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Review

The Value of Vegetation in Nature-Based Solutions: Roles, Challenges, and Utilization in Managing Different Environmental and Climate-Related Problems

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Abstract: To address the challenges of the twenty-first century, particularly the negative effects of climate change, mitigation measures such as Nature-based Solutions (NbS) are being employed. Vegetation, being a part of various NbS interventions, provides different ecosystem services that help combat current climate-related vulnerabilities. This research aims to illustrate the connection between plants' contribution to adapting to climate change and the creation of more sustainable spaces, focusing on the usage of bioretention systems (BRs) as an example of NbS. Some of the main aspects of how vegetation is selected for BRs according to qualities that may contribute to developing sustainable landscapes, along with providing key features of plants' adaptation, different taxonomic data, and specific plant species that have been demonstrated to be good candidates for planting in BRs, are also discussed. Therefore, the importance of this paper is in providing a comprehensive systematization of vegetation with insightful suggestions on plant species for future BR implementation.

Keywords: ecosystem services; sustainable landscapes; bioretention systems (BRs); urban sustainability; plant's adaptability

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1. Introduction

One of the biggest challenges to our natural systems is climate change, which has a significant effect on the population and poses a variety of health risks to the general public [1]. Future climate projections raise the possibility of 60% species extinction at 5 °C global mean surface air temperature warming, changes in the dominant vegetative form of an ecosystem, and other threats to the basic components of terrestrial and freshwater ecosystems [2]. Across 64.5% of the world's terrestrial vegetated area, climate change weakens ecosystems despite a stronger effect of temperature on vegetation resilience than precipitation, according to local research [3]. The "2030 Agenda for Sustainable Development", which was adopted by UN member states in 2015, is a call to action for all nations to take interventions to combat climate change, promote economic growth, improve health and education, and protect the environment and its natural resources [4]. Cities are the most advanced, populated, and affected by these issues, making them the primary mechanism for mitigating global concerns. To meet the defined contemporary challenges of the twenty-first century, as awareness of climate change grows, Nature-based Solutions (NbS) are becoming increasingly important in climate adaptation and mitigation activities. The International Union for Conservation of Nature (IUCN) defines NbS as efforts to preserve, sustainably manage, and restore natural or modified ecosystems. These methods of human adaptation to climate change can increase the resilience of ecosystem services and biodiversity in conjunction with ecosystem preservation and restoration [2]. As a broad concept, NbS encompasses a wide range of ecosystem-related approaches that address societal challenges, including the distribution of natural habitat space in floodplains that may lessen the effects of flood occurrences, as well as the creation of urban green spaces like parks and tree alleys that may reduce the intensity of city heat or control the flow of water and air, planting windbreaks for soil conservation, protecting urban green spaces, protecting and expanding forest areas to capture gaseous pollutants, and planting green roofs for various benefits like promoting biodiversity, carbon storage, or stormwater retention [5–7]. In addition, NbS can enhance the health and well-being of urban residents by implementing salutogenic elements in the urban environment that facilitate psychological relaxation and stress alleviation [8].

The most well-known vegetation-based climate-resilient NbS approaches are grasslands, constructed wetlands (CWs), green walls, green roofs, water-sensitive urban design elements like swales and bioretention systems (BRs), etc. Through providing ecosystem services, vegetation, as a component of NbS, helps to address a variety of climate-related difficulties and vulnerabilities (Table 1). For instance, the relationship between vegetation and enhanced infiltration, evapotranspiration, reduced erosion, pollution removal, weed control, temperature regulation of the water, and aesthetics is well-established and emphasized in implementing BRs [9–11]. Overall, because of processes like denitrification, phytoextraction, interception by plant leaves, and alteration of the rhizosphere and associated microbial population, it would be difficult to envision BRs and other NbS solutions without vegetation [12,13]. Vegetation is important for increased infiltration as well as nitrogen (N) removal, while for phosphorus (P) removal processes, the soil plays a more significant role [14]. Similar to the aforementioned, vegetation is important for rainfall collection, stormwater management, enhancing air quality, and food production in another type of NbS, known as green roofs [14,15]. Additionally, because of effective wastewater treatment, vegetation plays crucial roles in CWs in maintaining the rate of temperature change, reducing wind speed, preventing the amount of nutrients and sediment from being re-suspended, and supplying and establishing the conditions required for a variety of biological and physicochemical processes [16,17]. Halophytic plants, which store salts in their tissues, can also lower the salinity of wastewater in CWs.

Table 1. Primary vegetation roles in different NbS contribute to resolving different climate-related challenges and environmental vulnerabilities.

Brief Vegetation Roles in Different NbS Practices	Green Roofs	Green Walls	Constructed Wetlands	Bioretention/Rain Garden	Urban Forestry	Urban Gardening/Organic Farming	Impact on the Climate-Related Challenges and Vulnerabilities	Reference
Plants contribute to runoff reduction through the interception of rainwater and evapotranspiration	✔			✔	✔		Prevention of flooding	[17,18]
Preservation of the particulates, air purification	✔	✔			✔		Contamination reduction	[19]
Enhancement of water infiltration into soil				✔	✔		Recharge groundwater by infiltration	[20]
Noise reduction, CO_2 uptake	✔	✔		✔	✔		Positive impacts of public health, decarbonization	[19]
Plant roots continuously fracture the filter media's surface				✔	✔		Prevention of surface clogging and soil degradation	[21,22]
Improving food security						✔	Reduction in the chance of environmental pollution, improvement of the food quality	[23]
By slowing down water flow and enabling silt to fall out of it, plants help remove sediment and offer mechanical filtration			✔	✔			Prevention of water and soil pollution	[20]
Plants assimilate toxins and pollutants into their stems and roots	✔	✔	✔	✔	✔		Prevention of stormwater, wastewater, and soil pollution	[20]
Nitrogen (N) compounds can be transformed into nitrogen gas by microbes with the processes of nitrification and denitrification			✔	✔			Prevention of eutrophication	[20–22]
Plants absorb nutrients in the tissues and root system and provide space for the growth of bacteria			✔	✔			Improvement of organic degradation and prevention of erosion	[18]
Plants enhance microbial activity near roots			✔	✔	✔		Increase in pollutant degradation	[21,22]

Table 1. *Cont.*

Brief Vegetation Roles in Different NbS Practices	Green Roofs	Green Walls	Constructed Wetlands	Bioretention/Rain Garden	Urban Forestry	Urban Gardening/Organic Farming	Impact on the Climate-Related Challenges and Vulnerabilities	Reference
Plants provide food, shelter, and reproductive sites for pollinators and other creatures	✔			✔	✔		Supporting biodiversity	[21]
Plants create microclimates for flora and fauna	✔	✔	✔	✔	✔	✔	Lack of green space Reduce stormwater temperature impacts Wind speed reduction	[20,21]
Soil stabilization				✔	✔		Minimizing erosion	[20]
Plants create conditions for different biological and physicochemical processes				✔	✔		Improvement of wastewater quality	[18,21]

The ✔ mark indicates the roles of vegetation attributed to NbS practice.

2. Bioretention as a Type of NbS: Background and Applications

Since the fundamental concept and structure of bioretention were initially established in 1992, countries all over the world have adopted BRs, also known as rain gardens and biofilters, as a more organic and natural method of natural replacement for traditional gray stormwater and sewer infrastructure in cities [14,24]. Generally, BRs are designed as vegetated, shallow depressions intended to intercept, infiltrate, divert, alter volume and velocity, and regulate stormwater flow [25]. Bioretention can be installed in a variety of urban and rural contexts, taking a multitude of shapes and forms depending on the circumstances and goals [25]. The basic division of BRs is made into a group of BRs that are used only for retention (maintenance) and/or detention and increasing water quality, as well as BRs that relate to water quality. Regarding the typology of stormwater management systems, the authors Erickson et al. [25] group BRs into improved biological practices, which consist of two basic types of systems: biofiltration and bioinfiltration. Bioretention developed in areas with particularly favorable soil conditions for infiltration capacity is referred to as a bioinfiltration garden. The bioretention manual [14] offers the most comprehensive and detailed classification of BRs, with four categories used to group different types of bioretention systems (Table 2). If the aforementioned typology of BRs is taken into account, the most important constructive elements of BRs that can be singled out are (1) layers of soil or media, (2) drainage layer, (3) water retention zone (ponding area), (4) vegetation, (5) surface cover, (6) underground drainage pipe, (7) overflow device, (8) additional internal zone for nitrification, and (9) geotextile.

