I, Rochefort L (2013) Using functional diversity as an indicator of restoration success of a cut-over bog. *Ecological Engineering* 61:519-526
- de Bello F, Lavorel S, Díaz S, Harrington R, Cornelissen JHC, Bardgett RD, Berg MP, Cipriotti P, Feld CK, Hering D, Martins da Silva P, Potts SG, Sandin L, Sousa JP, Storkey J, Wardle DA, Harrison PA (2010) Towards an assessment of multiple ecosystem processes and services via functional traits. *Biodiversity and Conservation* 19:2873-2893
- de la Riva EG, Casado MA, Jiménez MD, Mola I, Costa-Tenorio M, Balaguer L (2011) Rates of local colonization and extinction reveal different plant community assembly mechanisms on road verges in central Spain. *Journal of Vegetation Science* 22:292-302
- Díaz S, Cabido M (2001) Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution* 16:646-655
- Díaz S, Lavorel S, de Bello F, Quétier F, Grigulis K, Robson TM (2007) Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Sciences* 104:20684-20689
- Francis RA, Lorimer J (2011) Urban reconciliation ecology: The potential of living roofs and walls. *Journal of Environmental Management* 92:1429-1437
- Fukami T, Bezemer TM, Mortimer SR, van der Putten WH (2005) Species divergence and trait convergence in experimental plant community assembly. *Ecology letters* 8:1283-1290
- Funk JL, Cleland EE, Suding KN, Zavaleta ES (2008) Restoration through reassembly: plant traits and invasion resistance. *Trends in Ecology & Evolution* 23:695-703

- García-Palacios P, Soliveres S, Maestre FT, Escudero A, Castillo-Monroy AP, Valladares F (2010) Dominant plant species modulate responses to hydroseeding, irrigation and fertilization during the restoration of semiarid motorway slopes. *Ecological Engineering* 36:1290-1298
- Gilardelli F, Sgorbati S, Citterio S, Gentili R (2013) Restoring Limestone Quarries: Hayseed, Commercial Seed Mixture or Spontaneous Succession? *Land Degradation & Development* 27:316-324
- Hedberg P, Saetre P, Sundberg S, Rydin H, Kotowski W (2013) A functional trait approach to fen restoration analysis. *Applied Vegetation Science* 16:658-666
- Heim A, Lundholm J, Philip L (2014) The impact of mosses on the growth of neighbouring vascular plants, substrate temperature and evapotranspiration on an extensive green roof. *Urban Ecosystems* 17:1119-1133
- Helsen K, Hermy M, Honnay O (2012) Trait but not species convergence during plant community assembly in restored semi-natural grasslands. *Oikos* 121:2121-2130
- Henriques DSG, Ah-Peng C, Gabriel R (2017) Structure and Applications of BRYOTRAIT-AZO, a Trait Database for Azorean Bryophytes. *Cryptogamie, Bryologie* 38:137-152
- Hespanhol H, Vieira C, Lomba Â, Séneca A (2005) New data on bryophyte distribution in the Peneda-Gerês National Park (NW Portugal): the use of GIS for conservation remarks. *Boletim de la Sociedad Espanola de Briologia*:59-74
- Hill MO, Preston CD, Bosanquet S, Roy DB (2007) BRYOATT: Attributes of British and Irish Bryophytes. Cambridgeshire, Centre for Ecology and Hydrology. Available at <http://nora.nerc.ac.uk/1131/1/BRYOATT.pdf>. Accessed on 10/01/2018.
- Honrado J, Alves P, Lomba Â, Rocha I, Torres J, Ortiz S, Caldas FB (2004) A new association of perennial nitrophilous vegetation from North-Western Iberian Peninsula. *Acta Botanica Gallica* 151:393-399
- Honrado JJP (2003) Flora e vegetação do Parque Nacional da Peneda-Gerês (PhD thesis). Faculty of Science of the University of Porto, Porto
- Kleyer M, Bekker RM, Knevel IC, Bakker JP, Thompson K, Sonnenschein M, Poschod P, Van Groenendael JM, Klimeš L, Klimešová J, Klotz S, Rusch GM, Hermy M, Adriaens D, Boedeltje G, Bossuyt B, Dannemann A, Endels P, Götzenberger L, Hodgson JG, Jackel A-K, Kühn I, Kunzmann D, Ozinga WA, Römermann C, Stadler M, Schlegelmilch J, Steendam HJ, Tackenberg O, Wilmann B, Cornelissen JHC, Eriksson O, Garnier E, Peco B (2008) The LEDA Traitbase: a database of life-history traits of the Northwest European flora. *Journal of Ecology* 96:1266-1274
- Laliberté E, Legendre P (2010) A distance-based framework for measuring functional diversity from multiple traits. *Ecology* 91:299-305

