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Nature-Based Management of Lawns—Enhancing Biodiversity in Urban Green Infrastructure

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Abstract: Urban green areas have multifunctional benefits that may mitigate unfavorable health and ecological effects. Green areas represent important biodiversity hideouts in anthropogenic regions. Lawns are the most common elements of urban greenery, covering a considerable number of green areas in cities. The aim of this analysis was to gain knowledge on urban greenery and elaborate recommendations related to management that favors grass lawn biodiversity. The established working hypothesis is that the limited intensity of management in urban grass areas is reflected in the modification of their species composition, as well as their potential ecological functions. An experiment on the management of city lawns was conducted in 2010 (still ongoing). There are three lawn variants under different management methods: ornamental, city, and permaculture lawns. Vegetation was assessed using the method of phytocoenological relevés. The coverage values of the individual plant species were processed using multidimensional analysis of ecological data. The results showed that human decisions and activities affected the species composition of these grassy areas. There were 46 plant taxa found during the monitoring: 12 in ornamental lawn variants, 24 in city lawn variants, and 31 in permaculture lawn variants. Permaculture lawns with extensive management represent the most environmentally friendly variant with respect to biodiversity and soil moisture content. However, changes in species composition have raised questions regarding the extent to which they may perform other ecosystem functions. Increasing the intensity of lawn management has resulted in lower plant diversity. Extensive management alters the aesthetic value of lawns and creates spaces for species that may spread in urban environments.

Keywords: urban green areas; biodiversity; grass lawns; management methods; species composition

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1. Introduction

Cities are responsible for significant negative environmental, economic, and health issues, but they also hold the key to a greener economy and sustainable future. According to [1], protecting and restoring urban ecosystems is important for sustainable urbanization. Cities are key to achieving the Sustainable Development Goals (SDGs), and there is a specific goal (SDG 11) for cities [2,3]. Urban green areas have multifunctional benefits that may mitigate unfavorable health and ecological effects [4–6]. They have several ecosystem functions, such as rainwater retention, urban heat-island effect mitigation, food supply, and air purification [5,7,8], particularly when they are located in the neighborhood of communication infrastructure [9]. Green areas are also important biodiversity hideouts in urban [10–12] and anthropogenic areas [13–17]. At present, lawns are the most common element of urban greenery, covering a considerable portion of all open green areas in cities (up to 70–75%) [18–20]. They have a positive impact on human life in cities [21–24]. However, it is crucial to emphasize that a lawn is a deliberately created plant community consisting of a variety of grass species, including numerous nonnative species [25,26]. These lawns are meticulously cultivated to attain the visually appealing aesthetic of a lush green carpet [27]. Lawns are often created in habitats that are strongly affected by humans; therefore, appropriate species compositions should be selected. Due to their unique microclimate and urban environment, the conditions in cities often deviate from natural ecosystems. As a result, it becomes necessary to explore plant species that may not be typical for the local area but have the ability to thrive and perform the expected functions within lawns. Moreover, lawn management depends entirely on humans. The presence of lawns is currently a topic of controversy due to the potential negative environmental impact caused by the extensive use of pesticides and fertilizers, as well as resource-intensive maintenance practices like frequent mowing, watering, aeration, and reseeding [28–33]. These anthropogenic factors alter habitat conditions, subsequently influencing the species composition of lawns. Additionally, lawns have the capacity to modify urban microclimates, facilitate rainfall infiltration, and contribute to increased biodiversity [10,34–36]. Predominantly, lawns play an aesthetic role [37]. Evergreen, dense, and compact lawns are highly appreciated, particularly in decorative parks, gardens, and flowerbeds [25,38]. Grass lawns are showcases in most Western European cities and are appreciated by most people in terms of culture and aesthetics [18]. However, these lawns require intense and expensive management [39]. The high costs of lawn management have raised questions related to their impact on the environment, particularly the carbon footprint associated with mowing and water usage [35,40–42]. Therefore, lawns with functions other than aesthetics represent an alternative. The shift in city lawn management practices, aimed at reducing their detrimental environmental impact, has given rise to the concept of permaculture [43]. Permaculture lawns or urban meadows are designed to require minimal human intervention while fulfilling various ecosystem functions. Urban meadows, characterized by natural, non-mowed green areas with or without flowering plants, serve as an alternative land cover to conventional mowed green areas. Although their establishment in urban areas is on the rise, they still constitute a small fraction of urban greenery [44].

Exploring polycultures of diverse plant species, including both grasses and dicotyledons, that can thrive and reproduce under traditional lawn management practices, presents an avenue for grass-lawn alternatives. The long-standing and consistent disturbances inflicted on grassland communities by human civilization have resulted in the development of vegetation specific to certain species. These changes in disturbance, driven by human activities, are also reflected in the composition of grassland communities [45]. The authors of [28] propose that polycultures consisting of grasses and native plant species represent relatively untapped resources with great potential for landscape applications.

Natural-based solutions refer to approaches that integrate green spaces and nature-based management practices into urban environments to address environmental, economic, and social challenges. Specifically, the focus is on using natural elements, such as vegetation and soil, to manage water, enhance biodiversity, mitigate urban heat islands, and improve air quality [35]. Nature-based management, particularly water management, involves the utilization of natural ecosystems and processes to regulate water flow, enhance water quality, and manage stormwater runoff. This can include strategies such as green infrastructure (e.g., green roofs, rain gardens, and permeable pavements), restoring wetlands and riparian zones, and promoting the infiltration and retention of rainwater within urban areas [20].

