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Azorean Vascular Plants with Potential Use in Constructed Wetlands with Horizontal Subsurface Flow

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Abstract: Constructed wetlands are considered integrated ecosystems and a promising wastewater treatment option, relying on vegetation, soils, and microbial assemblages. The potential dispersal of effluents from domestic septic systems, the application of dairy farm effluents containing excessive nutrients and pathogens into pastures, and undertreated effluent discharge in coastal areas are some of the threats to water quality in the Azores. Constructed wetlands could be used in the Azores to protect and preserve the quality of drinking water sources and bathing waters. However, the most used plant species in other regions are considered as introduced in the Azores, where a considerable number of invasive plants and weeds are already present. Here, we present a review of the plant taxa already present in the Azorean flora with the potential to be used in constructed wetland systems, based on a literature review, and on the assessment of nine criteria. We evaluated 73 taxa, including mostly Cyperaceae, Poaceae and Juncaceae, showing that, although some of the top-ranking species were considered potentially noxious, several native and some naturalized taxa could be used for wastewater treatment. This work supports the implementation of constructed wetlands in the Azores, while minimizing the risk of new invasions.

Keywords: Azorean flora; biological treatment; local biodiversity; nature based solutions; wastewater treatment; water quality

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1. Introduction

Since the 2000s, the term "nature-based solutions" (NBS) entered the scientific literature in the context of agricultural problems, land-use management, and water management [1]. NBS are defined by IUCN as "actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (. . .) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits" [2]. The European Commission's definition is broader and refers to NBS as those that not only use natural resources and processes but are also inspired and supported by natural ecosystems [2,3]. Within this context, here, we address the importance of constructed wetlands (CWs), in general, and in a perspective of their potential application in the Azores archipelago.

1.1. Constructed Wetlands as Nature-Based Solutions

CWs are wastewater treatment systems that use natural processes based on wetland vegetation (most commonly vascular plants), soils and their microbial assemblages [4,5]. There are many examples of CWs in temperate regions [6] that have been used for the treatment of different types of wastewaters, namely municipal, industrial, and agricultural [7–10].

CW classification depends on the macrophytes used—free-floating, floating leaves, emergent or submerged [7,8,10–12], and on the hydrology—free water surface or subsurface systems, the latter further classified as horizontal or vertical, according to their flow direction [5,13]. Several advantages of CWs include the requirement of low investment and maintenance costs, low energy consumption and the creation of habitats favourable to other species [12,14–17]. CWs present a favourable balance in the emission of greenhouse gases, compared to conventional wastewater systems [18], although this might depend on several factors, for example the selected plant species [19].

A horizontal subsurface flow (HSF) wetland is constructed as a bed filled with granular media of the appropriate size that is sealed by an impermeable layer and planted with vegetation. The wastewater enters and flows through the porous medium in a horizontal pathway up to the outlet zone. This medium acts as a filter, removing solids, organic compounds, nutrients, and biodegradable organic matter (measured through 5-day BOD), by microbial degradation, chemical, and physical processes. While the roots and rhizomes of the plants work as a substrate for attached bacteria, the whole plant is responsible for the uptake of nutrients, radial oxygen loss (oxygen diffusion from roots to the rhizosphere) and insulation of water preventing temperature variation [5,12,14]. Beyond the effects of water purification, plants fix carbon by photosynthesis. The main advantages of subsurface flow systems are the prevention of mosquitos and odours and the elimination of the risk of contact with the wastewater [4].

The choice of plants to use in CWs for phytoremediation depends on biomass, fast growth rate and tolerance to pollutant concentration [12,20]. Some of the most common macrophytes used in CWs are *Phragmites australis* (Cav.) Trin. ex Steud. and species belonging to the genus *Typha* [21].

Phragmites australis has been the preferred plant for application in CWs for wastewater treatment [22,23], due to its capacity to grow well under various types of habitats and climatic conditions. Its tolerance to different environments is explained by fast growth, high biomass accumulation, and high evapotranspiration rates, which protect the plants in case of toxic environments and flood conditions. In cold temperate maritime climates (e.g., Ireland), *P. australis* and *Typha latifolia* L. are predominant species in CWs [24]. Although *P. australis* is the most used macrophyte in Europe, it is not allowed in several regions, because it might invade natural wetlands [25–28]. Moreover, for instance, *Canna indica* has often shown better results than *P. australis* [12,19]. Therefore, other species must be tested for CWs.

1.2. Case Study Azores

1.2.1. Domestic effluents

In the Azores archipelago, the main method for domestic wastewater treatment is the use of decentralized systems with septic tanks (ST), serving 78% of the population, and in some islands being the unique treatment available [29]. However, when installed in suboptimal conditions (e.g., high effluent loads, inadequate soil type and drainage, proximity to sensitive aquatic ecosystems such as coastal areas or wetlands and shallow aquifers), ST can have a high potential for water pollution [30–32]. The absence of proper treatment can result in nearby groundwater and surface waters contamination, potentially affecting human health and environmental quality due to high concentrations of nitrates, and the presence of faecal microorganisms, leading to disease outbreaks, antibiotic resistance in aquatic microorganisms, or eutrophication of surface waters which cause loss of biodiversity and a decline in the aquatic ecosystem services [31,32].

1.2.2. Agricultural effluents

Artificial pastureland dominates the land cover in the Azores, where 51.9% (120,632 ha) of the land is utilized for agriculture, of which 74.6% corresponds to pasture. Recently, the area occupied by seasonal forage maize has also increased, corresponding to 22.1% of the utilized agricultural area. The number of cattle ascended to 282,820 animals in

2019, of which 95,385 were dairy cows [33]. Those pastures correspond to grazing systems where cattle can circulate following a utilization scheme defined by the farmers [34]. In the past, the production was extensive; thus, there was no need for animal housing, and the effluent production was lower. The excessive application of synthetic fertilizers rich in nitrogen (N) and phosphorus (P) associated with accentuated orography and high levels of precipitation favours the runoff of nutrients and pollution of water bodies [35,36]. In order to protect the watersheds and control the eutrophication, the regional government acquired about 300 ha of pasture lands to forest with endemic species [37]. However, in recent years, the intensification of production in the bigger islands has led to an increase in the extension and frequency of mowing, increased animal housing and, consequently, more effluent accumulation. This effluent is stored and spread in the soil as fertilizer without any treatment, at least twice per year. The application of synthetic and organic fertilizers and animal waste leaching have resulted in high concentrations of nitrate in groundwater, and consequently, in non-compliance with European Union and national water quality regulations [38].

1.2.3. Potential of CWs in the Azores

The CW technology could be applied to treat domestic and dairy effluents in the Azores, since it is a viable, cost-effective, and efficient alternative for small and decentralized agglomerates [39]. In warmer climates and insular territories, such as Mayotte (French outermost territories) and the Canary Islands, CWs showed good results in wastewater treatment. In Mayotte tropical weather, CWs planted with *Thysanolaena maxima* and *Typha angustifolia* showed reduced rates of COD, suspended solids and total Kjeldahl nitrogen that satisfied French national quality objectives for domestic wastewater treatment [40].

In agglomerations with more than 2000 population equivalents, urban wastewater should be collected and treated in centralized systems, before discharge (Council Directive 91/271/EEC). If the discharges occur in sensitive areas (i.e., freshwater lakes, estuaries, coastal waters, and surface freshwaters for human consumption), a more exigent quality of discharge is required, regarding microbiological and nutritional parameters. In those cases, CWs could contribute to improving the overall physical–chemical and microbiological quality of secondary effluents, reducing the impact of their discharge in water bodies [41].

Within this framework, this paper presents a review of the plant taxa already present in the Azorean Flora with the capacity to be used in CW systems, allowing for the implementation of those wastewater treatment systems in the Azores, without risking the loss of biodiversity through the importation of new invasive species.

2. Materials and Methods

2.1. Climate and Geographical Framework

The Azores archipelago, located in the Central North Atlantic Ocean (37–40° N, 25–31° W), 1400 km from Portugal mainland, is one of the five archipelagos included in the Macaronesia geographical region. It is composed by nine oceanic volcanic islands scattered along more than 600 km, with a total land surface of 2325 km^2. The archipelago is divided into three groups (Figure 1): Flores and Corvo (western group), Terceira, Graciosa, Pico, São Jorge and Faial (central group), and São Miguel and Santa Maria (eastern group).

The Azores climate is influenced by its location in the middle of the Atlantic Ocean, where there are low-pressure zones alternating with the presence of a large high-pressure system, the Azores anticyclone, and by the orography of the islands [42]. The Azores temperate oceanic climate, also designated temperate maritime climate, is characterized by mild temperatures, low thermal amplitudes, and precipitation well distributed during the year. According to the last census [33], in the Azores, there are 236,657 inhabitants, and the average population density was 101.8 people per km^2. In the Azores archipelago, 52% of the population lives in agglomerates with less than 2000 inhabitants, contrasting with 42% in the mainland territory [43].

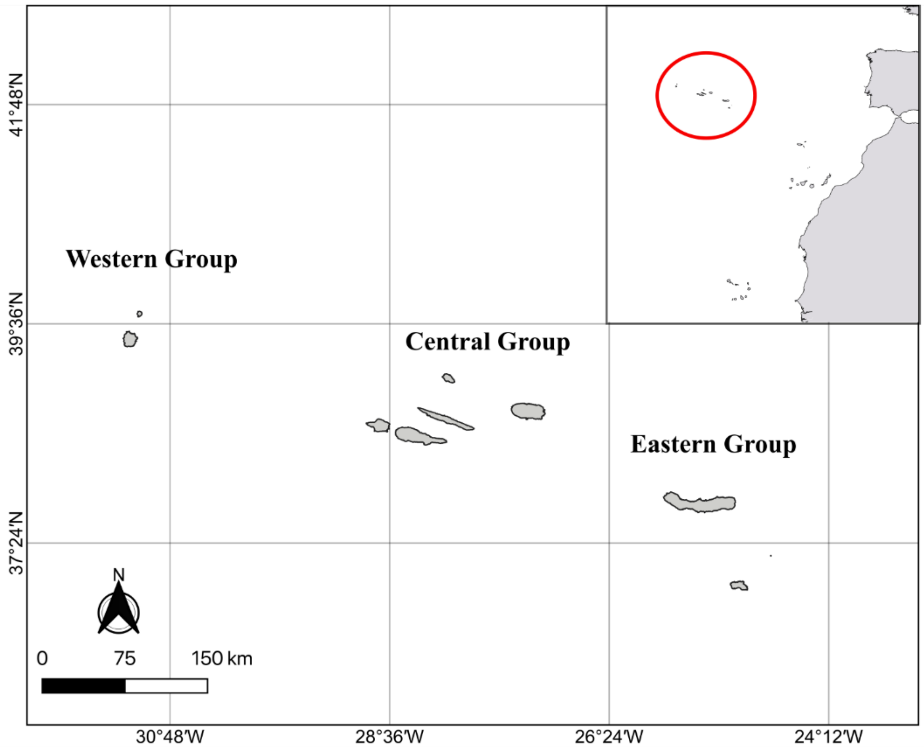

Figure 1. Location of the Azores archipelago in the Northeast Atlantic.