- Laliberté E, Legendre P, Shipley B (2014) FD: measuring functional diversity from multiple traits, and other tools for functional ecology. R package version 1.0-12.
- Lambrinos JG (2015) Water Through Green Roofs. Pages 81-105 In: Sutton RK, (ed) Green Roof Ecosystems. Springer International Publishing, Cham
- Larcher F, Battisti L, Bianco L, Giordano R, Montacchini E, Serra V, Tedesco S (2018) Sustainability of Living Wall Systems Through An Ecosystem Services Lens. Pages 31-51 In: Nandwani D, (ed) Urban Horticulture: Sustainability for the Future. Springer International Publishing, Cham
- Laughlin DC (2014) Applying trait-based models to achieve functional targets for theory-driven ecological restoration. *Ecology Letters* 17:771-784
- Li Y, Shipley B (2018) Community divergence and convergence along experimental gradients of stress and disturbance. *Ecology* 99:775-781
- Manso M, Castro-Gomes J (2015) Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews* 41:863-871
- Martínez-Ruiz C, Fernández-Santos B, Putwain PD, Fernández-Gómez MJ (2007) Natural and man-induced revegetation on mining wastes: Changes in the floristic composition during early succession. *Ecological Engineering* 30:286-294
- Mason NW, de Bello F (2013) Functional diversity: a tool for answering challenging ecological questions. *Journal of Vegetation Science* 24:777-780
- Mason NWH, Bello F, Moullot D, Pavoine S, Dray S (2013) A guide for using functional diversity indices to reveal changes in assembly processes along ecological gradients. *Journal of Vegetation Science* 24:794-806
- Mason NWH, Moullot D, Lee WG, Wilson JB (2005) Functional richness, functional evenness and functional divergence: the primary components of functional diversity. *Oikos* 111:112-118
- Matesanz S, Valladares F, Tena D, Costa-Tenorio M, Bote D (2006) Early Dynamics of Plant Communities on Revegetated Motorway Slopes from Southern Spain: Is Hydroseeding Always Needed? *Restoration Ecology* 14:297-307
- Mayrand F, Clergeau P (2018) Green Roofs and Green Walls for Biodiversity Conservation: A Contribution to Urban Connectivity? *Sustainability* 10:985
- Mayrand F, Clergeau P, Vergnes A, Madre F (2018) Chapter 3.13 - Vertical Greening Systems as Habitat for Biodiversity. Pages 227-237 In: Pérez G and Perini K, (eds) Nature Based Strategies for Urban and Building Sustainability. Butterworth-Heinemann
- Medl A, Florineth F, Kikuta SB, Mayr S (2018) Irrigation of 'Green walls' is necessary to avoid drought stress of grass vegetation (*Phleum pratense* L.). *Ecological Engineering* 113:21-26