Table 2. Typology of BRs according to their hydrological functions and applications [14,25,26].

Types of BRs According to Hydrological Functions	Types of BRs According to Applications Scale	Types of BRs in Urban Context
Infiltration/groundwater recharge type	Roadway projects; new residential developments; new commercial and industrial developments; urban retrofit stormwater management projects; institutional developments; redevelopment communities; parks and trails; revitalization and smart growth projects; streetscape projects; private residential landscaping	Bioretention swales
		Street tree bioretention pits/tree box
Filtration/partial groundwater recharge type		Curb extension—bulb-outs
Infiltration, filtration, and groundwater recharge type		Micro-bioretention—rain gardens
Filtration type		Bioretention planter

Throughout the years, many field measurements conducted on implemented urban BRs have indicated that these systems can reduce runoff by up to 100%. From early monitoring studies [24,27] to some of the more recent research [25–27], the results showed that bioretention cells retain stormwater inflow, lower peak flow, and may, therefore, lessen the hydrologic effects associated with variations in precipitation values. Furthermore, BRs have demonstrated great success in removing different pollutants like suspended matter, nutrients, polycyclic aromatic hydrocarbons (PAHs), and pathogenic microorganisms [27–32]. However, due to the significant roles that vegetation has demonstrated in BRs, careful plant species selection is required for BRs to ensure their functions. These advantages are divided into above- and below-ground benefits (Figure 1). This review aims to emphasize some of the main aspects of how vegetation is selected according to qualities that may contribute to developing sustainable landscapes and synthesize key features of plants' adaptation to extreme weather events combined with the different abiotic and biotic stresses. While our focus was on studies evaluating at least one plant species or comparing and evaluating the effectiveness of multiple plant species and overall plant development, we also examined articles that provided information about various plant types, scientific names, families, and their utilization. We were guided by several simple questions, as follows:

(1) Which plant species are most commonly used for BRs in field and laboratory-scale research projects? Which group of plants are they a part of?
(2) Are plants utilized to test how well they reduce runoff, eliminate contaminants, or both?

(3) Could plants in BRs be selected based on their morphological traits—such as roots, origins, or aesthetics?
(4) Is it possible to quantify the long-term effectiveness of BRs in achieving resilience based on how well plants adapt and survive?

Following a thorough examination of pertinent literature, 147 publications were reviewed, evaluated, and used as final references.

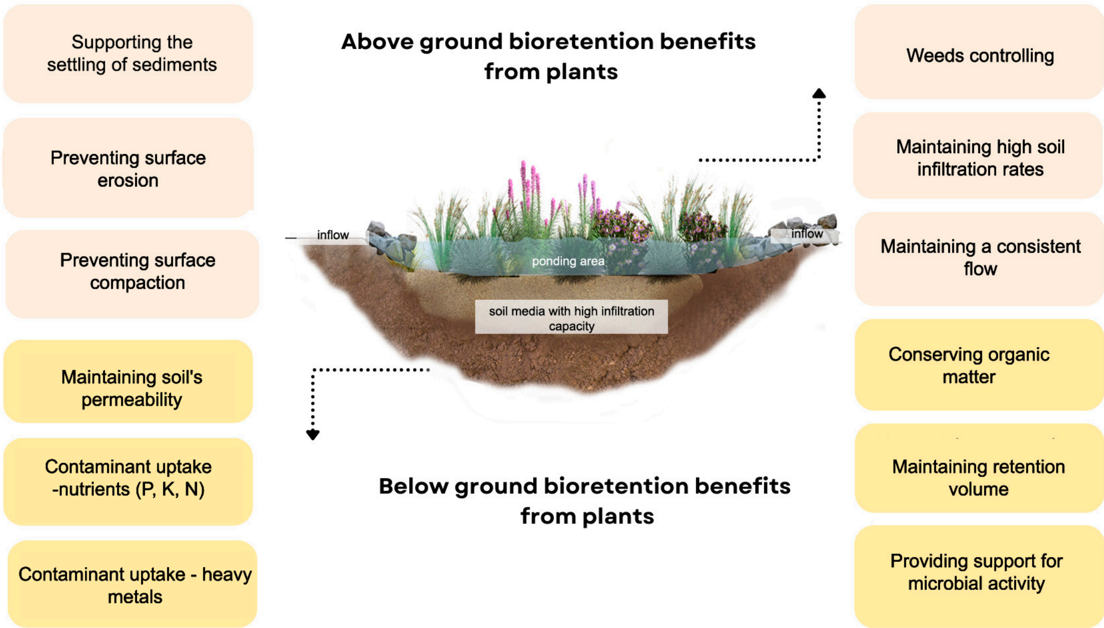

Figure 1. Cross section of infiltration/recharge BRs type with above-ground and below-ground bioretention benefits of plants [10–12,17] (author: Amela Greksa).

3. Plant Utilization for BRs in Response to Stress from Flooding and Different Contaminants Found in Stormwater

Bioretention is an example of NbS, with plants being exposed to multiple stress factors at the same time, biotic and abiotic, which can occur singly or in conjunction. However, it has been recorded that plants have evolved different defense mechanisms against these stressors, which are also supposed to contribute to plants thriving in BRs (Table S1). Abiotic stressors refer to elements, including temperature, salinity, drought, and cold, resulting from changes in the growth environment for the plant, while biotic stressors refer to harm resulting from germs, fungi, pests, vermin, and other insects [33]. Hunt et al. [34] state that vegetation selection for bioretention can be categorized according to three main moisture levels as follows: (1) plant species that can withstand standing water and variations in level can be found at the lowest elevation of BRs; (2) a slightly drier set of plants that grow on standard planting material but can withstand some variation in water levels is supported by the middle elevation; and (3) plants adapted to drier circumstances are found at the outer border of BRs, which is higher than the ponding level. Plant species being reported to survive in the flooding conditions in BRs are mostly different native species found in floodplains, primarily because of their adaptation to changing environmental conditions like variations in soil saturation and inundation [35]. However, there is also evidence demonstrating that the survival of plants differs in artificial conditions relative to their naturally occurring habitat and that plants have various survival strategies. A different capacity to withstand frequent periods of drought and flooding for plants belonging to the same vegetation type and species was noted in an investigation by Nelson et al. [36]. From seven tested *Carex* species (fam. Cyperaceae) native to the north-central United States, only three have shown the potential to thrive within the flooding conditions except for the worst drought situations: *Carex annectens* E.P. Bicknell, *Carex grayi* J. Carey, and

Carex brevior (Dewey) Mack. Although both plants, *Carex brevior* (Dewey) Mack. and *Carex annectens* (E.P. Bicknell), are mostly found in terrestrial, non-wetland habitats, they were not shown to be suitable for extreme dry conditions. Additionally, upland, non-wetland *Carex pensylvanica* Lam., which is also found in similar non-wetland conditions, survived the severe droughts and flooding [37].

The physical and physiological responses of plants reveal some of their survival strategies in flood and drought circumstances, specifically with reduced leaf area and biomass above ground [38]. From three wetland species, *Pontederia cordata* L. (fam. Pontederiaceae), *Saururus cernuus* L. (Saururaceae), and *Schoenoplectus tabernaemontani* C.C. Gmel. Palla (fam. Cyperaceae), only *Schoenoplectus tabernaemontani* was able to make the required modifications to enable increased drought resistance while maintaining strong plant growth. On the contrary, *Saururus cernuus* L. had the lowest output and seemed to be the most adaptable to long-term soil water shortages. Likewise, the resilience of perennial plants to waterlogging is more often highlighted compared to the annual one. For example, plant *Angelonia salicariifolia* Bonpl. (fam. Scrophulariaceae) retained its biomass and physiological value during the waterlogging experiment, while annual plants *Celosia argentea* L. (fam. Amaranthaceae) and *Melampodium paludosum* Kunth. (fam. Asteraceae) were severely impacted by waterlogging and showed no signs of recovery following drainage in terms of their sensitivity to internal and exterior stimuli [39].