Therefore, understanding the impact of lawn management on urban herbaceous vegetation is crucial. This study addresses four research questions. First, what is the effect of lawn management intensity on the species composition of the urban herbaceous vegetation? We hypothesized that low-intensity lawn management would increase the species diversity and proportion of native plant species. Second, what is the effect of low-intensity lawn management on the representation of the sown plant species? We hypothesized that intentionally sown species can be suppressed by nature-friendly lawn management. Third, different lawn management practices alter the representation of plant species, which is indicative of habitat moisture. We hypothesized that intensive management would increase evaporation and alter habitat moisture conditions, which would also affect the representation of moisture-loving plant species and cause them to decline. Fourth, does lawn management influence the proportion of nonnative species? We hypothesized that nature-friendly lawn management would reduce the representation of nonnative plants. By investigating these research questions, we aim to enhance our understanding of the impact of lawn management in urban environments and its implications for the provision of ecosystem services within a city's socio-ecological system.

2. Materials and Methods

2.1. Site Description

The Research and Educational Center—Water Center of the Warsaw University of Life Sciences (SGGW) is located at the main university campus in the southern part of Warsaw in the Ursynów district (Figure 1).

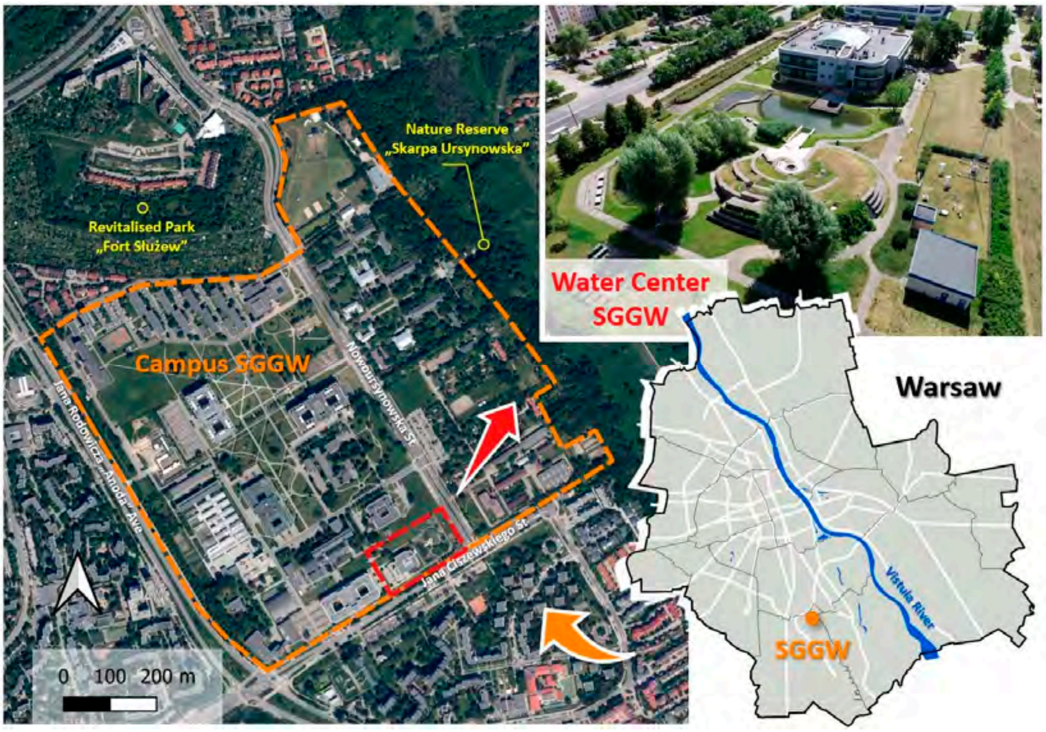

Figure 1. Location of the main campus and Water Center of SGGW.

The total project area is approximately 14,600 m^2. The Water Center is comprised of an educational and research facility with a development area of approximately 2000 m^2 and a total area of approximately 5600 m^2 (Figure 2). The Research Center—Water Center has the dual objective of enhancing the quality of education and promoting ongoing research and development among academic staff. This includes improving research methods and techniques and implementing practical experiences in various applications. The Water Center comprises a model of a watercourse connected with trophic reservoirs, with its outlet in the ultimate water reservoir. A large area of the Water Center is covered with lawns.

One notable feature of the water center park is a model watercourse interconnected with trophic reservoirs, ultimately leading to a water reservoir. To complement this design, a significant portion of the park area is covered with lawns. One of the lawns serves as an example of natural-based solutions, highlighting the benefits of incorporating green spaces and nature-based management approaches into urban environments.

Figure 2. View of the Water Center of SGGW with the water park.

2.2. Characteristics of the Lawns

The experiment on the management of city lawns was initiated in 2010, with three distinct lawn variants being implemented, each employing different management methods. The specific management approaches for each lawn variant are as follows: (i) Ornamental lawn: This variant involves the cultivation of low-growing grass species under intensive management. Regular cutting is performed every 2–3 weeks during the growing season, with the cut biomass being removed. The lawn receives regular mineral fertilization and watering when precipitation is insufficient. (ii) City lawn: A city lawn represents the typical management approach found in most urban grass areas. It is mowed two to four times per year, depending on biomass growth. After mowing, the biomass is collected and removed, and neither fertilization nor watering is applied to the lawn. (iii) Permaculture lawn: This lawn variant follows a nature-based management approach that promotes semi-natural succession, with minimal human intervention. The grass stand is irregularly mowed once a year in the autumn. The cut biomass is left on-site, and the lawn receives no fertilization or watering. The management practices of permaculture lawns align with the long-term sustainability principles of the permaculture approach. By implementing these distinct management methods, this experiment aimed to assess the ecological and biodiversity outcomes associated with each lawn variant.