- Medl A, Stangl R, Florineth F (2017a) Vertical greening systems – A review on recent technologies and research advancement. *Building and Environment* 125:227-239
- Medl A, Stangl R, Kikuta SB, Florineth F (2017b) Vegetation establishment on ‘Green Walls’: Integrating shotcrete walls from road construction into the landscape. *Urban Forestry & Urban Greening* 25:26-35
- Mouchet MA, Villéger S, Mason NWH, Mouillot D (2010) Functional diversity measures: an overview of their redundancy and their ability to discriminate community assembly rules. *Functional Ecology* 24:867-876
- Mouillot D, Villéger S, Scherer-Lorenzen M, Mason NW (2011) Functional structure of biological communities predicts ecosystem multifunctionality. *PloS one* 6:e17476
- Nagase A, Dunnett N (2010) Drought tolerance in different vegetation types for extensive green roofs: Effects of watering and diversity. *Landscape and Urban Planning* 97:318-327
- Nunes A, Tápiá S, Pinho P, Correia O, Branquinho C (2014) Advantages of the point-intercept method for assessing functional diversity in semi-arid areas. *iForest - Biogeosciences and Forestry* 8:471-479
- Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'hara R, Simpson GL, Solymos P, Stevens MHH, Wagner H (2013) Package ‘vegan’. Community ecology package, version 2
- Oliveira G, Clemente A, Nunes A, Correia O (2013) Limitations to recruitment of native species in hydroseeding mixtures. *Ecological engineering* 57:18-26
- Paço TA, Cruz de Carvalho R, Arsénio P, Martins D (2019) Green Roof Design Techniques to Improve Water Use under Mediterranean Conditions. *Urban Science* 3:14
- Pérez-Urrestarazu L, Egea G, Franco-Salas A, Fernández-Cañero R (2013) Irrigation systems evaluation for living walls. *Journal of Irrigation and Drainage Engineering* 140:04013024
- Proctor MCF, Oliver MJ, Wood AJ, Alpert P, Stark LR, Cleavitt NL, Mishler BD (2007) Desiccation-tolerance in bryophytes: a review. *The Bryologist* 110:595-621
- R Core Team (2017) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Rivera D, Mejías V, Jáuregui BM, Costa-Tenorio M, López-Archilla AI, Peco B (2014) Spreading topsoil encourages ecological restoration on embankments: soil fertility, microbial activity and vegetation cover. *PloS one* 9:e101413-e101413
- Ros RM, Mazimpaka V, Abou-Salama U, Aleffi M, Blockeel TL, Brugués M, Cano MJ, Cros RM, Dia MG, Dirkse GM, Saadawi WE, Erda A, Ganeva A, González-Mancebo JM, Herrnsstadt I, Khalil K, Kürschner H, Lanfranco E, Losada-Lima A, Refai MS, Rodríguez-Núñez S, Sabovljevi M, Sérgio C, Shabbara H, Sim-Sim M, Söderström L (2007)