The removal of nutrients in bioretention via plants is particularly emphasized, where the differences between nutrient uptake by plants differ about the size (age) of the plant and the plant species [40]. Previously reported plants with a high nutrient removal capacity in bioretention—total nitrogen (TN), total phosphorus (TP), and potassium (K)—are mainly *Juncus effusus* L. (fam. Juncaceae), *Iris versicolor* Thunb. (fam. Iridaceae), *Plantago asiatica* L. (fam. Plantaginaceae), *Carex* L. (fam. Cyperaceae), *Melaleuca ericifolia* Andrews (fam. Myrtaceae), *Digitaria sanguinalis* (L.) Scop. (fam. Poaceae), *Agapanthus* L'Hér. (fam. Alliaceae), and *Stenotaphrum* Trin. (fam. Poaceae) [41–43]. Additionally, there are proofs that *Calendula officinalis* L. (fam. Asteraceae), *Celosia cristata* L. (fam. Amaranthaceae), *Melastoma malabathricum* L. (fam. Melastomataceae), *Iris* var. chinensis (fam Iridaceae), and *Euphorbia milii* Des Moul. (fam. Euphorbiaceae) may be appropriate for the phytoremediation of heavy metals [44]. Among them, it was also demonstrated that flowering ornamental plants from the genera *Canna* L., *Iris* L., *Heliconia* L. (fam. Heliconiaceae), and *Zantedeschia* K.Koch (fam. Araceae) are showing a high contribution to the increment of water quality in different NbS [45]. Because they absorb nutrients in their tissues and root systems and provide space for the growth of bacteria that induce organic degradation, plants with large plant masses and relative plant growth rates are regarded as being the most successful in the nutrient removal process [43]. Studies that have been conducted in addition to examining the heavy metal accumulation in plants deriving from runoff and their metal accumulation mechanisms revealed that plants belonging to the family Cyperaceae can concentrate high levels of heavy metal in BRs, as pointed out in the research conducted at State University's Research Greenhouse [46]. *Phragmites australis* (Cav.) Steud. (fam. Poaceae) accumulated eight times more copper (Cu) in the above-ground tissue than *Scirpus acutus* (R.Br.) Spreng (fam. Cyperaceae), while *Carex microptera* Mack. (fam. Cyperaceae) accumulated eighteen times more lead (Pb) and six times more zinc (Zn) than *Scirpus validus* Benth. (fam. Cyperaceae). In addition, the presence of *Iris pseudacorus* L. in BRs contributed to about 18% of removing Pb and zinc Zn, whereas plant roots have absorbed 9–14 times greater concentrations of metals than the plants' leaves [47]. The catchment parameters, weather, stormwater runoff quality, facility structure, vegetation species, and physicochemical qualities of soil/media were found to be directly linked to the accumulation of heavy metals in BRs [48]. Additionally, the distribution and accumulation of heavy metals, or TP, are linked to metal elements, tissues, and pollution loading [49]. Certain plant species have shown that the concentrations of particular heavy metals in their tissues vary from those of other metals. As shown in the study [49], *Hylotelephium erythrostictum* (Miq.) H. Ohba (fam. Crassulaceae) is an appropriate plant for uptake of Cu and cadmium (Cd) over Zn and

Pb, while *Hosta plantaginea* (Lam.) Aschers (fam. Hostaceae) and *Viola verecunda* A. Gray (fam. Violaceae) are suitable plants for Pb removal. *Rehmannia glutinosa* (Gaetn.) Libosch. ex Fisch. (fam. Scrophulariaceae) and *Chlorophytum laxum* R. Br. (fam. Anthericaceae) can be chosen for Zn and TP removal, respectively.

Vegetation in BRs is also one of the biotic components that can improve the removal of fecal microorganisms from biofilters and other sustainable stormwater treatment systems. Plant *Melaleuca ericifolia* Andrews, Bot. Repos. (fam. Myrtaceae), which has been widely used in stormwater treatment systems in the past, has proven efficient intake of nitrogen, preservation of hydraulic conductivity, and usefulness in deactivating microbiological infection [50]. Some plant species included in the biofilter's design displayed the ability to remove *Escherichia coli* (*E. coli*) while also changing its nutrient content [51]. Among *Canna indica* L. (fam. Cannaceae), *Carex appressa* R.Br. (fam. Cyperaceae), *Ginkgo biloba* L. (Ginkgoaceae), and *Miscanthus sinensis* Andersson (fam. Poaceae), the best-performing plant was *Miscanthus sinensis*. The greatest root masses were found in *Carex appressa* and *Miscanthus sinensis*, which were, on average, four times higher than those of *Canna indica* and *Ginkgo biloba*.

Several studies are pointing to the advantage of including a saturated zone in BRs towards pollutant removal from runoff, e.g., [52–55]. One study used two combinations of vegetation in columns: columns planted only with *Zoysia matrella* (L.) Merr. (fam. Poaceae) and columns with combined plant species of *Zoysia matrella* (L.) Merr. and *Iris pseudacorus* L. In terms of eliminating TP, ammonium (NH_4-N), nitrate (NO_3-N), and turbidity, the columns planted with two species performed much better than single-planted columns [56]. In another study, during a prolonged dry time in BRs, within an experiment that involved testing different species during both wet and dry episodes, improved extraction of TN was noted with a saturated zone included [37]. Furthermore, *Carex appressa* R.Br. (fam. Cyperaceae), *Juncus pallidus* Hoppe. (fam. Juncaceae), and *Melaleuca incana* R.Br. (fam. Myrtaceae) were both the best-performing species for wet and dry periods. The removal of both TN and nitrate (NO_3–N) at rates of 83.54% and 92.15%, respectively, was accomplished by using saturated zones in conjunction with the hydroxy-aluminum vermiculite sludge particles (HAVSP), and it was recommended to create a fold-flow BRs [57].

4. Vegetation Performance and Adaptivity to Different Climatic Regions and Associated Challenges

Bioretention is being applied in various climate zones. Comparing the outcomes of hydrological and ecological effectiveness in different research projects is challenging because of variations in rainfall patterns and differences in bioretention design. Numerous experimental data on the characteristics of BRs in cold climate zones are primarily based on research on the infiltration capacity in the winter months, the influence of the cold climate on water retention, and the factors that influence the proper dimensioning of the BRs [58–62]. Challenges associated with BRs in cold climates are reflected in the freezing of underground pipes due to low temperatures, the reduction in biological activity and oxygen levels during the ice pack, the rate of deposition of particles, and reduced infiltration. These conditions may also lead to cold stress, freezing, frost, and decreased levels of biological activity in plants [63]. Nevertheless, based on existing findings, BRs maintain infiltration at a certain level throughout the winter, and many plant species show resistance, along with providing a significant degree of efficiency in the removal of pollutants even during the winter months when the soil is frozen [62,63]. High resistance to salt is an essential plant feature for bioretention in cold climates. Some of the species recommended to thrive in both cold and salt stress in wet and dry conditions are *Spartina* spp. (fam Poaceae), *Panicum virgatum* Muhl. (fam. Poaceae), and *Scirpus* spp. (fam. Cyperaceae) [63]. Laukli et al. [64] emphasized the significant variations in species' adaptation to a variety of compounded stresses, such as the winter ice cover, road dust, de-icing salts, sporadic flooding, and roadside water sprays, that pose a risk to these plants. Species *Amsonia tabernaemontana* Walter (fam. Apocynaceae), *Baptisia australis* (L.) R.Br. (fam. Fabaceae), *Calamagrostis* × *acutiflora*