2.3. Methods of Vegetation Assessment

Vegetation was assessed using a remote sensor method. The study used the unmanned aerial vehicle DJI Matrice 600 with the multispectral camera Parrot Sequoia+. The camera allows images to be recorded in four spectral channels: green (GRE), red (RED), near-infrared (NIR), redge (REG), and RGB images in visible lights. The data collected allowed a visual assessment of the plants and an evaluation of plant health based on the chlorophyll index. The chlorophyll index allows the amount of chlorophyll in the green parts of plants to be determined. The Normalized Difference Vegetation Index (NDVI), which is the most commonly used index due to its ease of calculation, was used in the study. The NDVI index is based on the ratio of the NIR and RED channels and is expressed by the Formula (1) [46]:

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

where:

NIR—near-infrared band
RED—red band

Vegetation was assessed using phytocoenological relevés with as size of 2 m^2. Four plots were surveyed for each lawn variant, on which vegetation was assessed in July 2020 and 2021. First, all taxa of plants that occurred on the phytocoenological relevés were identified, and then the aboveground biomass coverage was estimated for the respective taxa. The scientific names of the individual plant species were obtained from the Pladias database of flora and vegetation [47]. Based on the data from the Pladias database, plant species were classified into several groups according to the selected characteristics. The indicator value for moisture was expressed on an ordinal scale from 1 to 12, as defined by Ellenberg [48]. The values for the individual taxa were modified and extended by Chytrý [49].

The coverage values of individual plant species observed at each site were analyzed using a multidimensional analysis of ecological data. To determine the appropriate analytical method, the gradient length was assessed using segment Detrended Correspondence Analysis (DCA). Canonical Correspondence Analysis (CCA) was also performed. To assess statistical significance, a Monte Carlo test was employed, and 999 permutations were calculated. Data analysis was performed using Canoco 4.0, a computer program widely used for ecological data analysis [50].

3. Results and Discussion

3.1. Groups of Plant Species in Grasslands

There were 46 plant taxa found during the monitoring—12 of them in ornamental lawn variants, 24 in city lawn variants, and 31 in permaculture lawn variants. A representation of the identified plant taxa is shown in Table 1.

Table 1. The list of identified plant taxa with the average cover and plant species classification in groups.

Plan Species	Abbr.	Lawn Variants (Average Cover %)			Classification According to Groups:		
		Ornamental Lawn	City Lawn	Permaculture Lawn	Species Suitability for Lawns	Moisture Content	CCA Analysis
Achillea millefolium	*AchMill*	7.3	6.3	4.3	3	5	O/C
Armoracia rusticana	*ArmRust*			3.0	4	6	P
Artemisia vulgaris	*ArtVulg*		0.7	3.0	4	5	C/P
Bellis perennis	*BelPere*	6.7			3	5	O
Bidens tripartita	*BidTrip*			0.3	3	9	P
Calamagrostis epigejos	*CalEpig*			5.0	4	5	P
Carex hirta	*CarHirt*		1.3	1.7	3	6	C/P
Centaurea macrocephala	*CenMacr*			3.7	4	not specified	P
Cichorium intybus	*CicInty*		3.3	8.7	2	4	C/P
Cirsium arvense	*CirArve*		6.0	2.3	4	5	C/P
Convolvulus arvensis	*ConArve*		3.3		3	4	C
Conyza canadensis	*ConCana*		0.7		3	4	C
Cornus sanguinea	*CorSang*			0.3	4	5	P
Crepis mollis	*CreMoll*	3.0	0.7	0.7	3	4	O/C
Dactylis glomerata	*DacGlom*	4.3		13.3	1	5	P/O
Daucus carota	*DauCaro*		7.7	5.3	3	4	C/P
Equisetum arvense	*EquArve*			4.3	4	6	P
Erigeron annuus	*EriAnnu*	2.0		5.0	3	5	P/O
Festuca arundinacea	*FesArun*		1.3		1	7	C
Festuca pratensis	*FesPrat*			16.7	1	5	P

Table 1. *Cont.*

Plan Species	Abbr.	Lawn Variants (Average Cover %)			Classification According to Groups:		
		Ornamental Lawn	City Lawn	Permaculture Lawn	Species Suitability for Lawns	Moisture Content	CCA Analysis
Festuca rubra	*FesRubr*	25.0	58.3		1	5	O/C
Hypericum perforatum	*HypPerf*		1.3	6.0	3	4	C/P
Inula britannica	*InuBrit*			1.3	3	7	P
Lactuca serriola	*LacSerr*		0.3	2.0	4	4	C/P
Lolium perenne	*LolPere*	18.3	16.7		1	5	O/C
Lotus corniculatus	*LotCorn*		7.7		2	4	C
Lythrum salicaria	*LytSali*			1.7	4	9	P
Medicago falcata	*MedFalc*			2.0	2	3	P
Medicago lupulina	*MedLupu*	9.0	15.0		2	4	O/C
Medicago sativa	*MedSati*		4.0	6.7	2	4	C/P
Phalaris arundinacea	*PhaArun*			16.7	4	8	P
Plantago lanceolata	*PlaLanc*	10.7	7.0		3	5	O/C
Poa pratensis	*PoaPrat*		4.7	8.3	1	5	C/P
Potentilla argentea	*PotArge*	3.0			3	2	O
Potentilla reptans	*PotRept*			2.0	3	6	P
Rosa canina	*RosCani*			1.0	4	4	P
Rumex crispus	*RumCris*			0.3	4	6	P
Setaria viridis	*SetViri*	2.3			3	4	O
Silene latifolia	*SilLati*			3.0	4	4	P
Solidago canadensis	*SolCana*			1.8	4	5	P
Sonchus oleraceus	*SonOler*		0.3		3	5	C
Taraxacum sect. *Taraxacum*	*TarSect*		10.0	4.3	3	5	C/P
Trifolium pratense	*TriPrat*		7.7		2	5	C
Trifolium repens	*TriRepe*	11.7	6.0		2	5	O/C
Veronica maritima	*VerMari*			1.3	3	8	P
Vicia cracca	*VicCrac*		1.3		2	5	C