- Hepatics and Anthocerotales of the Mediterranean, an annotated checklist. *Cryptogamie, Bryologie* 28:351-437
- Ros RM, V. M, Abou-Salama U, Aleffi M, Blockeel TL, Brugués M, Cros RM, Dia M, Dirkse GM, Drape ID, El-Saadawi W, Erdag W, Ganeva A, Gabriel R, González RM, Granger C, Herrnstadt I, Hugonnot V, Khalil K, Kürschner HH, Losada-Lima A, Luís L, Mifsud S, Privitera M, M. P, Sabovijevic M, Sérgio C, Shabbara HM, Sim-Sim M, Sotiaux A, R. T, Vanderpoorten A, Werner O (2013) Mosses of the Mediterranean, an annotated checklist. *Cryptogamie, Bryologie* 34:99-283
- Sérgio C, Garcia CA, Hespanhol H, Vieira C, Stow S, Long D (2012) Bryophyte diversity in the Peneda-Gerês National Park (Portugal): selecting Important Plant Areas (IPA) based on a new survey and past records. *Bot. Complut.* 36:39-50
- SNIRH (2019) Sistema Nacional de Informação de Recursos Hídricos (National Hydrological Resources Information System). Available online at snirh.apambiente.pt. Accessed on August 2019. Portuguese Environment Agency (APA), Lisboa
- Statsoft I (2012) STATISTICA, version 12.0
- Tamura N, Lulow ME, Halsch CA, Major MR, Balazs KR, Austin P, Huxman TE, Kimball S (2017) Effectiveness of seed sowing techniques for sloped restoration sites. *Restoration Ecology* 25:942-952
- Tilman D, Knops J, Wedin D, Reich P, Ritchie M, Siemann E (1997) The Influence of Functional Diversity and Composition on Ecosystem Processes. *Science* 277:1300-1302
- Valdés B, Talavera S, Fernández-Galiano E (1987) Flora Vascular de Andalucía Occidental (Ed. Ketres). Vol. 1 2 3
- Van Mechelen C, Dutoit T, Hermy M (2015a) Adapting green roof irrigation practices for a sustainable future: A review. *Sustainable Cities and Society* 19:74-90
- Van Mechelen C, Dutoit T, Hermy M (2015b) Vegetation development on different extensive green roof types in a Mediterranean and temperate maritime climate. *Ecological Engineering* 82:571-582
- Veen GF, van der Putten WH, Bezemer TM (2018) Biodiversity-ecosystem functioning relationships in a long-term non-weeded field experiment. *Ecology* 99:1836-1846
- Villéger S, Mason NW, Mouillot D (2008) New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology* 89:2290-2301
- Violle C, Navas M-L, Vile D, Kazakou E, Fortunel C, Hummel I, Garnier E (2007) Let the concept of trait be functional! *Oikos* 116:882-892
- Zirbel CR, Bassett T, Grman E, Brudvig LA (2017) Plant functional traits and environmental conditions shape community assembly and ecosystem functioning during restoration. *Journal of Applied Ecology* 54:1070-1079

Table 1. Functional traits and respective categories, codes, and sources.

	Functional traits	Categories	Code	Source
Bryophytes	Growth-form	Acrocarpous	acro	(Hill et al. 2007)
		Pleurocarpous	pleu	
		Thallose	thal	
	Life-form	Mat, rough	Mr	(Hill et al. 2007)
		Mat, smooth	Ms	
		Mat, Thalloid	Mt	
		Turf	tf	
		Tuft	tuft	
		Weft	we	
	Life-strategy	Fugitive	fug	(Henriques et al. 2017)
		Colonist	cst	
		Pioneer colonist	pco	
		Short-lived shuttle	sls	
		Long-lived shuttle	lls	
		Perennial stayer	per	
		Competitive perennial	cop	
		Stress-tolerant perennial	stp	
Vascular plants	Growth-form	Fern	fern	TRY Database (www.try-db.org)
		Herbaceous	herb	
		Graminoid	grami	
		Shrub	shrub	
	Life-form	Therophyte	thero	TRY Database (www.try-db.org)
		Hemicryptophyte	hemi	
		Geophyte	geo	
		Chamaephyte	chamae	
	Life-strategy	Phanerophyte	phane	(Kleyer et al. 2008)
		Annuals	ann	
		Perennials	perenn	
		Biennial	bienn	
		Annual or Biennial	ann_bienn	

Table 2. Taxonomic and functional diversity measures (mean $\pm$ SD) of total, spontaneous, and sown plant species of Green Wall 1 (GW1; low-irrigated, i.e., irrigated only during the 1st year after installation), Green Wall 2 (GW2; irrigated), and considering both GWs simultaneously. Significant differences between pairs (Mann–Whitney *U* test) are indicated with * ($p < 0.05$) or ** ($p < 0.01$). Superscript letters: (a) comparison of total species between GW1 and GW2; (b) comparison of sown species between GW1 and GW2; (c) comparison of spontaneous species between GW1 and GW2; (d) comparison between sown species from GW1 and spontaneous species from GW2; (e) comparison between sown species from GW2 and spontaneous species from GW1; (f) comparison between total sown and total spontaneous species.