2.2. Flora of the Azores

About 6112 terrestrial species (6164 taxa) are given for the Azores, of which 411 are endemic. The vascular plants (Pteridophyta and Spermatophyta) include a total of about 1000 taxa [44]. However, recent reports indicate that the entire vascular flora, also including cultivated plants, includes more than 5000 taxa.

The Azorean plant cover before human settlement was most likely dominated by different vegetation belts corresponding to different types of scrubland, woodland and forest [45]. However, changes in land use have led to a drastic reduction in natural forest cover and the expansion of exotic woodland and production forest [45,46]. Besides land cover change, invasive species, including a large number of plant taxa that are recognized as problematic invaders worldwide, constitute a major threat to the preservation of the remaining natural plant communities in the Azores [47,48].

2.3. Evaluation of the Azorean Vascular Flora for CW Projects

In the study carried out by [23], the species used throughout the world in wetlands built with the horizontal subsurface flow were listed. The respective genera, in total 21, were listed, and their existence in the Azores archipelago was verified according to [44], the Azorean Biodiversity Portal and more recent reports. In addition, the genus *Lolium* has been added because it is known to tolerate large amounts of organic matter.

From the resulting list of genera, all taxa belonging to each genus and cited for the Azores were listed (73 taxa), according to the above references. In the case of *Lolium arundinaceum* (Schreb.) Darbysh. (*Festuca arundinacea* Schreb.), since the circumscription of the group is not clear [49], we included the species belonging to both genera. No data were available to distinguish between subspecies in terms of their potential use in CWs; therefore, our analysis relied on the available data at the species level.

This selection resulted in a list of existing species in the region with the potential to treat wastewater in CWs with the horizontal subsurface flow. Each species was described as to its (1) life form, (2) habitat, (3) status in the region, (4) aboveground biomass, (5) storage organs, (6) potential growth rate, (7) type of reproduction, (8) cultivation, and (9) tolerance to nutrient loadings and removal efficiency. To obtain a ranking of the most useful species, each criterion was classified between 0 and 4 points, according to species traits (Table 1).

Table 1. Description and quantification of the criteria.

Criteria		Parameters	Points
1	Life form	Helophyte, Hydrophyte, Hygrophyte	4
		Proto-hemicryptophyte, Hemicryptophyte, Microphanerophyte	2
		Therophyte	0
2	Habitat	Wetlands	4
		Terrestrial or wetlands, Terrestrial or Humid soils	2
		Terrestrial	0
3	Category of origin	Native	4
		Naturalized, Casual	2
		Endemic	0
4	Aboveground biomass	Large aboveground organs (>1.5 m height, large leaves with >0.5 m long)	4
		Medium sized aboveground organs (<1.5 m height, leaves up to 0.6 m long)	2
		Thin, slender stems or culms and small leaves (< 1 m height, leaves up to 0.5 m and 0.1 m wide)	0
5	Belowground organs	Large rhizome, Corm	4
		Rhizome, tuberose root, bulb, tuber	2
		Short fibrous roots	0
6	Potential growth rate (In a season)	High	4
		Medium	2
		Low	0
7	Reproduction	Vegetative reproduction	4
		Mainly by seed but some vegetative spread	2
		Only by seed	0
8	Cultivation	Cultivated in large areas	4
		Cultivated in small areas	2
		Not cultivated	0
9	Tolerance to nutrient loadings and removal efficiency	High tolerance and/or high nutrient removal	4
		Presence in habitats with nutrients, but no data on nutrient removal	2
		No tolerance or no data	0

Moreover, all species were classified according to their possible noxious status—invasive species or weeds. Regarding the origin of the species, we attributed a score of 0 points to endemic taxa since they usually correspond to relatively rare plants, circumscribed to habitats, to a sub-archipelago or an island e.g., [50]. Moreover, we wanted to avoid interfering with the evolutionary processes taking place in their natural populations e.g., [51]. In addition, in general, those taxa did not show relevant traits to be used in wastewater treatment.

Finally, we also considered if the species were presently used in cultivation in the Azores, attributing a positive score, from 2 (limited cultivation) to 4 (extensive cultivation), to that situation.

Information regarding plant traits used to score the evaluated taxa was obtained from the following sources: [52–61].

The resulting list of taxa was ranked according to the percentage value obtained by dividing the obtained score by the maximum total score possible (i.e., $4 \times 9 = 36$ points). The species were ordered into quartiles: 1st quartile—score < 25%; 2nd quartile—$25 \leq$ score < 50; 3rd quartile—$50 \leq$ score < 75; 4th quartile—score ≥ 75.

We applied a Mann–Whitney nonparametric test to compare the total scores from noxious and non-noxious plant species. Additionally, we applied a CATPCA—principal components analysis for categorical data to the item score dataset, to determine what were the most discriminating items and to assess possible differences among noxious and non-noxious plant species. The statistical analyses were performed using IBM SPSS version 26.

3. Results and Discussion

The resulting list integrates a total of 73 species distributed in 9 families and 21 genera (Supplementary Table S1). The Cyperaceae and the Poaceae dominated, followed by the Juncaceae (Figure 2). In the same direction, the genus *Carex* included more species (20), followed by *Juncus* (10), and *Cyperus* (8) (Supplementary Table S1).

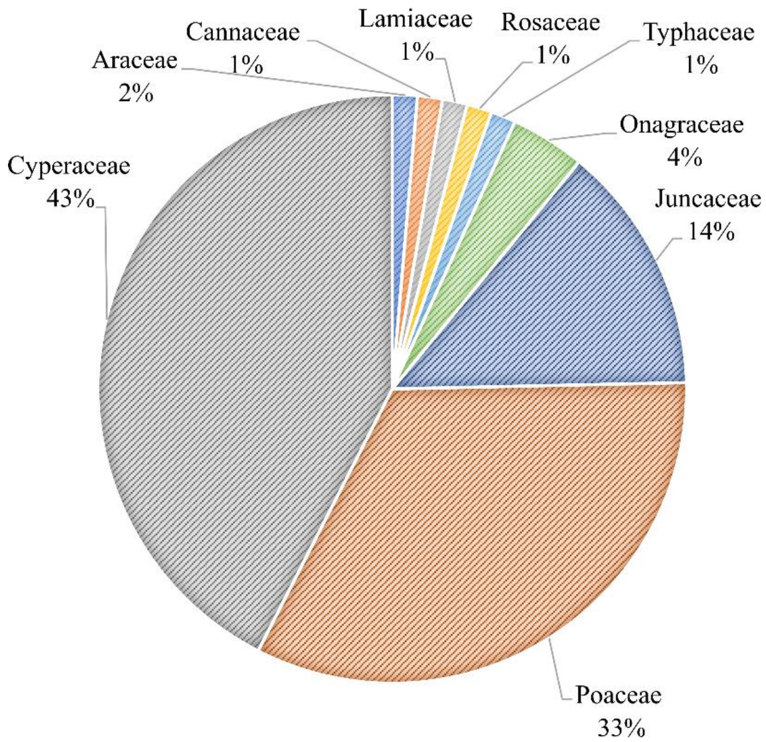

Figure 2. Distribution of evaluated taxa by families.

After scoring all 73 taxa according to the 9 criteria, the families including more taxa in the third and fourth quartiles (Figure 3) corresponded to the Cyperaceae (one in the 4th, seven in the 3rd) and Poaceae (one in the 4th, six in the 3rd), Typhaceae and Araceae (one taxa in the 4th), Juncaceae (three in the 3rd), and Cannaceae and Lamiaceae (one in the 3rd). The taxa included in the 4th quartile included *Colocasia esculenta*, *Bolboschoenus maritimus*, *Arundo donax* and *Typha domingensis*.

Only slight differences in some of the items were found among the four taxa in the 4th quartile (Figure 4). We scored *T. domingensis* a little lower than the others, regarding reproduction and cultivation. *B. maritimus* scored more in the category of origin since it was, among those taxa, the only one considered to be native to the Azores. The taxa in the 3rd quartile appeared to be divided into four groups within each taxa sharing the same score, but with slight differences, for the different item scores within those groups.

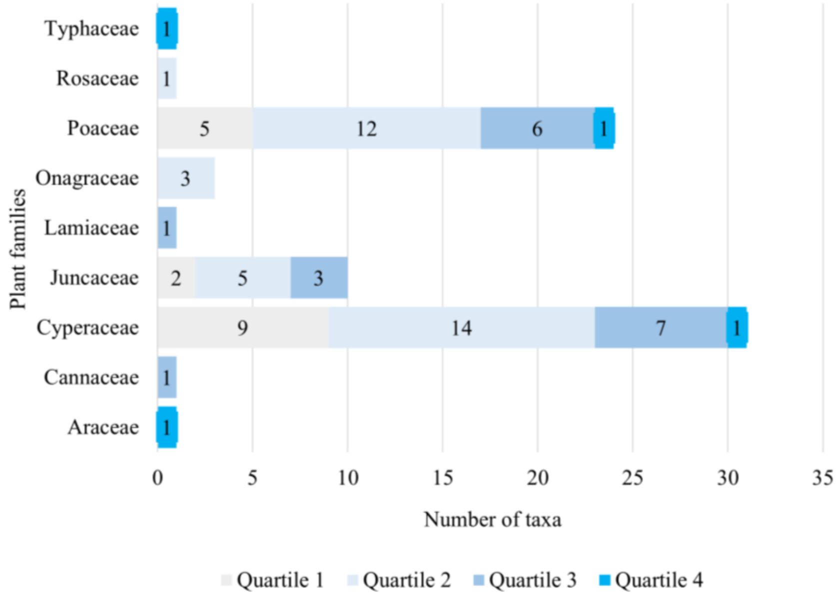

Figure 3. Number of taxa that were evaluated by plant family, discriminating their respective quartile, was determined based on their total score calculated as a percentage of the possible maximum score per species.