Legend: Groups according to suitability for lawns: 1—sown species, 2—useful species, 3—less suitable species, 4—undesirable species. Groups according to indicative value for moisture content: 2—transition between values 1 and 3; 3—missing on damp soil; 4—transition between values 3 and 5; 5—indicator of fresh soils, focus on soils of average moisture content, missing on wet soils and on soils that frequently dry out; 6—transition between values 5 and 7; 7—humidity indicator, focus on well-moistened, but not wet soils; 8—transition between values 7 and 9; 9—wetness indicator, focus on often soaked, poorly aerated soils. Groups according to CCA analysis: O—group consists of species which prevailingly occurred as part of the vegetation of ornamental lawns. O/C—group of species occurring predominantly in ornamental and city lawns. C—group of species which occurred predominantly in the city lawn variants. C/P—group of plant species recorded particularly in the city and permaculture lawn variants. P—group of plant species which dominated in permaculture lawns. P/O—group of plant species recorded in the ornamental and permaculture lawn variants.

Lawns represent a prominent component of green areas worldwide, regardless of regional climate variations. Despite their prevalence, lawns have not received extensive research attention [18]. Various definitions of a ‘lawn’ exist, but in this context, they are defined as an artificially created or modified plant habitat characterized by predominantly grass species (technically referred to as graminoids). Additionally, lawns may also contain spontaneous herbaceous species commonly known as ‘weeds of lawn’ [27]. These so-called ‘weeds of lawn’ play a vital role in fulfilling important ecosystem functions that hold significance for urban greenery as well as the lawn plant community itself. It is essential to recognize that lawns are dynamic plant communities, with their species composition shaped by human influence [51,52]. According to a study by Ignatieva [53], *Lolium perenne*, *Festuca rubra*, and *Poa pratensis* comprise the basic species composition of lawns in central Europe.

In terms of human intervention, lawn plant species can be classified as (1) sown, (2) useful, (3) less suitable, and (4) undesirable. We assessed the criteria from a turf perspective only. Sown species are grasses that create basic and characteristic types of lawns. Useful species include leguminous plants that enrich the soil with nitrogen [54,55], thus supporting the growth of grasses and participating in improved rainwater infiltration into the soil [23,56]. Species that are less suitable for lawns are other dicotyledonous plant species, but only low-growth ones. Species that are undesirable for lawns are high-growth herbs or woody plants; that is, species that significantly alter vegetation characteristics [27]. The classification of the plant species in each category is presented in Table 1. Each species was assigned to only one group according to its predominant importance. The ratios in the representation of plant species groups based on their suitability for lawns are shown in Figure 3.

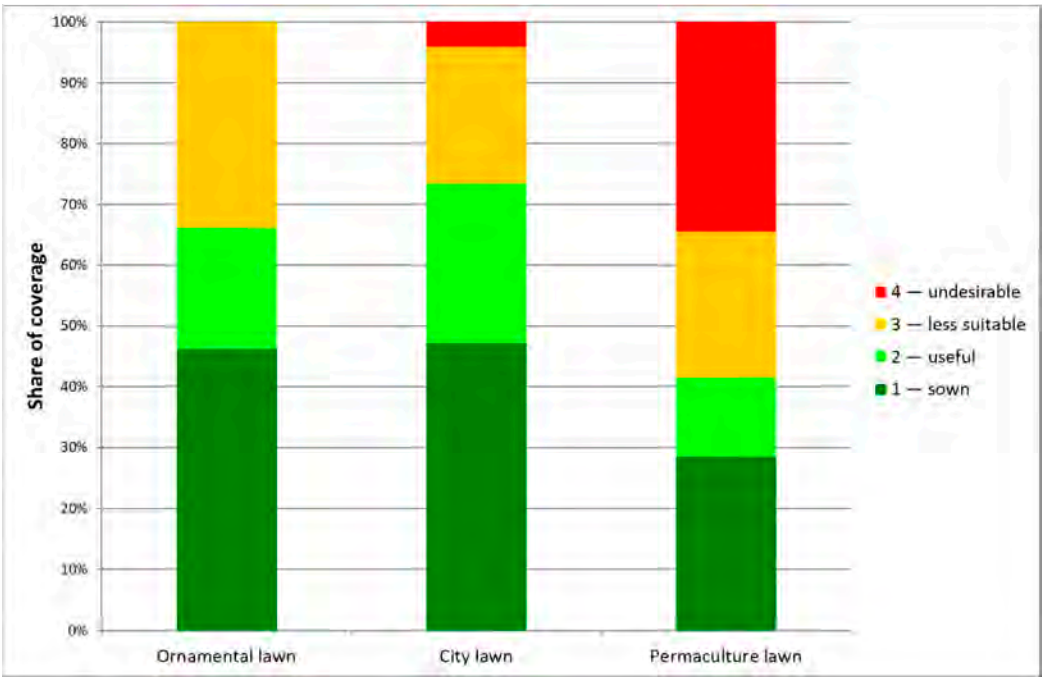

Figure 3. Lawn coverage shares by the groups of species suitability for lawns.

Sown species have the greatest cover contribution to cities and ornamental lawns. City lawns create a favorable ratio between sown grasses and useful species (family *Fabaceae*), which reduces their fertilization requirements (i.e., nitrogen). A considerably undesirable perennial species is *Cirsium arvense* with a sturdy root system, which occurs very unevenly. Therefore, local and targeted regulation is important.