'Overdam' (fam. Poaceae), *Hemerocallis* L., *Hemerocallis* 'Sovereign,' *Hemerocallis lilioasphodelus* L. (fam. Hemerocallidaceae), *Hosta* 'Sum & Substance' (fam. Asparagaceae), *Iris pseudacorus* L. (fam. Iridaceae), and *Liatris spicata* L. 'Floristan Weiss' (fam. Asteraceae) were the plants that developed the highest survival rates within the described conditions. It has also been shown that two plant species, namely, *Panicum virgatum* L. (fam. Poaceae) and *Aster nova angliae* "Red Shades" (fam. Asteraceae), can withstand excessive salt exposure. After being subjected to de-icing chemicals, the bioretention soil's ability to extract pollutants remained intact, which leads to the conclusion that under salinity stress, plants continue to maintain their functions [65]. In particular, species such as *Ficinia nodosa* (Rottb.) Goetgh. (fam. Cyperaceae) and *Juncus kraussii* Hochst. (fam. Juncaceae) showed a high tolerance to salt. On the contrary, *Carex appressa* R.Br. (fam. Cyperaceae), *Carex bichenoviana* (fam. Cyperaceae), *Juncus usitatus* L.A.S. Johnson (fam. Juncaceae), *Polygonum* L. (fam. Polygonaceae), and *Pontederia cordata* L. (fam. Pontederiaceae) were presented as salt-sensitive species [63,65]. Authors Paus et al. [66] have noticed that plant species like *Typha* L. are not good candidates for use in bioretention cells in the Nordic climate. The *Typha* L. species occurs naturally in wetlands, and therefore, the use of salt in winter can also increase the degree of clogging and contamination in bioretention. However, it was noted that strong-stemmed plants, like *Iris pseudacorus* L. (fam. Iridaceae), break through the ice in the spring, making it easier for water to infiltrate through the ice cover. Another suitable plant proven to be an appropriate species to mitigate clogs in BRs is *Acorus calamus* L. (fam. Acoraceae) [67]. Both species, *Acorus calamus* L. and *Iris pseudacorus* L., have been demonstrated to survive prolonged periods of oxygen deprivation caused by inadequate soil drainage, prolonged flooding, complete submersion, or ice-encasement, as well as to have a significant influence on the hydraulic conductivity of soil [68].

In general, there is less study on the effectiveness of bioretention in arid and semi-arid environments. This is primarily due to the abundance of urban runoff. Examples of installed BRs, however, include several modifications in design. According to some analysis, the optimal size for a BR in xeric climates is 6–8% of the area that contributes to impervious drainage [69]. The BRs should have two layers of media: a 0.6 m porous media layer that serves as temporary storage during a storm event and a 0.5 m low-nutrient topsoil layer. The vegetation should encourage ecological treatment in the topsoil and deep-rooted shrubs that require no watering after establishment to facilitate stormwater infiltration and evapotranspiration. In arid zones, BR usage is tested for greywater reuse and water conservation. Bioretention planted with *Phalaris arundinacea* (fam. Poaceae) was found to be effective in reducing the levels of salt and chemical oxygen demand in greywater [70]. For efficient BR performances in the semi-arid climate zone of Central Mexico, it is suggested that the design of a bioretention cell includes tolerant plants like succulents and grasses, namely *Festuca ovina* subsp. *glauca* (Vill.) (fam. Poaceae), for high evaporation and low precipitation levels [71]. Studies that are conducted for stormwater treatment in the City of Ekurhuleni, South Africa, revealed that species such as *Agapanthus praecox* Willd. (fam. Amaryllidaceae), *Carpobrotus edulis* (L.) N.E.Br. (fam. Aizoaceae), *Stenotaphrum secundatum* (Walter) Kuntze (fam. Poaceae), *Zantedeschia aethiopica* (L.) Spreng. (fam. Araceae), *Typha capensis* (Rohrb.) N.E.Br. (fam. Typhaceae), and *Phragmites australis* (Cav.) Trin. Ex Steud. (fam. Poaceae) are showing potential for being included in the design of BRs in arid climates [72].

5. Plants Effectiveness According to Vegetation Establishment Time

According to Spraakman et al. [73], the evaluation of implemented BR performances is more reliable when it is conducted two years after construction because that is the time expected for the soil and plant establishment. Mature BRs typically have a 20-year design life, but their performance is unclear. For two observation periods, shortly following construction in 2013–2014 and 4–5 years later in 2017–2018, it was demonstrated that despite an underutilization of the soil volume, the hydrologic performance was maintained five years after construction, with median volume decreases of 100% in both monitoring periods.

Croft et al. [74] also reported that the performances of 16–18-year-old BRs were successful in removing particulates that even matured, with average load reductions of 82% and 83%. A wide range of implemented green infrastructure facilities, including bioretention projects in Portland, testified that vegetation performances were high according to results of the evaluation of implemented BRs taken over a period of 4–5 years [75]. *Juncus patens* L. (fam. Juncaceae) and *Nyssa sylvatica* Marshall. (fam. Nyssaceae) have both been able to withstand the dry summer and wet winter cycles. Along with *Carex obnupta* L.H. Bailey. (fam. Cyperaceae), *Euonymus japonius* Wall. (fam. Celastraceae), *Mahonia repens* (Lindl.) G.Don (fam. Berberidacea), *Polystichum munitum* (Kaulf.) C.Presl (fam. Polypodiaceae), and *Carex testacea* Sol. ex Boott (fam. Cyperaceae), the vegetation that is mainly used within green infrastructure projects is *Juncus patens*. According to the results of this evaluation of implemented BRs, *Juncus* plants have been shown to grow much taller than expected. The plants were arranged more densely to minimize the need for upkeep (weeding, watering, etc.) and to swiftly produce a visually pleasing environment. In Lancaster, several plant species were discovered to be highly abundant and to be drivers of performance, including *Vernonia baldwinii* Torr. (fam. Asteraceae), *Nepeta cataria* (fam. Lamiaceae), *Itea virginica* L. (fam. Iteaceae), *Rudbeckia* sp. (fam. Asteraceae), and *Eragrostis pectinacea* (Michx.) Nees (fam. Poaceae) [76].

According to Dropkin [77], some plants that are utilized in BRs could present challenges during maintenance. Plants like *Eutrochium* Raf (fam. Asteraceae), *Juncus effusus* L. (fam. Juncaceae), and *Asclepias incarnata* L. (fam. Apocynaceae) need annual pruning, but this measure has a strong effect on N, P, and metal concentrations. Research revealed that the pruned biomass contained 2.1–3.5 times more N and P overall than the quantity that was presumably taken from the influent by the regrowth of the pruned columns on their own [78].

6. Utilization of Vegetation in BRs According to Their Distribution and Plant Groups

There is a wide range of biological types and functional traits found in the vegetation of BRs, which can be divided into four categories: shrubs, trees, grasses, and herbaceous plants [79]. For BRs projects, each of these vegetation groupings has demonstrated the ability to remove pollutants and survive in the different conditions in BRs (Table 3). Given that trees transpire more than common sedge or plant species, incorporating trees within BRs is connected with their ability to retain more runoff due to interception of the canopy and higher evapotranspiration [80,81]. By absorbing precipitation, transpiring water out of the soil, improving infiltration, and supporting the efficacy of other green infrastructure technologies, trees contribute to the urban hydrologic cycle [82]. Studies also revealed that bioretention in conjunction with big trees can increase outdoor thermal comfort during the day [83] and also accumulate the greatest amount of nutrients in their dry biomass [84]. Trees are mainly planted in tree box types of BRs to store water temporarily during stormwater runoff events. Very recent research investigated the impact on nine distinct tree species for short-term and seasonal waterlogging and potential water stress when they are being implemented inside tree boxes in Swedish conditions [85]. The two species that were unable to sustain leaf water potential were *Cercidiphyllum japonicum* Siebold & Zucc. (fam. Cercidiphyllaceae) and *Sorbus torminalis* (L.) Crantz. (fam. Rosaceae). This was explained by the natural occurrence of these tree species, which makes them more waterlogging-tolerant species. However, installing an underdrain or restricting installation to soils with a high enough exfiltration rate is recommended to help prevent waterlogging in tree box BRs [86].