Figure 5 shows a summary of the score distribution for the global set of taxa, for the taxa at the bottom two quartiles, and for those taxa at the top two quartiles.

Regarding life forms (Figure 5a), we found a pronounced increase in taxa with a more adequate life strategy at the two top quartiles and a very similar situation regarding the type of habitat of those taxa (Figure 5b). Regarding origin (Figure 5c), we found no endemic species at the top two quartiles and a predominance of naturalized taxa, although with a considerable contribution of native taxa (about one-third). Considering the aboveground biomass (Figure 5d), there was a clear distinction between top-rank and bottom-rank species, with the former including mostly medium potential, but also including about one-fifth with high potential in this topic. A similar situation was found for belowground biomass (Figure 5e), although almost 50% of the top-ranked taxa classified with a high potential due to the presence of storage organs. The growth rate (Figure 5f) did not show a clearly different pattern for the different groups of taxa. However, regarding the type of reproduction (Figure 5g), namely those taxa clearly including effective vegetative propagation, the proportion of taxa with this ability was clearly higher in the top-ranking taxa. The proportion of cultivated taxa (Figure 5h) was, in general, low. Finally, regarding tolerance to water contaminants (Figure 5i), for most of the top-ranking taxa, references were found documenting this capability.

Meanwhile, in the global species dataset, about one-third of the taxa were found to be potentially noxious (i.e., weeds or invaders), and this proportion raised to above 50% when considering the top-ranking species only (Figure 6).

Due to the similar characteristics of reproduction, development and morphology, the discussion is reviewed by family.

There was a significant difference between the total scores of noxious and non-noxious plant species, with the former obtaining larger scores (Figure 7; see Supplementary Materials).

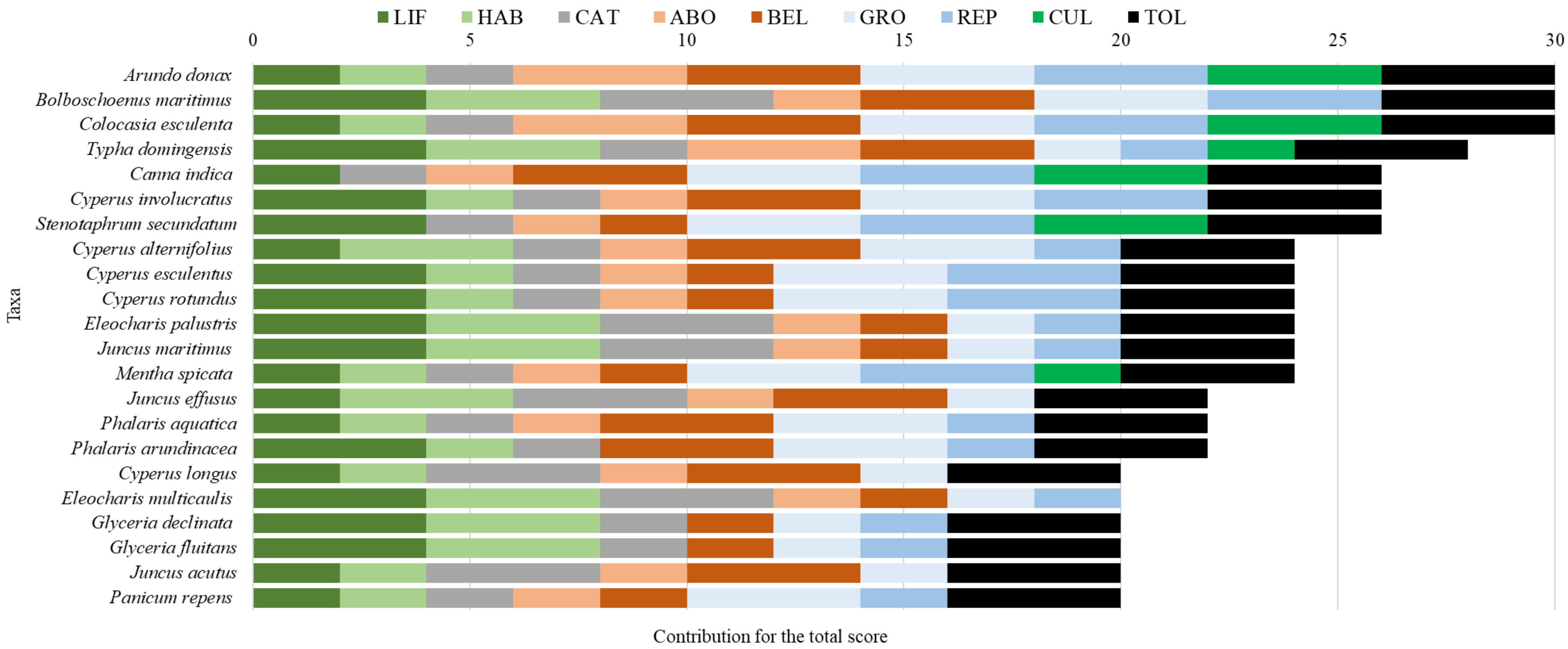

Figure 4. Scores of the evaluated taxa with higher ranks (third and fourth quartiles) for each of the nine criteria (different colours): LIF—life form, Hab—habitat, CAT—category of origin, ABO—aboveground biomass, BEL—belowground biomass, GRO—growth rate, REP—reproduction, CUL—cultivation, TOL—tolerance. For the complete table, see Supplementary Table S1. Here, the scores are presented as raw (i.e., 0, 2 or 4) and not as a percentage.

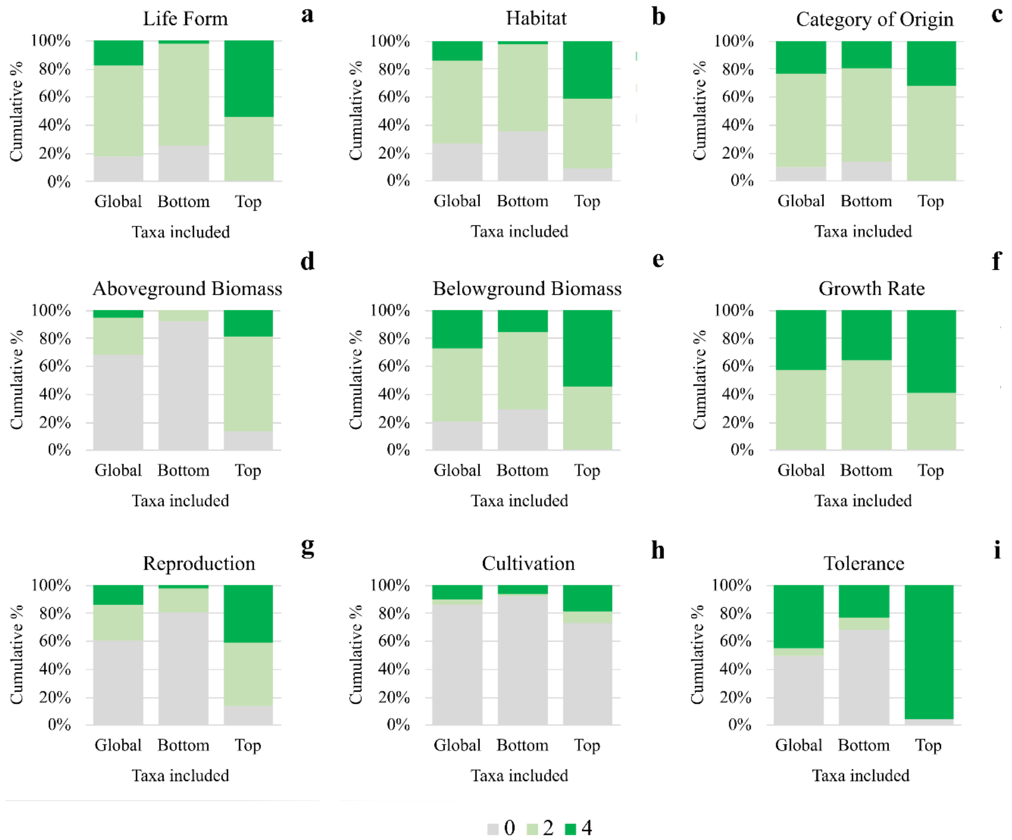

Figure 5. Score distribution (0, 2, or 4) for life form (**a**), habitat (**b**), category of origin (**c**), aboveground biomass (**d**), belowground biomass (**e**), growth rate (**f**), reproduction (**g**), cultivation (**h**) and tolerance to a high concentration of nutrients (**i**), for the global set of taxa and for the taxa located at the bottom or top two quartiles.

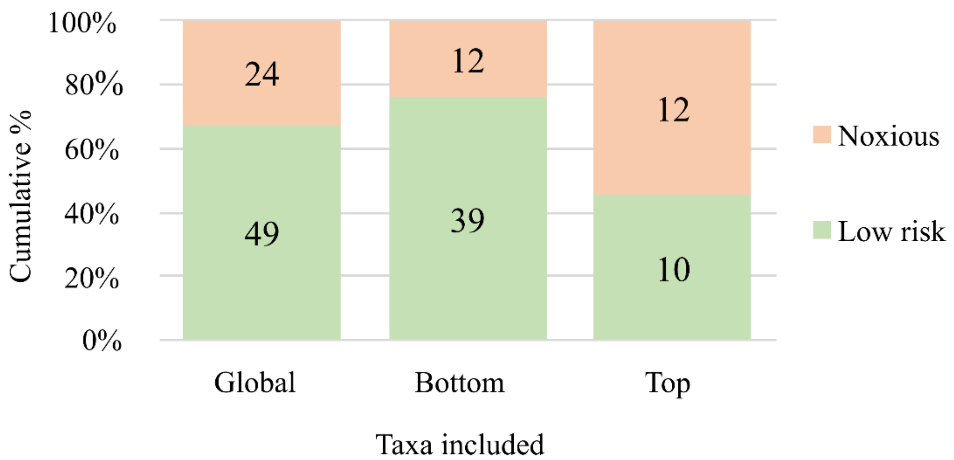

Figure 6. Percentage of taxa considered as noxious (i.e., weeds or invasive plants) in the global dataset, in the taxa located at the two lowest quartiles and in the top-ranking taxa (two upper quartiles).