Ornamental lawns have a lower contribution of useful species and a higher contribution of less suitable species. Although intensive management eliminates the occurrence of undesirable species, it also suppresses useful species (*Fabaceae*) and does not increase the contribution of the sown (grass) species. Our study indicates that intensive management significantly reduces plant species diversity and creates a category of species that can be characterized as 'turfgrass weeds'. Species that are less suitable for lawns include *Achillea millefolium*, *Bellis perennis*, and *Plantago lanceolata*. Our results are in accordance with those of Abu-Dieyeh [57], who confirmed that the occurrence of turfgrass weeds is rare in lawns mowed to a small height. According to Watson [58], intensive lawn management decreases plant and insect biodiversity, whereas frequent low mowing decreases plant structure and composition by favoring low-growth annual plants or grasses and decreases flower resources for pollinators by removing higher flower structures. Additionally, the results obtained by Watson [58] suggest that frequent mowing resulting from aesthetic requirements may cause other aesthetic problems by facilitating the increased invasion of weeds and pests. Busey [59] and Norton [60] confirmed that intense mowing is an important factor that contributes to weed invasion in city lawns and meadows.

The studies performed by Chollet [51] indicate that lawns with low mowing frequency are characterized by higher plant biodiversity than green areas with high mowing frequency (+15% to 62%). Frequent mowing can only be tolerated by a few plant species, which may tolerate repeatable perturbations; thus, lawns are favored by ruderal species that are more tolerant to such perturbations [25].

The results indicate that mowing frequency is a key indicator of plant species diversity in urban spaces. This is in accordance with studies on semi-natural green areas, such as the study performed by Socher [61], who showed that mowing intensity had a greater impact on plant species richness than fertilization intensity in the analyzed green areas in Germany.

Permaculture lawns create space for the highest species diversity but also for undesirable species. In addition to common meadow plants, the species composition includes undesirable species of clearly ruderal or invasive character which spread in the landscape, such as *Artemisia vulgaris*, *Calamagrostis epigejos*, *Cirsium arvense*, *Erigeron annuus*, *Lactuca serriola*, and *Solidago canadensis*. The investigations performed by Bertoncini [62] have shown that surprisingly, less than 10% of species (seven species) noted on lawns in Paris represent invasive taxa. This is a relatively low amount, considering the common pattern observed in cities, which is usually about 15–20% of invasive species in urban and natural habitats.

The occurrence of *Centaurea macrocephala* (Figure 4) was also remarkable. The species was formerly cultivated as ornamental and its current potential to further spread in the built-up areas of towns and cities is high. Naturalized *Centaurea macrocephala* has been found in grass communities in the United Kingdom (UK). According to Hitchmough and Woudstra [63], sites yielding this species represent managed or abandoned gardens. Other localities where this plant is often naturalized are roadsides and the margins of railway tracks bordering suburban gardens. Regular botanic monitoring and targeted and local control would be adequate for the occurrence of these species. Permaculture lawns differ significantly in character from the aesthetic values of other variants. Therefore, this variant cannot be used at all sites determined for lawns.

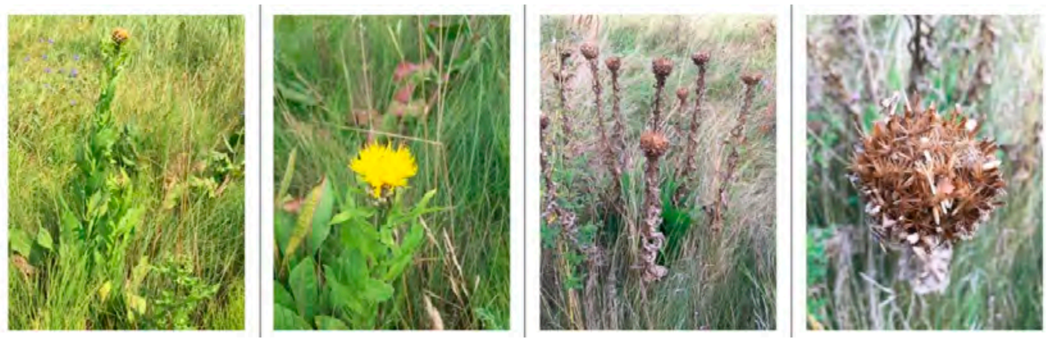

Figure 4. Photo documentation of *Centaurea macrocephala* identified at the Water Centre of SGGW.

3.2. Moisture Bioindication Using Dew Species and NDVI in Grasslands

Urban ecosystems present transformed soil conditions as well as a rapidly changing and often hotter microclimate, generating numerous barriers to fostering native plants, or even predicting which taxa may survive in such an environment [25]. Based on the indicative values for soil moisture content, it was found that the species occurring in the study had values ranging from 2 to 9. Species with an indicative value of 5 (indicator of fresh soils bound to soils with the average moisture content, missing in moist and frequently drying out soils) had a dominant share of coverage in all lawn variants. However, the permaculture lawn variants exhibited species with indicative values ranging from 7 to 9 (7, indicator of moisture content, bound to soils with a good water supply but not wet; 8, transition between 7 and 9; 9, indicator of wet soils, saturated with water and poorly aerated). Thus, the permaculture lawn variants indicated a sufficient amount of water in the soil. In contrast, these species were missing in the ornamental lawn variants where species occurred with an indicator value of 2; that is, species missing on moist soils up to species bound to dry soils. As this variant is irrigated, it should have sufficient water. Therefore, we can assume that intensive management will change the hydrological situation of lawns, facilitating the occurrence of drought-resistant species and suppressing the occurrence of moisture-loving species. The indicative values of the individual species are presented in Table 1. The representation of species groups according to their indicative values for moisture in the respective lawn variants is shown in Figure 5.