Studies that included herbaceous plants have also pointed to the potential of this group of plants for the removal of pollutants that can be found in runoff. For example, the removal of Pb and Cd by the BRs was over 87% with planted ornamental shrub species like *Lonicera pileata* Oliv. (fam. Caprifoliaceae), *Cotoneaster horizontalis* Decne. (fam. Rosaceae), and *Hypericum* × *hidcoteense* 'Hidcote' (fam. Clusiaceae), which are typically grown in Central and Northern Italy's urban regions [87]. A research study that involved natives and cultivars for testing the nutrient removal capacity with different plant types, respectively trees—*Magnolia* L. (fam. Magnoliaceae) and *Betula nigra* Du Roi (fam. Betulaceae), shrubs—*Viburnum* L. (fam. Caprifoliaceae) and *Itea* L. (fam. Escalloniaceae), herbaceous perennial flowers—*Helianthus angustifolius* L. (fam. Asteraceae) and *Eupatorium* L. (fam. Asteracea), a rush *Juncus efussus* L. (fam. Juncaceae) and an ornamental grass *Panicum virgatum* L. (fam. Poaceae) have demonstrated that *Panicum virgatum* L. and *Helianthus angustifolius* L. (fam. Asteraceae), two herbaceous species, sequestered the highest amounts of nutrients per unit area [84]. Various woody shrubs were shown to be resistant to long-term floods and drought, like the species *Hippophae rhamnoides* L. (fam. Elaeagnaceae), *Amorpha fruticosa* L. (fam. Fabaceae), *Salix arenaria* L. (fam. Salicaceae), *Salix purpurea* L. (fam. Salicaceae), *Shepherdia argentea* (Pursh) Nutt. (fam. Elaeagnaceae), and *Spiraea tomentosa* L. (fam. Rosaceae) [77]. A shrub, *Buxus sinica* Rehder & E.H.Wilson (fam. Buxuaceae), treated with three degrees of pollution concentrations and fluxes provided reduced peak flows while simultaneously eliminating nutrients in varying degrees [88].

Because of their wide range of ecological preferences, global distribution, huge differences in lineage diversity, species richness, and numerous adaptations, sedges are an excellent model family for BRs. The success of grasses (Poaceae) worldwide is supported by characteristics that promote colonization, persistence, and habitat alteration, as well as their tremendous species richness and ecological dominance over a wide range of environments [89]. Effective plant species belonging to the mentioned family for pathogen removal in BRs are shown to be *Leptospermum continentale* Joy. Thomps. (fam. Myrtaceae) and *Melaleuca incana* R.Br. (fam. Myrtaceae). *Miscanthus sinensis* Andersson. (fam. Poaceae) is being employed in a variety of BR moisture levels, from damp depression bottom to dry margin [90]. Plant species such as *Callistemon* R.Br. (fam. Myrtaceae) and *Pennisetum americanum* (L.) K.Schum. (fam. Poaceae) were the most effective at removing nutrients from wastewater [91], while for nutrient and *E. coli* removal, the best-performing plant, *Miscanthus sinensis* Andersson. (fam. Poaceae), was also discovered to be resistant to cold [92]. Searching for NbS in control of chromium (Cr) and nickel (Ni) polluting the water, Čule et al. [93] used floating treatment wetlands (FTW) as a tool that can be useful in the revitalization of polluted waters. Plant species included in the research were decorative macrophytes, respectively, *Phragmites australis* (Cav.) Steud (fam. Poaceae), *Iris pseudacorus* L. (fam. Iridaceae), *Canna indica* L. (fam. Cannaceae), *Alisma plantago-aquatica* L. (fam. Alismatacae), *Menyanthes trifoliata* L. (fam. Menyanthaceae), and *Iris sibirica* L. (fam. Iridaceae). This group of plants achieved a high accumulation of Cr and Ni in their below-ground parts. Certain plant species, in particular genera belonging to the Fabaceae family, have developed symbiotic interactions with the soil bacteria *rhizobia* and *frankia* that, together with the plants, establish symbiotic connections [77]. For example, *Lotus corniculatus* L. was selected as a suitable species for extensive green roofs in northern Nova Scotia, in particular for restoring N [94]. Moreover, the total mass of transpired water by *Lotus corniculatus* L. was almost 90 times its above-ground biomass. This important fact indicates that *Lotus corniculatus* L. can thrive under various environmental stresses, like waterlogging.

Benefits provided by plants in BRs are generally maximized when a mix of plant species is selected that have different functional attributes, like sedges and woody groundcovers, shrubs, and trees, because a number of interactions between soil and plants could affect how well-vegetated Earth barrier systems work to lower the danger of flooding. Mixed-species plantings perform better than single-species plantings [95]. The density of planted vegetation within BRs has been shown to have a great influence on maximizing the biological processing of nutrients [96,97]. Moreover, the amount of evapotranspiration is increased by dense vegetation, which also enhances soil porosity and infiltration capacity [98]. According to Yuan et al. [99], the best hydrologic performance is achieved by perennial mixes rich in forbs, both in stormwater detention and retention.

Table 3. Various vegetation types and plant species have shown the ability to remove pollutants and survive in different conditions in BRs.

Vegetation Type/Plant Community	Plant (Scientific Name) *	Family *	This Species' Native Range *	Tolerances/Sensitivity to Pollutants and Different Water Levels	Results of the Study	Reference
Grasses (M)	*Juncus effusus* L.	Juncaceae	The Tropical Northern Hemisphere to Western South America, Rwanda to Southern Africa	Testing the removal from synthetic stormwater with three different plant species	Significant NO_3 removal; greatest biomass increase in *Juncus* plants	[12]
Herbaceous perennial plant (O, M)	*Iris versicolor* L.	Iridaceae	South Siberia to Central China and Japan			
Grasses (M)	*Chrysopogon zizanioides* (L.) Roberty	Poaceae	Tropical and South Africa	The effectiveness of tropical plants in addressing greywater-polluted urban runoff	The removal of 86.4% of total nitrogen (TN), 93.5% of total phosphorus (TP), 89.8% of biological oxygen demand (BOD), 90% of total suspended solids (TSS), and 92.5% of chemical oxygen demand (COD) was completed.	[100]
Herbaceous plant (O, E)	*Hibiscus* L.	Malvaceae	Tropics and Subtropics to North America.			
Grasses (O)	*Carex appressa* R.Br.	Cyperaceae	New Guinea, Australia, New Zealand, New Caledonia			
Trees (O, M)	*Betula nigra* L.	Betulaceae	Central and Eeatern U.S.A.	Conducted to evaluate how much COD, TN, TON, TP, ortho-phosphate, and TSS is removed from stormwater; analyzing the capacity to lower peak runoff load	Effective lowering of the volume of effluent water; TN, TSS decreased	[101]
Trees (O, M)	*Betula nana* L.	Betulaceae	Subarctic and Mountains of Europe, E. Subarctic America			
Shrub (M)	*Salix lutea* Nutt.	Salicaceae	Western U.S.A.			
Grasses	*Digitaria sanguinalis* (L.) Scop	Poaceae	Medit. To Central Asia and Malesia	Evaluating the plants' capacity to lower the levels of ammonium (NH4 +–N), zinc (Zn), cadmium (Cd), and lead (Pb)	More than 90% of the plants have the capacity to lower concentrations of heavy metals, such as ammonium (NH4 +–N), zinc (Zn), cadmium (Cd), and lead (Pb)	[102]
Shrubs (O)	*Rhododendron indicum* L. Sweet	Ericaceae	Japan	Assessing how well two different bioretention system types manage nutrients from urban stormwater discharge	High TN and TP uptake by plants; a high number of flowers per plant	[103]