The CATPCA originated two dimensions explaining more than 90% of the variance in the item score matrix (Figure 8). The first dimension was more related with growth rate, belowground biomass and the category of origin, while the second was more related with habitat type, category of life-form, and category of origin (Supplementary Materials). The noxious species tended to show larger values on the first dimension; however, the native *Bolboschoenus maritimus* showed relatively high values in the two dimensions.

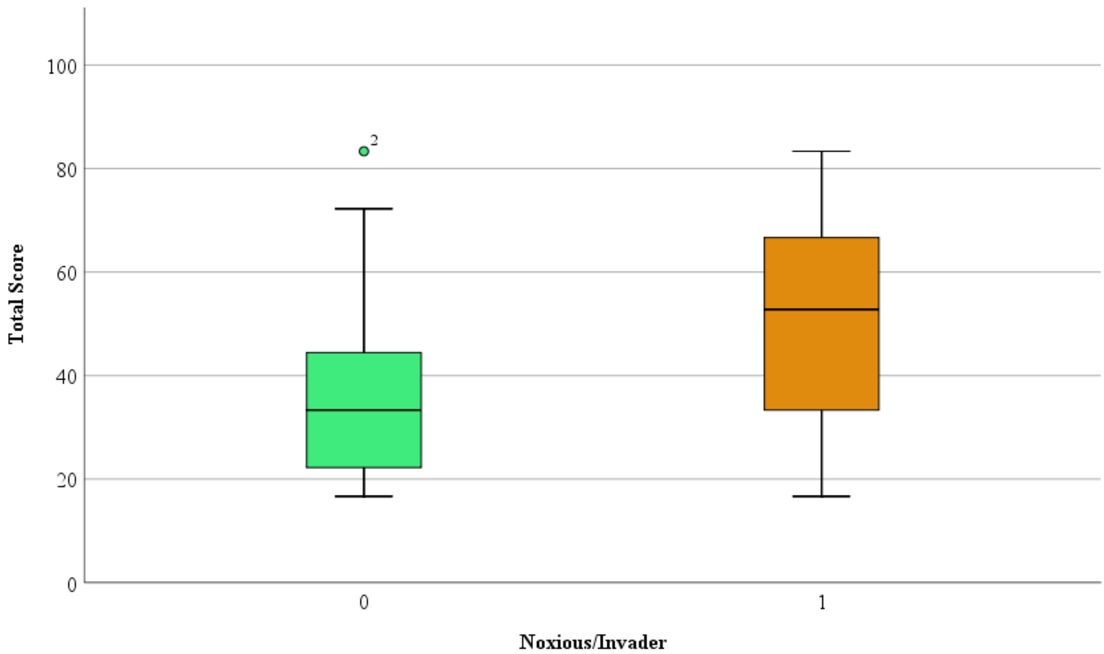

Figure 7. Comparison of the total scores from noxious (1) and non-noxious (0) plant species. Boxplot including frequency distribution of total score for both groups.

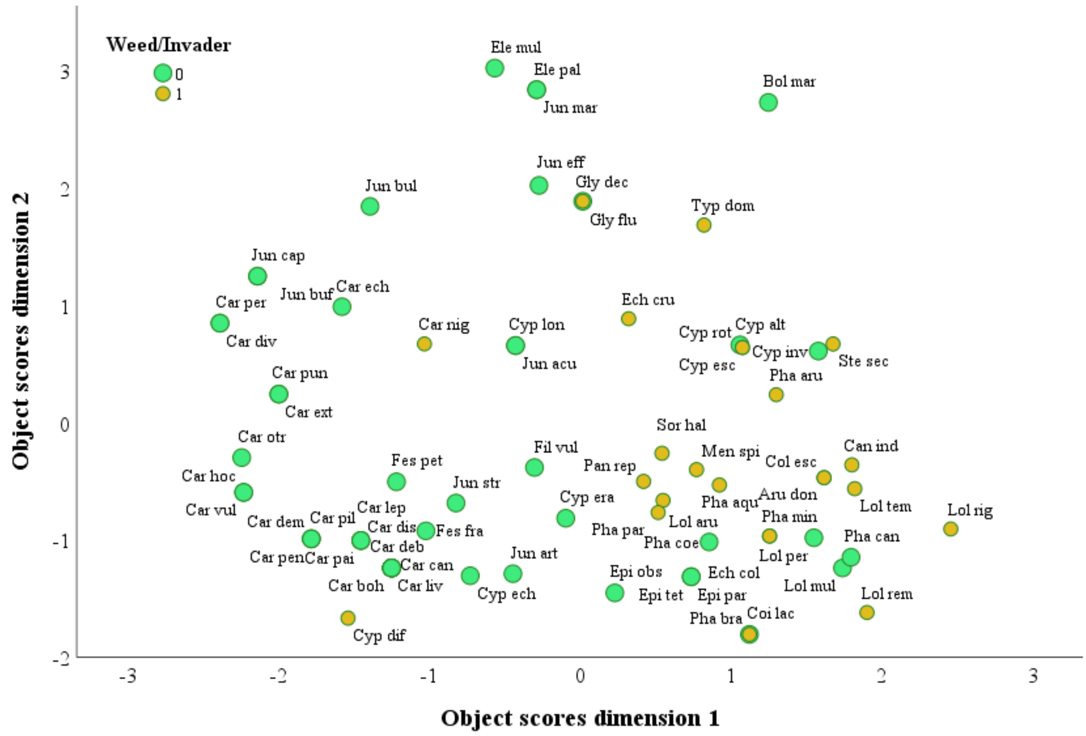

Figure 8. Results of the CATPCA − principal components analysis for categorical data. Plot with species scores for both extracted factors (dimensions 1 and 2).

Cyperaceae

Given the genera selected according to the literature, it was expected that this family would have the largest contribution, given its importance in the Azores and the worldwide [60].

From the eight species of *Cyperus*, four were included in the top 10 and five in the 3rd quartile, with three being considered as potentially noxious. Plants from the genus *Cyperus* are commonly used in CWs [62,63], and they play an important role in the maintenance and improvement of water quality [64]. Some studies showed a removal of up to 92% of total nitrogen and significant metal sequestration [65,66]. Ref. [67] verified that *C. longus* (17th in our study) can be a biological wastewater purifier through the removal of heavy metals. *Cyperus eragrostis* (27th in our study) was used in CWs in Australia as part of tertiary treatment [68–70], but the authors considered that more studies would be needed to test the efficiency of these plants. This taxon has recently been considered invasive in the Azores and in wetlands, although its expansion is somewhat limited, usually to scattered individuals or small groups of plants. Several studies using *C. involucratus* (6th in our study) showed that this species could be useful to treat wastewaters due to its fast growth, adaptation to different environments and nutrient removal [71]. Ref. [72] tested several species in a CW to treat seafood wastewater and concluded that *C. involucratus* showed high N and BOD_5 uptake and high biomass production. Ref. [73] verified that this species removed 99% of NH_4-N and 64% of inorganic N, concluding that it could be a good option to be used in CWs for N removal. *Cyperus alternifolius* (8th in our study) has also been studied in CWs to treat wastewater. This species showed good results for P removal in different wastewaters [74–76]. A study conducted by [77] comparing *C. alternifolius* with *Vetiveria zizanioides* to treat piggery wastewater revealed that the removal of N, P and some heavy metals by *C. alternifolius* was 4–7 times higher.

Bolboschoenus maritimus (2nd in our study) is a native plant from the Terceira and Faial islands, and it is adaptable to wetland habitats. It is propagated by rhizomes and has a reasonable amount of aboveground biomass. Associated with that, the fast growth and good tolerance to high nutrient loadings make this species the best option in the Azores to treat effluents in CWs with HSSF, according to this methodology. This is not one of the most common species used in CWs; however, some studies showed its efficiency in nutrient accumulation [78]. In the Azores, this species was already tested to treat domestic effluents and showed good performance in phosphorus, organic matter and faecal coliforms removal, and a growth rate comparable to that of *A. donax* [41].

While *Eleocharis sphacelata* is the most common species of *the* genus to be used in CWs with HSSF, *E. palustris* (11th in our study) and *E. multicaulis* (18th in our study), both in the 3^{rd} quartile, are native species from the Azores, which we considered to accumulate only medium levels of biomass above and belowground. The elemental percentages of C, N and P for the aboveground biomass of *E. palustris* in CWs was determined by [79], and the results showed a high N percentage when compared to other species such as *Carex nebrascensis*, *Juncus balticus*, *Scheonoplectus maritimus* (=*Bolboschoenus maritimus*), *S. acutus*, *S. pungens*, and *T. latifolia*. Meanwhile, *E. multicaulis* is characteristic of oligotrophic environments, i.e., with low nutrient levels.

Typhaceae

Typha domingensis (4th in our study) is the only species belonging to the genus *Typha* recorded in the Azores, but its distribution is restricted to Santa Maria Island, although probably being cultivated on other islands in artificial wetlands. Notwithstanding the well-known phytoremediation effect and nutrient removal of *T. latifolia*, *T. domingensis* has also had promising results in several studies [80–82]. *T. domingensis* presents the morphological characteristics to be used in CWs, and the previous studies conducted with this species raise it to the 4th position of the ranking. However, it has recently been considered as invasive in the Azores, in water streams, where it occurs out of cultivation, although with a limited extension.

Araceae

Colocasia esculenta (3rd in our study) is an abundant species in all the Azores archipelago that is easy to obtain and maintain in cultivation. Despite being a potentially invasive species in many places, in the Azores and Madeira Island [48], particularly along water streams and in steep, wet coastal areas, it has been widely used for commercial and agricultural purposes in the Azores, being planted but also frequently escaping from cultivation, forming from small groups of plants to dense stands, resulting from vegetative propagation of the rhizomes. Previous research showed removal of nitrate, phosphate and organic matter, and tolerance to very high COD concentrations. There are studies with *C. esculenta* in domestic wastewater treatment with promising results for nutrient and heavy metal removal [83–89]. In Tanzania, results of this species used in CWs showed that phosphorus, sulphate, ammonia, and COD can be effectively removed [90]. Moreover, *C. esculenta* was revealed to be a technically and economically viable option for CWs to treat rice mill wastewater [83].

Juncaceae

In the Azores, we have records of ten species of *Juncus*. According to our results, three species were in the 3rd quartile, and the remaining were distributed among the 2nd and 1st quartiles. *Juncus maritimus*, *J. acutus* and *J. effusus* are all common in the Azores, the first two mostly near the coast, and the latter at inland wetlands (e.g., lake and water stream margins, wet pastureland). Plants belonging to this genus are considered helophytes and are tolerant to water-clogged soils and, in some cases, are halotolerant.