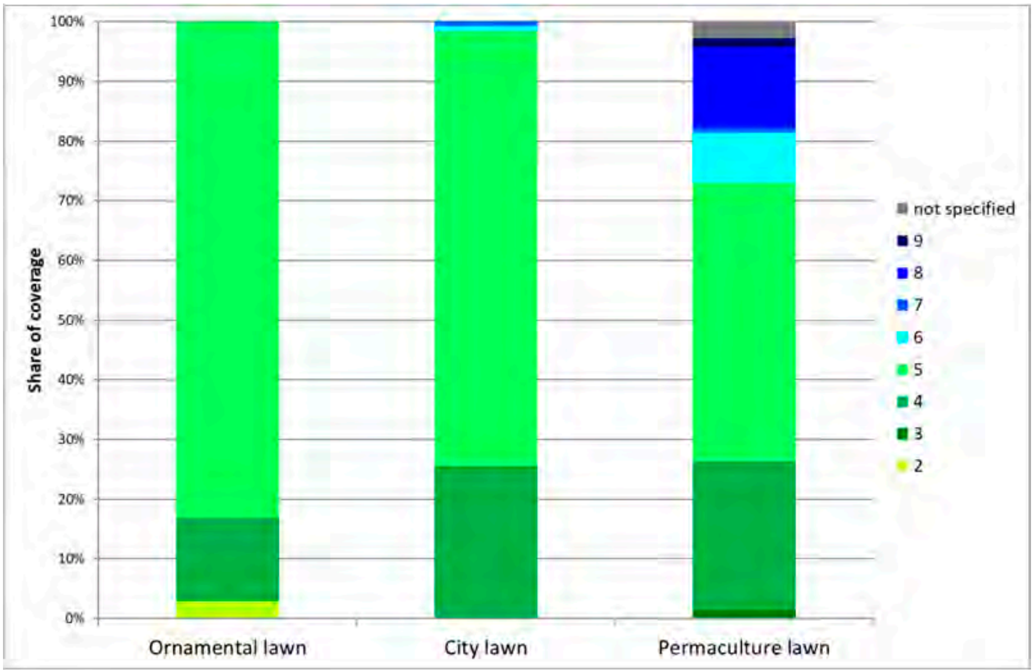

Figure 5. Lawn coverage share according to indicative values for moisture. Groups according to indicative value for moisture content: 2—transition between values 1 and 3; 3—missing on damp soil; 4—transition between values 3 and 5; 5—indicator of fresh soils, focus on soils of average moisture content, missing on wet soils and on soils that frequently dry out; 6—transition between values 5 and 7; 7—humidity indicator, focus on well-moistened but not wet soils; 8—transition between values 7 and 9; 9—wetness indicator, focus on often soaked, poorly aerated soils.

The NDVI index is based on the value of the contrast between the largest reflection (in the NIR band) and the absorption in the red band and contains in a range of values from −1 to 1. The value of the NDVI index increases as the reflection in the NIR band increases and the reflection in the red band decreases. A high value of the index corresponds to good plant health. The results of the analyses are shown in Figures 6 and 7.

The value of the NDVI index visibly differed between the three study areas. Statistical analysis of the study areas showed that the best condition was found in area (a) and the worst in area (b) (Figure 8).

According to the NDVI, the best condition for vegetation is the lawn of option a (ornamental lawn). Lawn vegetation that is frequently and regularly mowed can serve aesthetic purposes. However, this condition is provided by high external input (irrigation and fertilization). The species composition of the lawns with a higher proportion of species that tolerate drought in conjunction with irrigation suggests that water is likely to evaporate quickly.

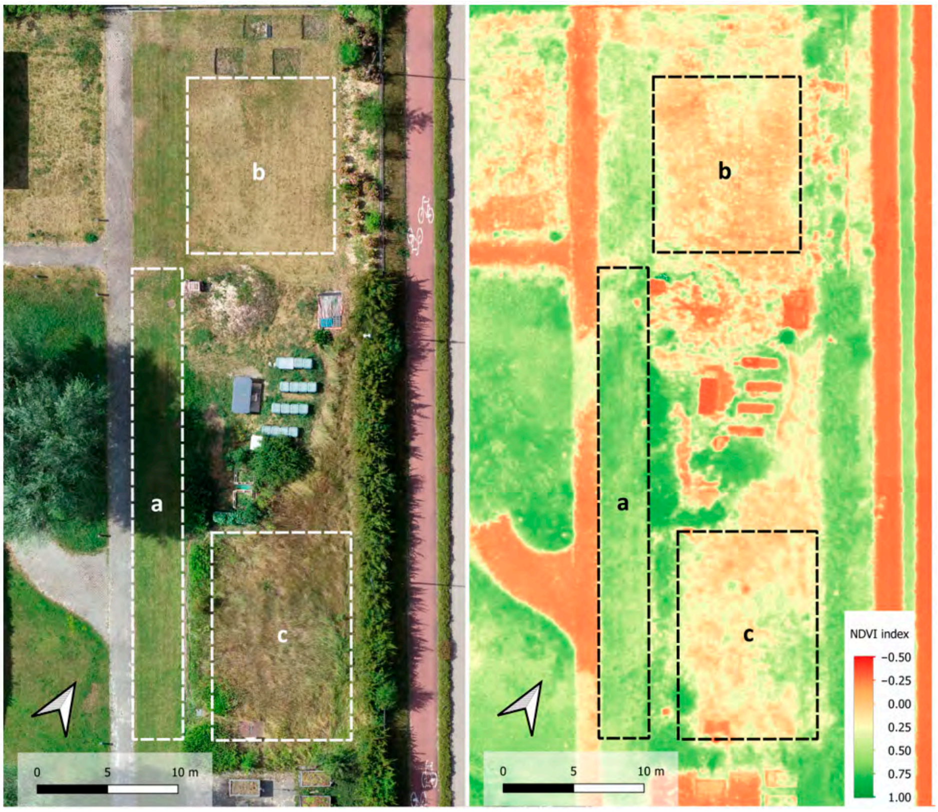

Figure 6. Orthophotomap with marked study areas (**left**). Spatial distributions of NDVI (**right**).