Table 3. *Cont.*

Vegetation Type/Plant Community	Plant (Scientific Name) *	Family *	This Species' Native Range *	Tolerances/Sensitivity to Pollutants and Different Water Levels	Results of the Study	Reference
Shrubs (O)	*Cornus sericea* L.	Cornaceae	North America	Evaluating the efficiency of four different plant species' bioretention throughout growth and dormancy	Removal of macronutrients, lowering water volume and flow, with an average mass removal of 55% for TN, 81% for TP, and 61% for K.	[42]
Perennial (O)	*Iris versicolor* L.	Iridaceae	Central and E. Canada to N. Central and E. U.S.A.			
Grasses (O)	*Sesleria autumnalis* (Scop.) F.W.Schultz	Poaceae	Italy to W. Balkan Peninsula			
Sedges (O)	*Carex appressa* R.Br.	Cyperaceae	New Guinea, Australia, New Zealand, New Caledonia	Evaluating stormwater biofilters' ability to remove phosphorus, nitrogen, and sediment	Enhanced nutrient removal in biofilters	[40]
Shrub (O)	*Melaleuca ericifolia* Sm.	Myrtaceae	SE. Australia			
Perennial (O)	*Agapanthus* L'Hér.	Amaryllidaceae	Mozambique to S. Africa	Examining how well nine naturally occurring plant species remove nitrate (NO3-), ammonia (NH3), and orthophosphate (PO4-3)	The findings demonstrate that every species lowered the average amounts of NH3 by 90% and PO4-3 by 81%	[43]
Grasses	*Stenotaphrum* Trin.	Poaceae	Tropics and Subtropics			
Grasses (O)	*Pennisetum* Rich.	Poaceae	Tropical and Subtropical Old World, America			
Shrubs (O)	*Lonicera pileata* Oliver	Caprifoliaceae	China	Evaluating the efficacy of ornamental plants in bioretention pot trials in Italian cities to improve water quality	Plants removed more than 87% of the lead and cadmium.	[87]
Shrubs (O, E)	*Cotoneaster horizontalis* Decne.	Rosaceae	China			
Shrubs (M)	*Hypericum hidcoteense* 'Hidcote'	Clusiaceae	*H. addingtonii* × *H. calycinum* × H.			
Perennial (O)	*Iris pseudacorus* L.	Iridaceae	Europe to Caucasus, Medit. to Iran	Examining nitrogen removal, the state of the substrate layer, and the composition of the bacterial community to comprehend microbial diversity and assess its impact on nitrogen removal performance	Ammonia nitrogen removal in the bioretention cell with *Lythrum salicaria* L. was the highest (88.1%); the bioretention cell containing Canna indica L. had the highest removal rates for both nitrate and total nitrogen.	[104]
Perennial (O, M)	*Canna indica* L.	Cannaceae	Tropical and Subtropical America			
Perennial (O, M)	*Lythrum salicaria* L.	Lythraceae	Eurasia, NW. Africa, Ethiopia, Australia			

Table 3. *Cont.*

Vegetation Type/Plant Community	Plant (Scientific Name) *	Family *	This Species' Native Range *	Tolerances/Sensitivity to Pollutants and Different Water Levels	Results of the Study	Reference
Grasses (M)	*Phragmites australis* (Cav.) Trin. ex Steud	Poaceae	Temp. and Subtropical to Tropical Mountains	To confirm a mass balance of pollutants and infrequently assess variations in the intake of nutrients by different species	Compared to *Typha latifolia*, *Scirpus validus*, and Scirpus acutus, it was discovered that *Phragmites australis*, *Carex praegracilis*, and *Carex microptera* absorb noticeably more TP and Total Nitrogen (TN) mass into harvestable tissue	[46]
Grasses (O)	*Carex praegracilis* W.Boott	Cyperaceae	Alaska to Guatemala			
Grasses (O)	*Carex microptera* Mack.	Cyperaceae	Yukon to W. and W. Central U.S.A., Mexico			
Shrub (O, E)	*Spiraea prunifolia var. simpliciflora*	Rosaceae	China	Examining the environmental variables and pollutants that affect *Spiraea prunifolia* var. simpliciflora while using LID approaches	Nutrient concentrations were assessed as variables influencing the Spiraea prunifolia var. simpliciflora's growth and activity in LID technologies	[105]
Perennial (O, E, M)	*Aster novae-angliae* L. *'Red Shades'*	Asteraceae	Central and E. Canada to U.S.A	Testing the impact of winter road salting on bioretention functions	All plants showed no reduction in total biomass, chlorosis, or necrosis exposed to the extreme salt exposure	[74]
Grasses (O)	*Panicum virgatum* L.	Poaceae				
Shrub (E, M)	*Vaccinium ashei* Reade	Ericaceae	E. Canada to Central and E. U.S.A	Testing for phytoremediation potential	Blueberry roots' showed capacity to accumulate heavy metals, like copper (Cu)	[106]

* IPNI (2024) Plants of the world [107]; (O) = also ornamental; (E) = also edible; (M) = also medical.

7. Species That Produce Food and Retain Runoff

There are a few studies that investigated pollutant uptake from stormwater by vegetables or the reduction in runoff quantity. A column study was conducted to determine whether biofilters made of vegetable crops might treat urban runoff [108]. Nine vegetable species like broad beans (*Vicia faba* L.), kohlrabi—*Brassica oleracea Gongylodes Group* (fam. Brassicaceae), kale—*Brassica oleracea Acephala Group* (fam. Brassicaceae), lettuce—*Lactuca sativa* L. (fam. Asteraceae), mint—*Mentha spicata* L. (fam. Lamiaceae), mustard spinach—*Brassica juncea* L. (fam. Brassicaceae), radish—*Raphanus sativus* L. (fam. Brassicaceae), spinach—*Spinacia oleracea* L. (fam. Chenopodiaceae), and sweet corn—*Zea mays* L. (fam. Poaceae) were irrigated with stormwater. Although the amount of heavy metal accumulation, namely Cd and Pb, was highest in non-edible portions and plant growth was not affected by heavy metals, the levels of Cd and Pb concentration were higher than recommended by the World Health Organization, Australia's Food Standards, and New Zealand. As a result, the food was considered dangerous for ingestion. In terms of urban agriculture, however, vegetable rain gardens are advantageous since they may help home vegetable gardening overcome its limitations in terms of both space and water. The infiltration-style rain garden decreased the amount and frequency of runoff by more than 90%. The results show that rain gardens can continue to reduce urban runoff while still yielding a sufficient amount of crop [109]. Concerning the study's findings, there are also records of evidence of the usage of *Vaccinium ashei* Reade (family Ericaceae), also known as blueberries, which are species having a variety of uses in medicine, food, and the environment. The ability of blueberries' roots to store Cu has been highlighted as a way for the metal to be less harmful above ground. This makes using blueberries a viable technique for phytoremediation of soil contaminated with Cd and reducing Cd migration in mining areas [110].

8. Linkage between Vegetation Morphology and Adaptability to Fluctuating Environmental and Climatic Conditions in BRs

Because roots have a major role in the phytoremediation process, the basic morphological traits of plants employed in BRs are mostly focused on root characteristics. Several general morphological considerations that have been reported to contribute to contaminant removal, nutrients' absorption (nitrogen, phosphorus, etc.), heavy metals (Pb, Zn, and Cu), and other pollutants by vegetation in BRs include (a) plant origin; (b) plant growth patterns; (c) plant form; (d) plant scale; (e) rooting depth; and (f) rooting volume [111] (Table 4). Greater water infiltration into the soil media via root channels and macropores is reported due to deeper root systems and, in general, in vegetated BRs compared to control ones without vegetation [112]. Furthermore, root biomass and total dissolved metal concentrations were shown to be positively correlated [113]. In unlined systems, root mass densities between 0.1 and 2.2 $kg \cdot m^3$ were found to positively correlate with high infiltration rates, while roots with a diameter of around 1 mm encouraged preferred flows associated with macropores [114]. Plant root development continually fractures the filter media's surface to avoid surface blockage, whereas root depth and mass are important for developing resistance to pests and diseases in bioretention [115]. Broad and exquisite root systems that sustain a large microbial community, maximize absorption capacity, and allow contact with rainwater, allowing bacteria and algae to flourish, which cycles nutrients and decomposes organic matter, are beneficial for BRs [116]. In comparison to the roots, it is also reported that the shoots of three plant species, *Carex panicea* J.Carey (fam. Cyperaceae), *Phalaris arundinacea* L. (fam. Poaceae), and *Juncus conglomeratus* L. (fam. Juncaceae), collected greater quantities of heavy metals, demonstrating effective metal transport within the BRs [61].