Juncus effusus has been used in the United States of America [23,91] in domestic wastewater treatment with positive results for total phosphorus, total Kjeldahl nitrogen and ammoniacal nitrogen removal. It has been also used in CWs in several regions in mainland Portugal [92–94]. The occurrence of this species near pastures where the rainwater flows with high concentrations of nutrients due to leaching shows the probable good adaptation to agricultural wastewaters, particularly from cattle farms.

Juncus acutus has been used in CWs in several studies. This species tolerates drought, flood, and salty conditions [95] and can be used in different environments. Ref. [20] demonstrated that *J. acutus* is appropriate for phytoremediation purposes, especially in antibiotic and contaminant removal. *J. bofonius* is also a native species from the Azores; however, the biomass of this plant is very low, which according to some studies, can affect removal efficiency.

Cannaceae

Canna indica is found in the Azores both as an ornamental plant in gardens, but it also frequently escapes from cultivation along the margins of exotic woodland, agricultural land, and water streams, ranking 5th in our analysis, being the first species in the 3rd quartile. It is one of the main emergent and ornamental macrophytes in CWs in the Mediterranean countries [63], being used for various purposes such as domestic, municipal, and agricultural wastewater treatment [62,96]. Ref. [97] used this species to treat dairy-farm effluents with high concentrations of organic matter and obtained very high COD removal. Beyond the improvement of water quality, *C. indica* also contributes to the aesthetic value of the locations.

In some cases, fibrous-root plants, as in the case of *C. indica*, *Juncus*, and *C. esculenta*, displayed higher photosynthesis and nutrient removal when compared to thick-root plants [98]. The rhizosphere of wetland plants is the most important element of the CW, where the physicochemical and biological processes take place and all components (i.e., plant tissues, wastewater, microorganisms, substrate) contact directly [70,99,100]. Furthermore, some studies indicated a relation between nutrient removal and plant root number and root surface area [101,102].

Lamiaceae

Mentha spicata is cultivated in the Azores at very small stands as an aromatic herb, being occasionally found as escaping cultivation, ranking 13th in our analysis. Ref. [103] tested *M. spicata* in CWs together with other species and obtained high removals for BOD_5, TSS and faecal coliforms. This species showed a good response to high levels of P and N [104]. Ref. [105] used *M. spicata* to treat effluents of aquaponics, and the removal of NH_4 and PO_4 was 48% and 55%, respectively.

Poaceae

According to the genera cited in the literature as of interest in CWs, we listed 24 taxa, most of which (17) ranked in the bottom two quartiles. Of the remaining 7 taxa, *Arundo donax* ranked 1st, *Stenotaphrum secundatum* 7th, two *Phalaris* species ranked 15th and 16th, two *Glyceria* species ranked 19th and 20th, and *Panicum repens* as 22nd. The family is one of the most represented in the Azores, since it includes numerous weeds, forage and lawn species. However, the plants belonging to Poaceae are not commonly used in wastewater treatment due to the low biomass of aerial organs. Nonetheless, several are used in pastureland (e.g., *Lolium* spp.), being able to tolerate high amounts of organic matter (e.g., manure applications).

Arundo donax was introduced intentionally in the Azores to hedgerows, to control soil erosion, handcraft, ornamental, and agriculture, but when established, it caused drastic ecological changes and affected several endemic and native species, including vascular plants and seabirds [48,106]. It has invaded large areas in all the archipelago, particularly along water streams and in coastal areas, including very steep sea cliffs. Presently, it is classified as one of the 100 invasive species in Macaronesia [48]. Despite that *A. donax* is attracting attention to be used in CWs due to these promising results [107–110], encouraging further cultivation and dispersal would be a threat to native and endemic plants and to coastal habitats.

Stenotaphrum secundatum has been extensively used in the Azores in lawns, but it tends to escape cultivation and expand into the surrounding natural areas, including coastal and inland ecosystems, completely changing the vegetation structure [48]. Some studies demonstrated the capacity of *S. secundatum* to remove nutrients from different types of wastewater [62,111,112].

Phalaris arundinacea has been used in CWs in consortium with other plants in the Czech Republic and the United States [23,113]. This species can survive in poorly drained regions and can withstand long periods of flooding [114].

Most of the existing studies in CWs using *Glyceria* are focused on *Glyceria maxima*; however, this species is not recorded for the Azores. Some studies demonstrated the potential of *G. declinata* and *G. fluitans* (19th and 20th in our study) for phytoremediation, especially in heavy metal reduction and nutrient uptake [115,116], although the above biomass is very low. *Sorghum halapense* was studied by [117] and presents the morphological requirements to be used in CWs; however, this species is a worldwide weed, which could deter its more extensive use.

Panicum repens is a very common plant in wetland areas and is very difficult to control [118]. Some studies demonstrated that *P. repens* is suitable to reduce metals [119,120] and that it can also reduce water salinity [121].

Other families

The Onagraceae were represented in our list by three species of *Epilobium*, although all scored relatively low (28th to 30th), corresponding to small stature hemicryptophytes mainly adapted to terrestrial environments. In addition, they present low biomass, and no wastewater treatment studies were found for these taxa. *Epilobium obscurum* can survive in mesotrophic habitats [58]; however, no data about nutrient removal were found with this species. Regarding Rosaceae, the selected genus according to the literature corresponded to *Filipendula vulgaris*, ranking 31st in our analysis, typical of terrestrial habitats, with low biomass and for which no studies on nutrient removal were found. For both families, studies were performed with other species of the same genera (*E. hirsutum* and *F. ulmaria*) by [113] in the Czech Republic.

The experimental tests to be carried out with the results of this study should consider mixed cultures, with two or more species, since according to several authors [23,103,122,123], the association of species represents higher efficiencies of pollutant removal. Since some species only occur on specific islands of the Azores (e.g., *B. maritimus* on Terceira and Faial islands and *T. dominguenses* on Santa Maria island), when selecting species to be used, preference should be given to the best ranked species occurring locally.

4. Conclusions

Several of the most common plant taxa used in CWs with HSF are classified as invasive species in the Azores; a proposal of alternatives is of utmost importance. Given its potential as a top invasive species, we do not recommend the use of *Arundo donax* in CWs in the Azores, although it ranked first in our analysis. Furthermore, *Bolboschoenus maritimus* and the three species of *Juncus* with the highest scores all are considered native in the Azores, and their use in CWs in the region should be further encouraged if the material used comes from the Azores and no threat to the natural populations of these species is ensured. A similar approach would be acceptable for the *Eleocharis* species. Regarding *Typha domingensis* and *Canna indica*, their use in CWs in the Azores should be considered in those cases where escape from cultivation could be avoided, which might be problematic in terms of logistics. Nonetheless, both species are presently being used as ornamental plants in gardens and artificial lakes. More research would be needed to better understand their present and potential impact on natural habitats. Finally, *Colocasia esculenta* is presently being used extensively in the Azores as an agricultural crop, particularly along water stream margins; therefore, its use in CWs could be envisioned if regulations and procedures would be defined and implemented to avoid further expansion into natural environments.

As a whole, this study showed that in the Azores, plant resources are available to ensure the development of further research and pilot studies devoted to the use of CWs in water treatment approaches.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142214681/s1, Table S1: Numerical assessment of criteria for each species. LIF: life form; HAB: habitat; CAT: category of origin; ABO: aboveground biomass; BEL: belowground organs; GRO: potential growth rate (in a season); REP: reproduction; CUL: cultivation; TOL: tolerance to nutrient loadings and removal efficiency: NOX: noxious (weed or invasive). The total value was calculated by dividing the obtained score by the maximum total score possible; File S1: Statistical analyses.

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References

1. Potschin, M.; Kretsch, C.; Haines-Young, R.; Furman, E.; Berry, P.; Baró, F. Nature-based solutions. *In OpenNESS Ecosystem Service Reference Book*; Potschin, M., Jax, K., Eds.; Reference Book. EC FP7 Grant Agreement n. 308428; 2015. Available online: http://www.openness-project.eu/library/reference-book (accessed on 10 July 2022).
2. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. (Eds.) *Nature-based solutions to address global societal challenges*; IUCN: Gland, Switzerland, 2016; Volume 97, pp. 2016–2036. [CrossRef]
3. European Commission. Towards an EU research and innovation policy agenda for nature-based solutions and re-naturing cities. In *Final Report of the Horizon 2020 Expert Group on Nature-Based Solutions and re-Naturing Cities*; Publications Office: Brussels, Belgium, 2015. Available online: http://data.europa.eu/doi/10.2777/479582 (accessed on 2 August 2022).
4. U.S. EPA: United States Environmental Protection Agency. *Wastewater Technology Fact Sheet Wetlands: Subsurface Flow*; EPA 832-F-00-023; EPA: Washington, DC, USA, 2000.
5. Vymazal, J. Constructed wetlands for wastewater treatment. *Water* **2010**, *2*, 530–549. [CrossRef]
6. Haddis, A.; Van der Bruggen, B.; Smets, I. Constructed wetlands as nature-based solutions in removing organic pollutants from wastewater under irregular flow conditions in a tropical climate. *Ecohydrol. Hydrobiol.* **2020**, *20*, 38–47. [CrossRef]