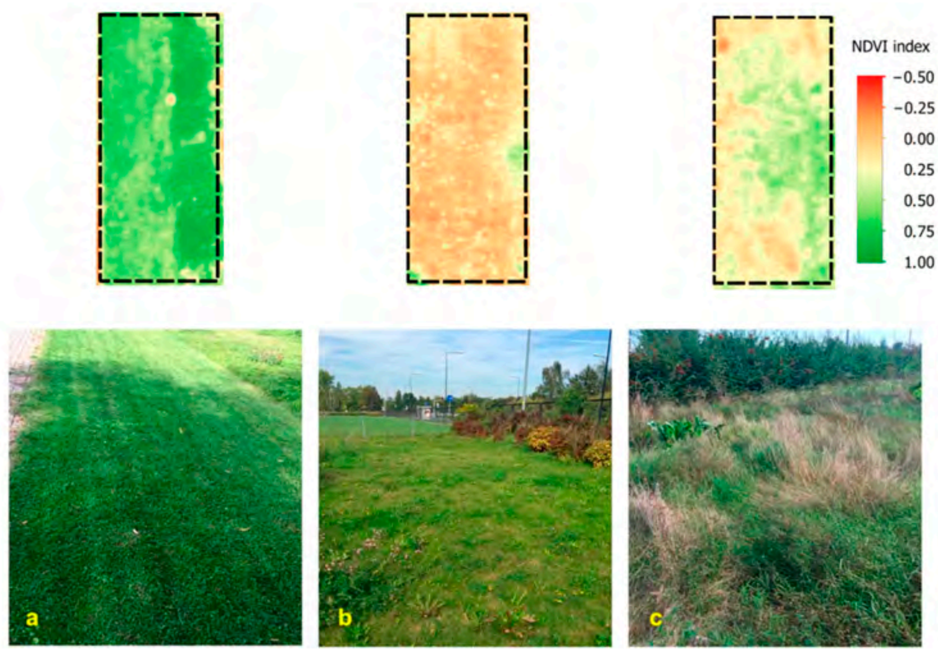

Figure 7. The lawn management variants in the Water Park and spatial distributions of NDVI (upper part): (**a**) ornamental lawn with intensive management; (**b**) city lawn with common management; (**c**) permaculture lawn with extensive management.

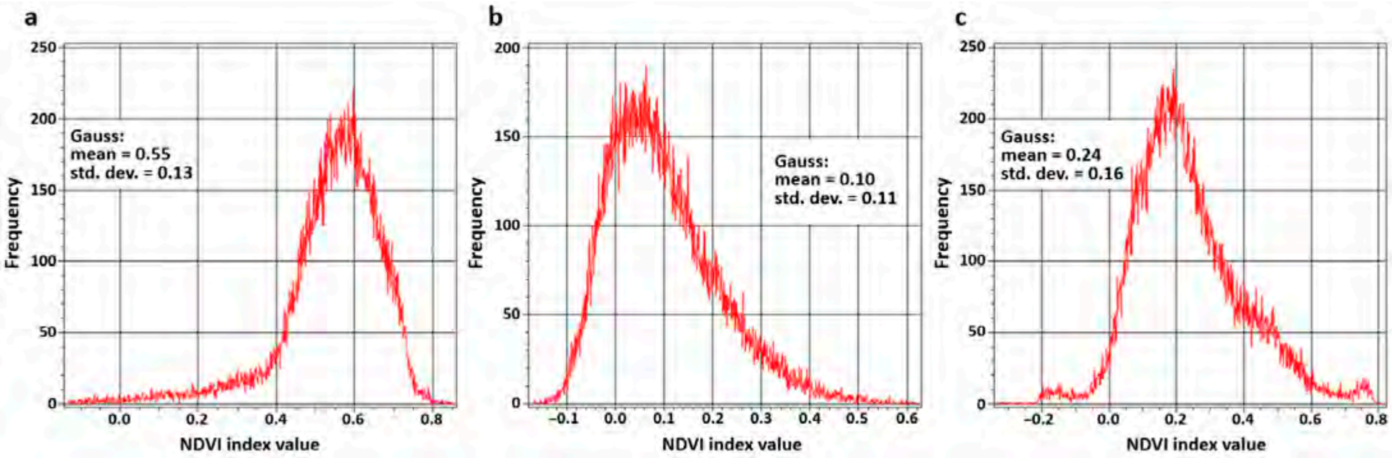

Figure 8. Histograms of the distribution of NDVI by area: (**a**) ornamental lawn with the intensive management; (**b**) city lawn with the common management; (**c**) permaculture lawn with the extensive management.

The vegetation in variant b (city lawn) exhibited the worst conditions. Most lawn species respond to unfavorable conditions (drought and high temperatures) during summer dormancy. A higher proportion of species tolerating drought point to more intense evaporation. Vegetation limitations allow plant species to survive adverse summer periods. City lawns do not require external inputs but lose their aesthetic value in some seasons.

NDVI analysis also showed that the highest heterogeneity in vegetation conditions was in variant c (permaculture land). The heterogeneity in vegetation conditions is due to high species diversity and the presence of dead biomass. The low vegetation condition was found at sites with dead biomass left in place. New biomass grows at sites with good vegetation conditions. Species composition with a higher proportion of wetland species indicates conditions with limited water evaporation. The management applied to permaculture lawns is reflected in the high heterogeneity of conditions and is close to natural grassland communities.

3.3. Plant Species Diversity in Grasslands

The values of plant taxa cover recorded during monitoring were first processed using DCA analysis. The calculated gradient length was 3.25. Based on this calculation, the CCA was used for further processing. CCA defines the spatial arrangement of individual plant species and the monitored lawn variants. The results of the analysis were graphically expressed using an ordination diagram (Figure 9).

The results of the CCA analysis which was used to assess the degree of coverage of individual plant taxa were significant at a level of $\alpha = 0.001$ for all canonical axes. Based on the CCA analysis, the found plant taxa can be classified into six groups (Table 1).