Among other crucial considerations, the utilization of herbaceous ground coverings of at least three to four different species to stop soil layers and mulch from eroding in BRs is suggested [117]. Because of restricted water resources, deeper rooting is needed, and mixtures with a preponderance of shrubby species might be more appropriate. Plants determined for erosion control in the manual for bioretention [117] are *Panicum virgatum* L. (fam. Poaceae), *Andropogon gerardii* Vitman (fam. Poaceae), and *Elymus virginicus* L. (fam. Poaceae). In arid climates, it has been noted that during the early stages of the plant's growth, the plant canopy has a significant impact on the amount of sand that is accumulated, and fast-growing shrubs like *Ephedra przewalskii* Stapf. (fam. Ephedraceae), *Calligonum zaidamense* Losinsk (fam. Polygonaceae), and *Sympegma regelii* Bunge (fam. Chenopodiaceae) are recommended for erosion control. The ability of shrubs to provide erosion protection and manage runoff and sediment, in particular *Quercus coccifera* L. (fam. Fagaceae) and *Pistacia lentiscus* L. (fam. Anacardiaceae), was also proven in Mediterranean shrubland ecosystems as the best plant species to reduce soil and water loss [118]. Although tap roots are capable of withstanding drought, research conducted by Li et al. [119] pointed out that there were no discernible variations in the amount of erosion reduction between grass with fibrous root systems and grass with taproots. In moderate areas with seasonal fluctuations and plant dormancy, the species with the highest root density and plant size made the greatest contributions to lowering the amount, flow, and pollution levels of water, whereas the species shown to be most effective was *Cornus sericea* L. (fam. Cornaceae), followed by *Juncus effusus* L. (fam. Juncaceae) [42].

A comprehensive study that evaluated 42 common plant species in Singapore's horticulture environment to demonstrate the plant traits that can be significant for nutrient removal included native and non-native species and different plant types, namely climbers, herbaceous and small- to medium-sized shrubs, large- to small-trees, and trees. Nitrate and phosphate elimination were substantially correlated with root and total plant biomass for the native species that were the subject of this investigation. While the associations between phosphate removal and plant features were not as robust as those found for nitrate removal, the root biomass of native tree species shows the highest relationship with nitrate removal [120]. In the presence of a saturated zone, it was shown that plants *Carex appressa* R.Br. (fam. Cyperaceae) achieved notably greater specific root length, surface area, and volume than plants cultivated on loamy sand, demonstrating the capacity of *Carex appressa* to modify root morphology to sustain growth in the presence of nutrient limitations [121].

Another study investigated vegetation performance, growth, and health under rainy garden conditions [122]. *Juncus effusus* L. (fam. Juncaceae) plants have been shown to be more resilient to various environmental conditions, like higher velocities and frequent flooding, causing them to accumulate vast biomass, grow quickly, and take on a very advantageous plant shape, while *Equisetum scirpoides* Michx. Plants (fam. Equisetaceae) had the greatest and fastest biomass increase. This study also pointed out the advantage of densely planted vegetation in minimizing weed growth. Increased biomass density has also been reported to contribute to a bioretention cell's lifespan extension [123]. In comparison to heavy metal accumulation, higher concentrations were observed in plant roots than in shoots of grass species like *Panicum virgatum* L. (fam. Poaceae) and *Bromus ciliatus* L. (fam. Poaceae).

As mentioned, plants absorb nutrients in the tissues and root system and provide space for the growth of bacteria responsible for organic degradation, so plants with relative plant growth rates and high-biomass plants are generally considered to maximize the mass of contaminants assimilated into plant biomass [12,100]. On the contrary, some studies have demonstrated that biomass production is not the most important parameter for amounts of accumulated metals. Despite large differences in biomass, similar levels of heavy metals were accumulated by *Miscanthus sinensis* Andersson (fam. Poaceae), a plant with the highest biomass production, and *Armeria maritima* (Mill.) Skottsb (fam. Plumbaginaceae), a hyperaccumulator with the lowest shoot biomass [113].

Table 4. Desirable morphological plant traits to meet various challenges in BRs [34,39,116,117,124].

Morphological Plant Traits	Enhancing Infiltration	Enhancing Evapotranspiration	Removal of Pollutants	Tolerance to Drought and Temporary Flood	Fluctuating Water Levels	Stabilize Soil and Minimize Erosion	Tolerance to Growing Conditions on Sandy Soils	Tolerance to Salt Runoff	Prevent Media Clogging
Root depth	●	●	●	●	●	●	●		●
Plant form		●	●						
Plant scale	●								
Rooting volume	●	●			●	●		●	●
Plant biomass	●	●	●						
Plant Origin	●			●	●	●			

The green color indicates the challenges in BRs that are attributed to the morphological plant traits.

9. Planting for Biodiversity: Healthy Habitats Supported by BRs Vegetation

Rich biodiversity supports the health and resilience of ecosystems [125]. As a primer, riparian ecosystems in arid and semi-arid regions represent hotspots for biodiversity in otherwise diverse and barren environments because riparian ecosystems act as sinks for pollutants, nutrients, and other elements [126]. Furthermore, studies that evaluated positive outcomes of the implementation of NbS based on vegetation performances, like increased biodiversity, biomass production, or increased water quality, are being mostly conducted on projects that used native species. The genetic mechanisms triggered by native planting in appropriate soil conditions allow them to thrive in inaccessible conditions like floods, droughts, and other extreme situations with minimal maintenance intervention [127]. Namely, native species are fundamentally the species used for phytoremediation because of their rapid growth, wide root system, high biomass yield, adaptability to a variety of ecosystems, high tolerance, and capacity to store contaminants in the above-ground portions of the plant [128]. Since they have developed defenses against pests and diseases, they require no pesticides or fertilizers. Native plants also attract and provide habitat for a variety of insects and animals, and they form deep root systems that encourage infiltration by creating additional spaces in the soil [79]. For example, grasses and forbs, both plant communities, are widely used in BRs because most grass roots grow to 1.83 m, while forbs are very deeply rooted, from 2.44 m to 4.57 m in maturity [129]. A study was conducted that looked at the establishment of native forb communities composed of 26 plant species that are common in northwest Europe, the availability of resources for foraging by these communities, and the functional connectivity among basins for pollinating insects [130]. The tested plant species were mainly from the family Asteraceae and native to Denmark. The findings in this study showed that tall hemi-rosette forbs can withstand mostly dry climatic conditions and irregular, variable water levels. Moreover, it was concluded that bioretention basins can contribute to the preservation of urban biodiversity by offering important foraging habitats and functional connections for pollinators. The availability of pollinators and the diversity of plant species are generally decreased by urbanization. Kazemi et al. [131] concluded that the number of species, species richness, and diversity were higher in bioretention swales than in gardenbed and lawn-type green spaces, respectively, in the Melbourne area. As measures of biodiversity, sweep-netting-captured invertebrates were employed.

Although meadows and grasslands have a beneficial impact on urban ecology, some studies suggest the need to carefully consider the use of natural meadows in urban areas. In a study that aimed to investigate the establishment of 17 different species of North American prairie grasses and forbs in Sheffield, England, through field planting [132], plants that were successful in establishment were those from the family Asteraceae. The most effective species that were established were *Echinacea pallida* Nutt. (fam. Asteraceae), *Echinacea purpurea* (L.) Moench (fam. Asteraceae), *Monarda fistulosa* L. (fam. Lamiaceae), *Ratibida pinnata* (Vent.) Barnhart (fam. Asteraceae), and *Solidago rigida* L. (fam. Asteraceae). The least successful species were *Coreopsis tripteris* L. (fam. Asteraceae), *Solidago ohioensis* L. (fam. Asteraceae), *Sporobolus heterolepis* A.Gray (fam. Poaceae), and *Veronicastrum virginicum* (L.) Farw (fam. Scrophulariaceae). It was concluded that low-intensity approaches may be used to successfully manage the prairie vegetation, which was first established by field sowing.