7. Li, X.; Wu, S.; Yang, C.; Zeng, G. Microalgal and duckweed based constructed wetlands for swine wastewater treatment: A review. *Bioresour. Technol.* **2020**, *318*, 123858. [CrossRef] [PubMed]
8. Varma, M.; Gupta, A.K.; Ghosal, P.S.; Majumder, A. A review on performance of constructed wetlands in tropical and cold climate: Insights of mechanism, role of influencing factors, and system modification in low temperature. *Sci. Total Environ.* **2021**, *755*, 142540. [CrossRef] [PubMed]
9. Vymazal, J. The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecol. Eng.* **2009**, *35*, 1–17. [CrossRef]
10. Wang, H.; Sheng, L.; Xu, J. Clogging mechanisms of constructed wetlands: A critical review. *J. Clean. Prod.* **2021**, *295*, 126455. [CrossRef]
11. Brix, H. The use of aquatic macrophytes in water-pollution control. *Ambio* **1989**, *28*, 100–107.
12. Vymazal, J.; Zhao, Y.; Mander, Ü. Recent research challenges in constructed wetlands for wastewater treatment: A review. *Ecol. Eng.* **2021**, *169*, 106318. [CrossRef]
13. Vymazal, J.; Kröpfelová, L. *Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow (Vol. 14)*; Springer Science & Business Media: Prague, Czech Republic, 2008.
14. Brix, H. Functions of macrophytes in constructed wetlands. *Water Sci. Technol.* **1994**, *29*, 71–78. [CrossRef]
15. Cui, L.; Ouyang, Y.; Yang, W.; Huang, Z.; Xu, Q.; Yu, G. Removal of nutrients from septic tank effluent with baffle subsurface-flow constructed wetlands. *J. Environ. Manag.* **2015**, *153*, 33–39. [CrossRef]
16. Vymazal, J. The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. *Ecol. Eng.* **2002**, *18*, 633–646. [CrossRef]
17. Vymazal, J. Removal of nutrients in various types of constructed wetlands. *Sci. Total Environ.* **2007**, *380*, 48–65. [CrossRef] [PubMed]
18. Maucieri, C.; Barbera, A.; Vymazal, J.; Borin, M. A review of the main affecting factors of the greenhouse gases emission in constructed wetlands. *Agric. For. Meteorol.* **2017**, *236*, 175–193. [CrossRef]
19. Chen, X.; Zhu, H.; Yan, B.; Shutes, B.; Xing, D.; Banuelos, G.; Cheng, R.; Wang, X. Greenhouse gas emissions and wastewater treatment performance by three plant species in subsurface flow constructed wetland mesocosms. *Chemosphere* **2020**, *239*, 124795. [CrossRef]
20. Syranidou, E.; Christofilopoulos, S.; Kalogerakis, N. Juncus spp.—The helophyte for all (phyto) remediation purposes? *New Biotechnol.* **2017**, *38*, 43–55. [CrossRef] [PubMed]
21. Vymazal, J. The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development. *Water Res.* **2013**, *47*, 4795–4811. [CrossRef] [PubMed]
22. Srivastava, J.; Kalra, S.J.; Naraian, R. Environmental perspectives of *Phragmites australis* (Cav.) Trin. Ex. Steudel. *Appl. Water Sci.* **2014**, *4*, 193–202. [CrossRef]
23. Vymazal, J. Plants used in constructed wetlands with horizontal subsurface flow: A review. *Hydrobiologia* **2011**, *674*, 133–156. [CrossRef]
24. Healy, M.G.; Rodgers, M.; Mulqueen, J. Treatment of dairy wastewater using constructed wetlands and intermittent sand filters. *Bioresour. Technol.* **2007**, *98*, 2268–2281. [CrossRef]
25. Abeysinghe, T.; Simic Milas, A.; Arend, K.; Hohman, B.; Reil, P.; Gregory, A.; Vázquez-Ortega, A. Mapping invasive *Phragmites australis* in the Old Woman Creek estuary using UAV remote sensing and machine learning classifiers. *Remote Sens.* **2019**, *11*, 1380. [CrossRef]
26. Gonzalez Mateu, M.; Baldwin, A.H.; Maul, J.E.; Yarwood, S.A. Dark septate endophyte improves salt tolerance of native and invasive lineages of *Phragmites australis*. *ISME J.* **2020**, *14*, 1943–1954. [CrossRef] [PubMed]
27. Pyšek, P.; Skálová, H.; Cuda, J.; Guo, W.; Dolezal, J.; Kauzál, O.; Lambertini, C.; Pyšková, K.; Brix, H.; Meyerson, L.A. Physiology of a plant invasion: Biomass production, growth and tissue chemistry of invasive and native *Phragmites australis* populations. *Preslia* **2019**, *91*, 51–75. [CrossRef]
28. Quirion, B.; Simek, Z.; Dávalos, A.; Blossey, B. Management of invasive *Phragmites australis* in the Adirondacks: A cautionary tale about prospects of eradication. *Biol. Invasions* **2018**, *20*, 59–73. [CrossRef]
29. PGRH. Plano de Gestão da Região Hidrográfica dos Açores (RH9) 2016-2021—Síntese da Caracterização e Diagnóstico (Management Plan for the Azores Hydrographic Region (RH9) 2016–2021—Synthesis of Characterization and Diagnosis), Strategic Environmental Assessment, Regional Secretary of Agriculture and Environment. 2015. Available online: https://servicos-sraa.azores.gov.pt/grastore/DRA/PGRHA_2016-2021/PGRH-A_2016-2021_AAE-RA.PDF (accessed on 15 June 2022).
30. Del Rosario, K.; Mitra, S.; Humphrey Jr, C.; O'Driscoll, M. Detection of pharmaceuticals and other personal care products in groundwater beneath and adjacent to onsite wastewater treatment systems in a coastal plain shallow aquifer. *Sci. Total Environ.* **2014**, *487*, 216–223. [CrossRef] [PubMed]
31. Hube, S.; Wu, B. Mitigation of emerging pollutants and pathogens in decentralized wastewater treatment processes: A review. *Sci. Total Environ.* **2021**, *779*, 146545. [CrossRef] [PubMed]
32. Withers, P.J.; Jordan, P.; May, L.; Jarvie, H.P.; Deal, N.E. Do septic tank systems pose a hidden threat to water quality? *Front. Ecol. Environ.* **2014**, *12*, 123–130. [CrossRef]
33. INE: National Statistics Institute. The Agricultural Census. *Analysis of the Main Results—2019, Lisboa.* 2019. Available online: www.ine.pt (accessed on 10 July 2022).

34. Morais, T.G.; Teixeira, R.F.; Rodrigues, N.R.; Domingos, T. Carbon footprint of milk from pasture-based dairy farms in Azores, Portugal. *Sustainability* **2018**, *10*, 3658. [CrossRef]
35. Bajouco, R.; Pinheiro, J.; Pereira, B.; Ferreira, R.; Coutinho, J. Risk of phosphorus losses from Andosols under fertilized pasture. *Environ. Sci. Pollut. Res.* **2020**, *27*, 19592–19602. [CrossRef]
36. Cordeiro, R.; Luz, R.; Vilaverde, J.; Vasconcelos, V.; Fonseca, A.; Gonçalves, V. Distribution of Toxic Cyanobacteria in Volcanic lakes of the Azores Islands. *Water* **2020**, *12*, 3385. [CrossRef]
37. Pinheiro, J.; Matos, M.D.L. Characterization and strategies for the control of eutrophication in the Furnas watershed (Azores Portugal). In *Novel Methods for Reducingagricultural Nutrient Loadingand Eutrophication, Proceedings of the Meeting of Cost 869, Jokioinen, Finland, 14–16 June 2010*; Turtola, E., Ekholm, P., Chardon, W., Eds.; MTT Agrifood Research Finland: Jokioinen, Finland, 2010.
38. Cruz, J.V.; Silva, M.O.; Dias, M.I.; Prudêncio, M.I. Groundwater composition and pollution due to agricultural practices at Sete Cidades volcano (Azores, Portugal). *Appl. Geochem.* **2013**, *29*, 162–173. [CrossRef]
39. Pereira, A.; Fernandes, R.; Martins, A.; Freire, J. Exploration of Constructed Wetlands WWTPs: Seven Years of Águas do Algarve Experience. In *INCREaSE 2017*; Springer: Cham, Switzerland, 2018; pp. 612–623. [CrossRef]
40. Molle, P.; Lombard Latune, R.; Riegel, C.; Lacombe, G.; Esser, D.; Mangeot, L. French vertical-flow constructed wetland design: Adaptations for tropical climates. *Water Sci. Technol.* **2015**, *71*, 1516–1523. [CrossRef] [PubMed]
41. Quadros, S.; Rio, P.; Mesquita, E.; Rosa, M.J. Exploring the use of Azorean native plants and rock material for sustainable wastewater treatment through constructed wetland systems. In Proceedings of the 2nd European Water Association Spring Conference, Lisbon, Portugal, 10 May–11 May 2017.
42. Miranda, P.M.A.; Valente, M.A.V.; Tomé, A.R.; Trigo, R.; Coelho, M.F.; Aguiar, A.; Azevedo, B. O clima de Portugal nos séculos XX e XXI. In *Alterações Climáticas em Portugal: Cenários, Impactos e Medidas de Adaptação*; Santos, F.D., Miranda, P.M.A., Eds.; Gradiva: Lisboa, Portugal, 2006; pp. 47–113.
43. PROTA: Azores Regional Planning Plan 2021. Available online: http://ot.azores.gov.pt/Instrumentos-de-Gestao-Territorial-Documento.aspx?id=2 (accessed on 10 December 2021).
44. Borges, P.A.; Costa, A.; Cunha, R.; Gabriel, R.; Gonçalves, V.; Martins, A.F.; Melo, I.; Parente, M.; Raposeiro, P.; Rodrigues, P.; et al. (Eds.) *A List of the Terrestrial and Marine Biota from de Azores*; Princípia: Cascais, Portugal, 2010.
45. Borges Silva, L.; Pavão, D.C.; Elias, R.B.; Moura, M.; Ventura, M.A.; Silva, L. Taxonomic, structural diversity and carbon stocks in a gradient of island forests. *Sci. Rep.* **2022**, *12*, 1038. [CrossRef] [PubMed]
46. Lourenço, R.W.; Silva, D.C.C.; Martins, A.C.G.; Sales, J.C.A.; Roveda, S.R.M.M.; Roveda, J.A.F. Use of fuzzy systems in the elaboration of an anthropic pressure indicator to evaluate the remaining forest fragments. *Environ. Earth Sci.* **2015**, *74*, 2481–2488. [CrossRef]
47. Costa, H.; Bettencourt, M.J.; Silva, C.; Teodósio, J.; Gil, A.; Silva, L. Invasive alien plants in the Azorean protected areas: Invasion status and mitigation actions. In *Plant Invasions in Protected Areas*; Foxcroft, L., Pyšek, P., Richardson, D., Genovesi, P., Eds.; Invading Nature—Springer Series in Invasion Ecology; Springer: Dordrecht, The Netherlands, 2013; Volume 7, pp. 375–394. [CrossRef]
48. Silva, L.; Land, E.O.; Luengo, J.L.R. (Eds.) *Invasive Terrestrial Flora and Fauna in Macaronesia: TOP 100 in Azores, Madeira and Canaries*; ARENA: Ponta Delgada, Portugal, 2008.
49. Hand, M.L.; Cogan, N.O.; Stewart, A.V.; Forster, J.W. Evolutionary history of tall fescue morphotypes inferred from molecular phylogenetics of the *Lolium-Festuca* species complex. *BMC Evol. Biol.* **2010**, *10*, 303. [CrossRef] [PubMed]
50. Moura, M.; Silva, L.; Dias, E.F.; Schaefer, H.; Carine, M.A. A revision of the genus *Leontodon* in the Azores based on morphological and molecular evidence. *Phytotaxa* **2015**, *210*, 024–046. [CrossRef]
51. Dias, E.F.; Moura, M.; Schaefer, H.; Silva, L. Geographical distance and barriers explain population genetic patterns in an endangered island perennial. *AoB Plants* **2016**, *8*, plw072. [CrossRef] [PubMed]
52. ABP. Azorean Biodiversity Portal. 2022. Available online: https://azoresbioportal.uac.pt (accessed on 20 July 2022).
53. CABI. *Invasive Species Compendium*; CAB International: Wallingford, UK, 2022. Available online: www.cabi.org/isc (accessed on 1 September 2022).
54. EOL. Encyclopedia of Life. 2022. Available online: http://eol.org (accessed on 22 July 2022).
55. Franco, J.A.; Afonso, M.L.R. *Nova Flora de Portugal—Vol. III—Fascículo I*; Escolar Editora: Forte da Casa, Portugal, 1994.
56. Franco, J.A.; Afonso, M.L.R. *Nova Flora de Portugal—Vol. III—Fascículo II*; Escolar Editora: Forte da Casa, Portugal, 1998.
57. Franco, J.A.; Afonso, M.L.R. *Nova Flora de Portugal—Vol. III—Fascículo III*; Escolar Editora: Forte da Casa, Portugal, 2003.
58. GBIF.Org GBIF Home Page. 2022. Available online: https://www.gbif.org (accessed on 22 July 2022).
59. JBUTAD. Portal do Jardim Botânico da Universidade de Trás-os-Montes e Alto Douro, Flora Digital de Portugal. 2022. Available online: https://jb.utad.pt/ (accessed on 22 July 2022).
60. POWO. Plants of the World Online. *Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet*. 2022. Available online: http://www.plantsoftheworldonline.org/ (accessed on 22 July 2022).
61. USDA, NRCS. United States Department of Agriculture -Natural Resources Conservation Service. The Plants Database, Greensboro, NC USA. 2022. Available online: https://www.nrcs.usda.gov/ (accessed on 22 July 2022).
62. Calheiros, C.S.C.; Rangel, A.O.S.S.; Castro, P.M.L. Constructed wetland systems vegetated with different plants applied to the treatment of tannery wastewater. *Water Res.* **2007**, *41*, 1790–1798. [CrossRef]