Taxonomic and functional diversity measures	Green Wall 1			Green Wall 2			Both Green Walls		
	Total species N=13	Sown species N=5	Spontaneous species N=8	Total species N=37	Sown species N=7	Spontaneous species N=30	Sown species N=10	Spontaneous species N=32	
Species Richness	6.67 ± 0.47 ^{a*}	2.33 ± 0.47 ^{b,d*}	4.33 ± 0.47 ^{c*,e}	19.8 ± 1.79 ^{a*}	4.50 ± 1.5 ^{b,e}	15.3 ± 2.28 ^{c*,d*}	3.57 ± 1.59 ^{f*}	10.6 ± 5.68 ^{f*}	
Simpson's Diversity Index	3.72 ± 1.41 ^a	1.98 ± 0.77 ^{b,d}	3.31 ± 0.71 ^{c,e}	8.86 ± 1.56 ^a	2.68 ± 0.17 ^{b,e}	6.68 ± 1.46 ^{c,d}	2.38 ± 0.63 ^{f*}	5.23 ± 2.05 ^{f*}	
Functional Richness									
Growth-form	3.33 ± 0.47 ^{a*}	2.00 ± 0 ^{b,d*}	2.00 ± 0.82 ^{c*,e}	5.75 ± 0.43 ^{a*}	2.00 ± 0 ^{b,e}	4.75 ± 0.43 ^{c*,d*}	2.00 ± 0 ^f	3.57 ± 1.50 ^f	
Life-form	4.43 ± 0.47 ^{a*}	2.33 ± 0.47 ^{b,d*}	2.67 ± 0.47 ^{c*,e}	7.75 ± 1.48 ^{a*}	1.50 ± 0.50 ^{b,e}	7.00 ± 0.71 ^{c*,d*}	1.86 ± 0.64 ^{f**}	5.14 ± 2.23 ^{f**}	
Life-strategy	4.67 ± 0.47 ^{a*}	1.67 ± 0.47 ^{b,d*}	3.67 ± 0.47 ^{c*,e*}	8.25 ± 0.83 ^{a*}	1.00 ± 0 ^{b,e*}	8.25 ± 0.83 ^{c*,d*}	1.29 ± 0.45 ^{f**}	6.29 ± 2.37 ^{f**}	
Rao's quadratic entropy									
Growth-form	0.06 ± 0.03 ^a	0.17 ± 0.08 ^{b,d}	0.04 ± 0.03 ^{c,e}	0.10 ± 0.01 ^a	0.20 ± 0.03 ^{b,e}	0.10 ± 0.01 ^{c,d}	0.19 ± 0.06 ^{f*}	0.08 ± 0.04 ^{f*}	
Life-form	0.04 ± 0.01 ^a	0.14 ± 0.08 ^{b,d}	0.04 ± 0.02 ^{c,e}	0.06 ± 0.01 ^a	0.04 ± 0.05 ^{b,e}	0.07 ± 0.01 ^{c,d}	0.08 ± 0.08 ^f	0.06 ± 0.02 ^f	
Life-strategy	0.05 ± 0.01 ^a	0.06 ± 0.06 ^{b,d}	0.05 ± 0.01 ^{c,e*}	0.07 ± 0.01 ^a	0 ± 0 ^{b,e*}	0.07 ± 0.01 ^{c,d}	0.03 ± 0.05 ^{f*}	0.06 ± 0.01 ^{f*}	

Figure 1. Location of the Peneda-Gerês National Park (PNPG) (a), in the NW of the Iberian Peninsula (c), and the location of the studied Green Walls (b).

Figure 2. General view of Green Wall 1 (a) and Green Wall 2 (b), three years after installation, in August 2018.

Figure 3. Schematic figure of the Green Wall systems applied over shotcrete walls.

Figure 1.

Figure 2.