The first group (O) consists of species that prevailingly occur as part of the vegetation of ornamental lawns; that is, either poor competitors or those that are of annual character and gain ground only in low turfgrass. The second group of species (O/C) is represented by species occurring predominantly in ornamental and city lawns; that is, species less assertive against tall plant species and species that cope with regular cutting and removal of biomass. Plant species in the third group (C) tolerate regular cutting and do well under the lower competitive pressure of other species. Such species occurred predominantly in city lawn variants. The fourth group of plant species (C/P) was recorded particularly in city and permaculture lawn variants. These species were tolerant of regular cutting but was also capable of winning ground in competition with stronger species. The fifth group of plant species (P) dominated the permaculture lawns. These species were tolerant to extensive turfgrass management and were strong competitors. The sixth group of plant species (P/O) was recorded in ornamental and permaculture lawns. These species were tolerant to extreme variants and able to adapt to diverse environments. Different types of lawns under different management practices create different conditions that show a conspicuous change in the species spectrum of lawn vegetation. The consequences of human civilization activities have led to the development of a new plant community that changes and adapts to these activities [64–69].

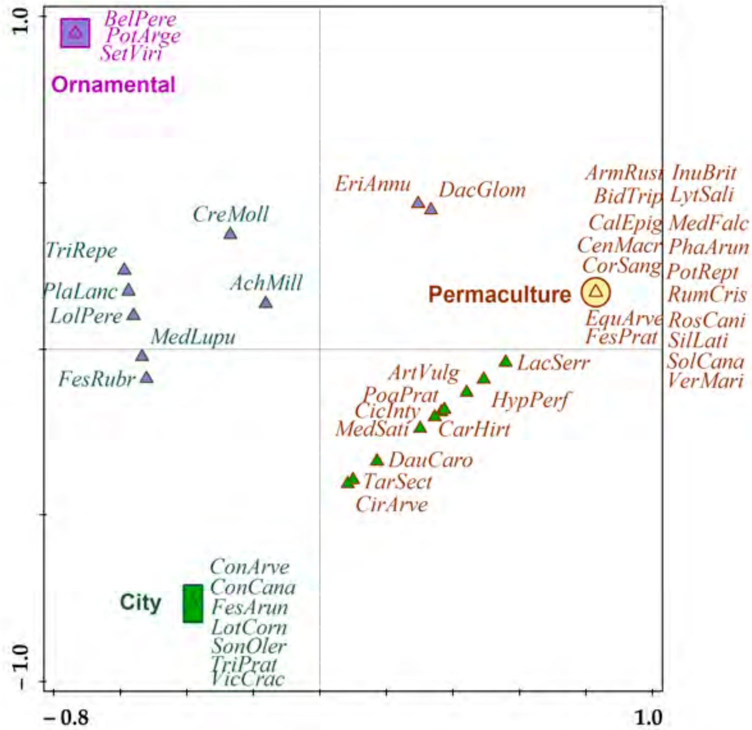

Figure 9. Relationships between the identified plant taxa and monitored lawn types (results of CCA analysis; F-ratio = 4.4; *p*-value = 0.001). Species Group O is indicated by purple font color and purple dots, Species Group O/C is indicated by green font color and purple dots, Species Group C is indicated by green font color and green dots, Species Group C/P is indicated by brown font color and green dots, Species Group P is indicated by brown font color and light yellow dots, Species Group P/O is indicated by brown font color and purple dots.

Increasingly, more studies indicate how aesthetics and ecosystem values influence landscape management and public policy, especially in urban ecosystems [70,71]. Lawns are close to everyday human habitats and are thus one of the most affected by human design. Intensive management is indispensable when the aim is to achieve a uniform and idealized lawn [62]. However, considering the significance of these green areas to city residents, it is necessary to find measures that may reconcile the presence of human societies with biodiversity management. According to Tabassum [4], cities are significant repositories of biodiversity; therefore, it is imperative to create resilient urban green spaces in the face of climate and environmental change.

4. Conclusions

The conclusions drawn from this study highlight the dynamic response of urban grass vegetation to various anthropogenic management practices. This reaction manifests as altered plant species composition, leading to shifts in the function and perception of urban grass areas. The trends observed in our study can be regarded as being universally applicable.

Our results highlight the significant influence of human decisions and activities on the species composition of urban lawns. First, we found that management intensity directly affects species richness, with intensive management resulting in lower plant diversity compared to less intensive approaches. Second, nature-based management decreases the representation of intentionally sown plant species, facilitating the proliferation of undesired species that can alter the aesthetic appeal of lawns and potentially spread in the urban environment.

Third, intensive management practices exacerbate evaporation and surface drying, favoring drought-resistant species over moisture-loving ones. This shift in favorability towards certain plant types, such as grasses and drought-resistant species, comes at the expense of legumes and other high-growth plants. Notably, our analysis of permaculture lawns revealed high vegetation heterogeneity, suggesting differences in water regimes and potential reductions in evapotranspiration owing to the presence of dead biomass.

Furthermore, permaculture lawns managed with a nature-based approach exhibit the highest species diversity, including undesired species, surpassing the levels reported in the scientific literature. These undesired species, including neophytes and invasive species, underscore the complexity of managing urban grassy areas.

Given the pivotal role of lawns in urban ecosystems and their impact on biodiversity, achieving a balance between aesthetic appeal and ecological value is crucial. Our findings emphasize the urgency of developing resilient urban green spaces capable of adapting to climate and environmental changes while safeguarding biodiversity. Integrating nature-based solutions, such as permaculture lawns, offers sustainable alternatives for lawn management, and contributes to urban biodiversity conservation. Future research could delve into understanding human perceptions and preferences in shaping lawn management decisions and their consequent impact on biodiversity, providing valuable insights for sustainable urban landscape management.

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