63. Korkusuz, E.A. Manual of practice on constructed wetlands for wastewater treatment and reuse in Mediterranean countries. *Tech. Rep. AVKR* **2005**, 5. [CrossRef]
64. Simpson, D.A.; Yesson, C.; Culham, A.; Couch, C.A.; Muasya, A.M. Climate change and Cyperaceae. In *Climate Change, Ecology and Systematics*; Hodkinson, T., Jones, M., Waldren, S., Parnell, J., Eds.; Cambridge University Press: Cambridge, UK, 2011; pp. 439–456.
65. Murray-Gulde, C.L.; Huddleston, G.M.; Garber, K.V.; Rodgers, J.H. Contributions of *Schoenoplectus californicus* in a constructed wetland system receiving copper contaminated wastewater. *Water Air Soil Pollut.* **2005**, *163*, 355–378. [CrossRef]
66. Tanner, C.C. Plants for constructed wetland treatment systems: A comparison of the growth and nutrient uptake of eight emergent species. *Ecol. Eng.* **1996**, *7*, 59–83. [CrossRef]
67. Ganjo, D.G.A.; Mirza, H.A. *Cyperus longus* L. as a biological purifier of wastewater for irrigation purposes: Removal efficiency and Zn, Cd, Cu, Fe and Mn. *Environ. Health Risk VII* **2013**, *16*, 249.
68. Greenway, M.; Woolley, A. Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation. *Ecol. Eng.* **1999**, *12*, 39–55. [CrossRef]
69. Greenway, M. Suitability of macrophytes for nutrient removal from surface flow constructed wetlands receiving secondary treated sewage effluent in Queensland, Australia. *Water Sci. Technol.* **2003**, *48*, 121–128. [CrossRef] [PubMed]
70. Greenway, M. The role of macrophytes in nutrient removal using constructed wetlands. In *Environmental Bioremediation Technologies*; Singh, S.N., Tripathi, R.D., Eds.; Springer: Berlin/Heidelberg, Germany, 2007; pp. 331–351.
71. Jampeetong, A.; Brix, H.; Kantawanichkul, S. Effects of inorganic nitrogen forms on growth, morphology, nitrogen uptake capacity and nutrient allocation of four tropical aquatic macrophytes (*Salvinia cucullata*, *Ipomoea aquatica*, *Cyperus involucratus* and *Vetiveria zizanioides*). *Aquat. Bot.* **2012**, *97*, 10–16. [CrossRef]
72. Sohsalam, P.; Englande, A.J.; Sirianuntapiboon, S. Seafood wastewater treatment in constructed wetland: Tropical case. *Bioresour. Technol.* **2008**, *99*, 1218–1224. [CrossRef]
73. Pincam, T.; Brix, H.; Jampeetong, A. Growth performance of tropical wetland species (*Cyperus involucratus* Rottb. and *Thalia geniculata* L.) in anaerobic digester effluent and their water treatment efficiency. *Ecol. Eng.* **2020**, *143*, 105667. [CrossRef]
74. Cui, L.H.; Zhu, X.Z.; Ouyang, Y.; Chen, Y.; Yang, F.L. Total phosphorus removal from domestic wastewater with *Cyperus alternifolius* in vertical-flow constructed wetlands at the microcosm level. *Int. J. Phytoremediation* **2011**, *13*, 692–701. [CrossRef]
75. Ebrahimi, A.; Taheri, E.; Ehrampoush, M.H.; Nasiri, S.; Jalali, F.; Soltani, R.; Fatehizadeh, A. Efficiency of constructed wetland vegetated with *Cyperus alternifolius* applied for municipal wastewater treatment. *J. Environ. Public Health* **2013**, 815962. [CrossRef]
76. Thongtha, S.; Teamkao, P.; Boonapatcharoen, N.; Tripetchkul, S.; Techkarnjararuk, S.; Thiravetyan, P. Phosphorus removal from domestic wastewater by *Nelumbo nucifera* Gaertn. and *Cyperus alternifolius* L. *J. Environ. Manag.* **2014**, *137*, 54–60. [CrossRef]
77. Liao, X.; Luo, S.; Wu, Y.; Wang, Z. Comparison of nutrient removal ability between *Cyperus alternifolius* and *Vetiveria zizanioides* in constructed wetlands. *Ying Yong Sheng Tai Xue Bao J. Appl. Ecol.* **2005**, *16*, 156–160.
78. Bragato, C.; Brix, H.; Malagoli, M. Accumulation of nutrients and heavy metals in *Phragmites australis* (Cav.) Trin. ex Steudel and *Bolboschoenus maritimus* (L.) Palla in a constructed wetland of the Venice lagoon watershed. *Environ. Pollut.* **2006**, *144*, 967–975. [CrossRef] [PubMed]
79. Ray, A.M.; Inouye, R.S. Vegetative nutrient pools in a constructed wetland in southeaster Idaho. *J. Freshw. Ecol.* **2006**, *21*, 593–601. [CrossRef]
80. de Oliveira, J.P.V.; Pereira, M.P.; Duarte, V.P.; Corrêa, F.F.; de Castro, E.M.; Pereira, F.J. Root anatomy, growth, and development of *Typha domingensis* Pers. (Typhaceae) and their relationship with cadmium absorption, accumulation, and tolerance. *Environ. Sci. Pollut. Res.* **2022**, *29*, 19878–19889. [CrossRef]
81. Hegazy, A.K.; Abdel-Ghani, N.T.; El-Chaghaby, G.A. Phytoremediation of industrial wastewater potentiality by *Typha domingensis*. *Int. J. Environ. Sci. Technol.* **2011**, *8*, 639–648. [CrossRef]
82. Lorenzen, B.; Brix, H.; Mendelssohn, I.A.; McKee, K.L.; Miao, S.L. Growth, biomass allocation and nutrient use efficiency in *Cladium jamaicense* and *Typha domingensis* as affected by phosphorus and oxygen availability. *Aquat. Bot.* **2001**, *70*, 117–133. [CrossRef]
83. Balachandran, T.; Nanthakumaran, A.; Sukanyah, S.; Sivanesan, K.S. Role of *Colocasia esculenta* in Constructed Wetlands for Treating Rice mill Wastewater. *J. Agric. Sci.* **2018**, *12*, 19–26. [CrossRef]
84. Bindu, T.; Sylas, V.P.; Mahesh, M.; Rakesh, P.S.; Ramasamy, E.V. Pollutant removal from domestic wastewater with Taro (*Colocasia esculenta*) planted in a subsurface flow system. *Ecol. Eng.* **2008**, *33*, 68–82. [CrossRef]
85. Chayapan, P.; Kruatrachue, M.; Meetam, M.; Pokethitiyook, P. Phytoremediation potential of Cd and Zn by wetland plants, *Colocasia esculenta* L. Schott., *Cyperus malaccensis* Lam., and *Typha angustifolia* L. grown in hydroponics. *J. Environ. Biol.* **2015**, *36*, 1179.
86. Madera-Parra, C.A.; Peña-Salamanca, E.J.; Peña, M.R.; Rousseau DP, L.; Lens, P.N.L. Phytoremediation of landfill leachate with *Colocasia esculenta*, *Gynerum sagittatum* and *Heliconia psittacorum* in constructed wetlands. *Int. J. Phytoremediation* **2015**, *17*, 16–24. [CrossRef]
87. Rai, U.N.; Tripathi, R.D.; Singh, N.K.; Upadhyay, A.K.; Dwivedi, S.; Shukla, M.K.; Mallick, S.; Singh, S.N.; Nautiyal, C.S. Constructed wetland as an ecotechnological tool for pollution treatment for conservation of Ganga river. *Bioresour. Technol.* **2013**, *148*, 535–541. [CrossRef]