In a study that involved *Calamagrostis* × *acutiflora* 'Overdam' (Poaceae), *Pycnanthemum muticum* (Michx.) Pers. (fam. Lamiaceae), *Rudbeckia fulgida* 'Goldsturm' (fam. Asteraceae), *Carex stricta* subsp. elata (fam. Cyperaceae), *Pycnanthemum virginianum* (L.) T.Durand (fam. Lamiaceae) and *Rudbeckia hirta* L. (fam. Asteraceae), species *Calamagrostis and Pycnanthemum*, two native and ornamental species, both demonstrated 100% cover in bioretention plots. *Rudbeckia fulgida* 'Goldsturm' was unable to withstand a period of flooding, while *Rudbeckia hirta* failed to resurface [133]. The studied native species expressed a substantial relationship between the removal of N and P and the biomass of both the roots and the entire plant [120]. Native tree species' root biomass has shown the strongest relationship with nitrate clearance. However, it was found that increasing the plant diversity with native species within bio-cells can help increase the number of predators and pollinators in urban landscapes. Additionally, a few studies have demonstrated the high performance of non-native plants. For instance, a study that investigated the removal effectiveness of pathogens, namely *E. coli,* from highway stormwater runoff in Texas by five pilot bioretention units indicated that non-native grasses could also show significant effectiveness in pathogen removal among other vegetation [134]. The amount of nutrients removed from runoff by native and ornamental plants was comparable, although *Carex comosa* Boott. (fam. Cyperaceae) and *Iris virginica* L. (fam. Iridaceae), two native wetland species, showed a superior level in the reduction in N and P relative to one non-native plant species, *Poa pratensis* L. (fam. Poaceae).

10. Concluding Remarks and Future Perspectives in Utilization of Vegetation in BRs towards Resolving Environmental Challenges

According to the literature and an existing sizable body of research that has been released on vegetation performances in BRs, it is evidenced that vegetation is the most important component of BRs and that it can help address a number of climate-related issues and environmental vulnerabilities. Therefore, it can be concluded that knowledge about the process of selecting the proper plant species for BRs is essential when planning for sustainability and resilience. The literature that was reviewed in this study suggested the following:

- Perennial vegetation most often receives significant attention in BRs, leading to a concentration of studies on the utilization of grasses, sedges, and other perennials;
- Species belonging to the family Poaceae, Myrtaceae, Asteraceae, and Cyperaceae have, in particular, demonstrated high efficiency in toxic substance removal from contaminated water in diverse geographical locations. Similar to the family Poaceae, the family Myrtaceae is one of the most significant plant families that comprise the numerous globally scattered genera of ecological and economic value [135], while the family Asteraceae is considered to be important in urban contexts as a sustainable design tool for phytoremediation and increasing biodiversity [136];

- According to reviewed studies, the most significant plant species belonging to the family Asteraceae that are utilized in BRs are *Aster nova angliae*, followed by *Rudbeckia* sp., *Echinacea purpurea* L., and *Liatris spicata* L. From the family Poaceae, notable species include *Miscanthus sinensis* Andersson., *Panicum virgatum* Muhl., and *Phragmites australis* (Cav.) Steud.; from the family Myrtaceae—*Melaleuca ericifolia* Andrews and Leptospermum continentale Joy Thomps; and from the family Cyperaceae, the most utilized plant species belong to the genus *Carex*;
- Plants like *Miscanthus sinensis* Andersson are highly utilized in BRs because of their high biomass and resistance to different water levels and different pollutants like heavy metals and pathogens. Likewise, plants from the genus *Juncus* have also been shown to be resistant to waterlogging, drought, and salt, and it is recommended that they be included in BRs within various geographic locations. Plants from the genus *Iris* also contributed to the increase in water quality while simultaneously surviving different biotic and abiotic stresses. Additionally, *Panicum virgatum* L. is an effective plant species that can be involved in BRs for various water treatment goals;
- The statements about the survival of some plant species at different temperatures need to be taken cautiously. For example, although *Canna indica* L. (family Cannaceae) is considered to survive the winter, it was shown that the lowest survival temperature recorded for this plant was actually −7.4 °C [137];
- It can be concluded that plants with high above-ground biomass rhizomes show the highest potential for pollutant accumulation because it has been recorded that the pollutants are mainly accumulated in the roots and biomass of the plants;
- Plants for different moisture levels in BRs are mainly being chosen due to their naturally occurring habitats (wetland, terrestrial, etc.). However, it is often suggested to choose native plant species of a geographical area, adapted to the living conditions of the specific area, that are more suited to the local climate zone;
- A community with a modest number of species is likely to be more resilient than one with fewer species in terms of ground cover, soil conservation, runoff, and productivity. Because not all species will be affected equally by environmental changes, pests, and diseases, a planting palette with greater diversity replicates more natural systems and has intrinsic resilience against these threats.

This research outcome recognizes how various plant species and communities in various geographic locations have the greatest impact on the removal of diverse pollutants from soil and water, achieving a balance between plant function and plant health while also providing multiple benefits for the environment within different NbS. Figure 2 summarizes the main aspects of considering vegetation for future BRs and how this aspect is related to the challenges mentioned to achieve both ecological and aesthetic values. Important advantages during the planning of vegetation for BRs are primarily reflected through plant adaptation, utilization, application of ornamental and native plants, and overall maintenance of BRs.

By implementing high-diversity plant communities through NbS, it is possible to guarantee the existence of more functionally rich flora with species that have the necessary physiological adaptations to the local environment for appropriate hydrological functioning and vegetative cover. Although the focus of this paper was to present BRs from the perspective of creating resilient and more sustainable places, we also wanted to encourage the use of green areas in general and to approach them from different ecological and other perspectives. Given the unpredictability of future impacts of climate scenarios, implementation of NbS should be the focus of future research and landscape planning, especially in regions with increased exposure to climate change and human activity.

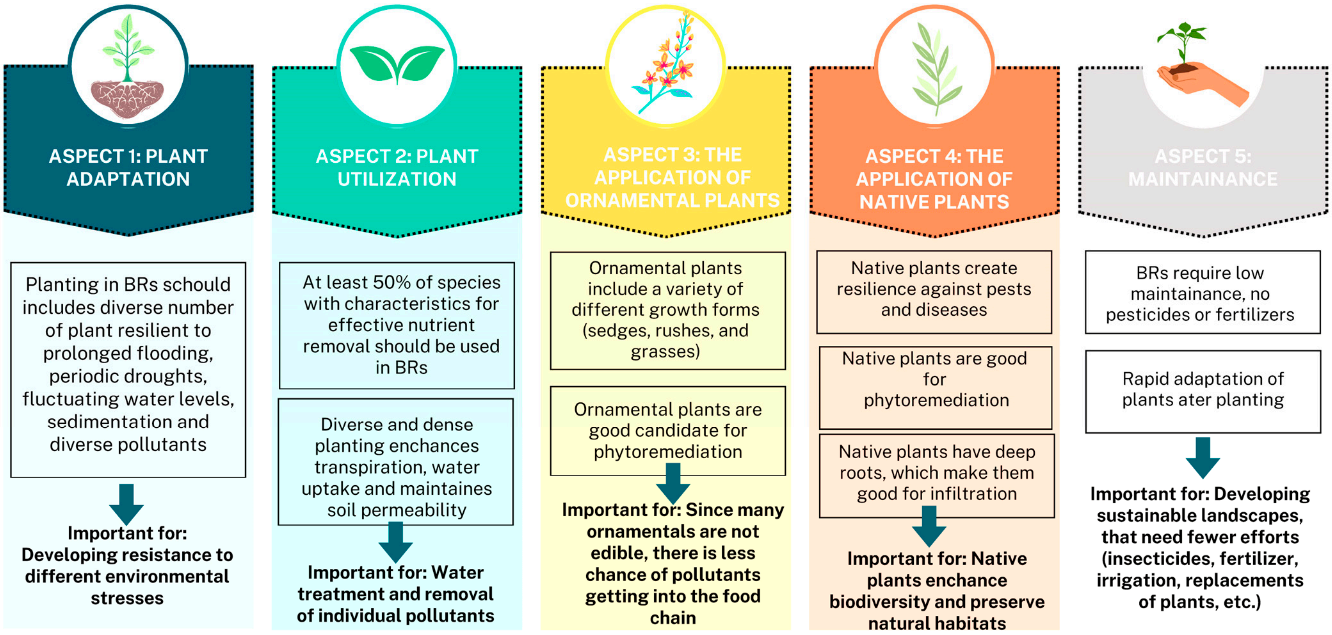

Figure 2. The main aspects of vegetation for bioretention that ensure resilience and sustainability [12,19,53,56,84,116,117,132] (Author: Amela Greksa).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16083273/s1, Table S1: Vegetation responses to different abiotic and biotic stresses [138–147].

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