88. Rana, V.; Maiti, S.K. Municipal wastewater treatment potential and metal accumulation strategies of *Colocasia esculenta* (L.) Schott and *Typha latifolia* L. in a constructed wetland. *Environ. Monit. Assess.* **2018**, *190*, 328. [CrossRef] [PubMed]
89. Skinner, K.W.N.; Porter-Goff, E. Mercury uptake and accumulation by four species of aquatic plants. *Environ. Pollut.* **2007**, *145*, 234–237. [CrossRef]
90. Mbuligwe, S.E. Comparative effectiveness of engineered wetland systems in the treatment of anaerobically pre-treated domestic wastewater. *Ecol. Eng.* **2004**, *23*, 269–284. [CrossRef]
91. Coleman, J.; Hench, K.; Garbutt, K.; Sexstone, A.; Bissonnette, G.; Skousen, J. Treatment of domestic wastewater by three plant species in constructed wetlands. *Water Air Soil Pollut.* **2001**, *128*, 283–295. [CrossRef]
92. Dias, V.N.; Pacheco, P.M. Constructed wetlands for wastewater treatment in Portugal: A global overview. In *Transformations of Nutrients in Natural and Constructed Wetlands*; Vymazal, J., Ed.; Backhuys Publishers: Leiden, The Netherlands, 2001; pp. 271–303.
93. Duarte, A.A.; Seco, T.C.; Peres, J.A.; Bentes, I.; Pinto, J. Performance Evaluation of Portuguese Constructed Wetlands for Municipal Wastewater Treatment. In *Advances in Waste Management, Proceedings of the 4th WSEAS International Conference on Waste Management, Water Pollution, Air Pollution, Indoor Climate (WWAI '10), Kantaoui, Tunisia, 3–6 May 2010*; World Scientific and Engineering Academy and Society (WSEAS), 2010; Available online: https://hdl.handle.net/1822/17617 (accessed on 20 August 2022).
94. Maurício, J.F.M. Zonas Húmidas Construídas Para Tratamento Complementar de Efluentes Domésticos: Ensaio Experimental na ETAR da Maia –Ribeira Grande (Constructed Wetlands for the Complementary Treatment of domestic Effluents: Experimental Test at the WWTP of Maia –Ribeira Grande). Master's Thesis, University of Azores, Ponta Delgada, Portugal, 2019.
95. Batriu, E.; Ninot, J.M.; Pino, J. Interactions between transplants of *Phragmites australis* and *Juncus acutus* in Mediterranean coastal marshes: The modulating role of environmental gradients. *Aquat. Bot.* **2015**, *124*, 29–38. [CrossRef]
96. Liu, F.; Sun, L.; Wan, J.; Shen, L.; Yu, Y.; Hu, L.; Zhou, Y. Performance of different macrophytes in the decontamination of and electricity generation from swine wastewater via an integrated constructed wetland-microbial fuel cell process. *J. Environ. Sci.* **2020**, *89*, 252–263. [CrossRef]
97. Mohammed, N.A.; Ismail, Z.Z. Green sustainable technology for biotreatment of actual dairy wastewater in constructed wetland. *J. Chem. Technol. Biotechnol.* **2020**, *96*, 1197–1204. [CrossRef]
98. Lai, W.L.; Wang, S.Q.; Peng, C.L.; Chen, Z.H. Root features related to plant growth and nutrient removal of 35 wetland plants. *Water Res.* **2011**, *45*, 3941–3950. [CrossRef]
99. Stottmeister, U.; Wießner, A.; Kuschk, P.; Kappelmeyer, U.; Kästner, M.; Bederski, O.; Müller, R.A.; Moormann, H. Effects of plants and microorganisms in constructed wetlands for wastewater treatment. *Biotechnol. Adv.* **2003**, *22*, 93–117. [CrossRef]
100. Weber, K.P.; Gehder, M.; Legge, R.L. Assessment of changes in the microbial community of constructed wetland mesocosms in response to acid mine drainage exposure. *Water Res.* **2008**, *42*, 180–188. [CrossRef]
101. Cheng, X.Y.; Chen, W.Y.; Gu, B.H.; Liu, X.C.; Chen, F.; Chen, Z.H.; Zhou, X.Y.; Li, Y.X.; Huang, H.; Chen, Y.J. Morphology, ecology and contaminant removal efficiency of eight wetland plants with differing root systems. *Hydrobiologia* **2009**, *623*, 77–85. [CrossRef]
102. Kyambadde, J.; Kansiimea, F.; Gumaeliusb, L.; Dalhammar, G. A comparative study of *Cyperus papyrus* and *Miscanthidium violaceum*-based constructed wetlands for wastewater treatment in a tropical climate. *Water Res.* **2004**, *38*, 475–485. [CrossRef] [PubMed]
103. Karathanasis, A.D.; Potter, C.L.; Coyne, M.S. Vegetation effects on fecal bacteria, BOD, and suspended solid removal in constructed wetlands treating domestic wastewater. *Ecol. Eng.* **2003**, *20*, 157–169. [CrossRef]
104. Juárez-Rosete, C.R.; Olivo-Rivas, A.; Aguilar-Castillo, J.A.; Bugarín-Montoya, R.; Arrieta-Ramos, B.G. Nutrition assessment of NPK in mint (*Mentha spicata* L.) cultivated in soilless system. *Annu. Res. Rev. Biol.* **2014**, *4*, 2462–2470. [CrossRef]
105. Espinosa Moya, E.A.; Angel Sahagún, C.A.; Mendoza Carrillo, J.M.; Albertos Alpuche, P.J.; Álvarez-González, C.A.; Martínez-Yáñez, R. Herbaceous plants as part of biological filter for aquaponics system. *Aquac. Res.* **2016**, *47*, 1716–1726. [CrossRef]
106. Silva, C.M.; Silva, L.; Oliveira, N.; Geraldes, P.; Hervías, S. Control of giant reed *Arundo donax* on Vila Franca do Campo Islet, Azores, Portugal. *Conserv. Evid.* **2011**, *8*, 93–99.
107. Calheiros, C.S.; Quitério, P.V.; Silva, G.; Crispim LF Brix, H.; Moura, S.C.; Castro, P.M. Use of constructed wetland systems with Arundo and Sarcocornia for polishing high salinity tannery wastewater. *J. Environ. Manag.* **2012**, *95*, 66–71. [CrossRef]
108. Idris, S.M.; Jones, P.L.; Salzman, S.A.; Croatto, G.; Allinson, G. Evaluation of the giant reed (*Arundo donax*) in horizontal subsurface flow wetlands for the treatment of recirculating aquaculture system effluent. *Environ. Sci. Pollut. Res.* **2012**, *19*, 1159–1170. [CrossRef]
109. Leto, C.; Tuttolomondo, T.; Bella, S.L.; Leone, R.; Licata, M. Growth of *Arundo donax* L. and *Cyperus alternifolius* L. in a horizontal subsurface flow constructed wetland using pre-treated urban wastewater—A case study in Sicily (Italy). *Desalination Water Treat.* **2013**, *51*, 7447–7459. [CrossRef]
110. Sylla, A. Domestic wastewater treatment using vertical flow constructed wetlands planted with *Arundo donax*, and the intermittent sand filters impact. *Ecohydrol. Hydrobiol.* **2020**, *20*, 48–58. [CrossRef]
111. Ayres, J.R.; Awad, J.; Burger, H.; Marzouk, J.; van Leeuwen, J. Investigation of the potential of buffalo and couch grasses to grow on AFIs and for removal of nutrients from paper mill wastewater. *Water Sci. Technol.* **2019**, *79*, 779–788. [CrossRef] [PubMed]
112. Saxena, G.; Goutam, S.P.; Mishra, A.; Mulla, S.I.; Bharagava, R.N. Emerging and ecofriendly technologies for the removal of organic and inorganic pollutants from industrial wastewaters. In *Bioremediation of Industrial Waste for Environmental Safety*; Springer: Singapure, 2020; pp. 113–126. [CrossRef]

113. Vymazal, J. The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic. In *Focus on Ecology Research*; Burk, A.R., Ed.; Nova Science Publishers Inc.: New York, NY, USA, 2006; pp. 175–196.
114. Wrobel, C.; Coulman, B.E.; Smith, D.L. The potential use of reed canarygrass (*Phalaris arundinacea* L.) as a biofuel crop. *Acta Agric. Scand. Sect. B–Soil Plant Sci.* **2009**, *59*, 1–18. [CrossRef]
115. Matheson, F.E. Nitrogen Removal and the Fate of Nitrate in Riparian Buffer Zones. Ph.D. Thesis, Durham University, Durham, UK, 2001.
116. Matthews, D.J.; Moran, B.M.; McCabe, P.F.; Otte, M.L. Zinc tolerance, uptake, accumulation and distribution in plants and protoplasts of five European populations of the wetland grass *Glyceria Flutings*. *Aquat. Bot.* **2004**, *80*, 39–52. [CrossRef]
117. Al-Omari, A.; Fayyad, M. Treatment of domestic wastewater by subsurface flow constructed wetlands in Jordan. *Desalination* **2003**, *155*, 27–39. [CrossRef]
118. Brown, P.J.; Cross, R.B.; McCarty, L.B.; Kerr, R.A. Control of torpedograss (*Panicum repens*) and Southern watergrass (*Luziola fluitans*) in bermudagrass turf. *Weed Technol.* **2019**, *33*, 616–619. [CrossRef]
119. El-Gendy, A.S.; El-Kassas, H.I.; Razek, T.A.; Abdel-Latif, H. Phyto-dewatering of sewage sludge using *Panicum repens* L. *Water Sci. Technol.* **2017**, *75*, 1667–1674. [CrossRef]
120. Zeng, X.; Gao, G.; Yang, J.; Yuan, J.; Yang, Z. The integrated response of torpedo grass (*Panicum repens*) to Cd–Pb co-exposures. *Ecol. Eng.* **2015**, *82*, 428–431. [CrossRef]
121. Ghaly, F.M. Role of natural vegetation in improving salt affected soil in northern Egypt. *Soil Tillage Res.* **2002**, *64*, 173–178. [CrossRef]
122. Licata, M.; Gennaro, M.C.; Tuttolomondo, T.; Leto, C.; La Bella, S. Research focusing on plant performance in constructed wetlands and agronomic application of treated wastewater–A set of experimental studies in Sicily (Italy). *PLoS ONE* **2019**, *14*, e0219445. [CrossRef]
123. Nema, A.; Yadav, K.D.; Christian, R.A. A small-scale study of plant orientation in treatment performance of vertical flow constructed wetland in continuous flow. *Int. J. Phytoremediation* **2020**, *22*, 849–856. [CrossRef]