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The Effect of Visitors on the Properties of Vegetation of Calcareous Grasslands in the Context of Width and Distances from Tourist Trails

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Abstract: Over the last decades, valuable natural areas considered as zones of silence and rest have been increasingly struggling with the problem of mass tourism. In this study, an investigation of the effect of visitors on the properties of vegetation of calcareous grasslands in the context of width and distances from tourist trails is performed. The study was conducted in seven localities in Cracow (southern Poland) involving calcareous grasslands impacted by tourist trails. The results show that the lower height of plants, the greater number of species and the greater percentage of plant cover damaged by trampling in plots located close to the edge of tourist trails, as well as lower total plant cover and greater mean cover-abundance degree per species along narrow pathways. The dominance of meadow and grassland species, as well as the prevalence of native species, suggests that the composition of the examined vegetation has not been drastically changed. In the majority of the study plots, the dominance of hemicryptophytes and chamaephytes, inconsiderable share of phanerophytes and therophytes, as well as the low share of geophytes, were observed. The infrequent occurrence of species presenting *Bidens* dispersal type along narrow pathways, as well as in plots located close to the edge of tourist trails, suggests low external transport of epizoochorous seeds by passing people, while the prevalence of species presenting *Cornus* type in plots located away from the edge of tourist trails might be the effect of dung deposition by animals.

Keywords: life form; overtourism; dispersal mode; semi-natural habitats; trampling; vascular plants

1. Introduction

The phenomenon of overtourism, which is understood as the opposite of sustainable tourism, has been known and described so far mainly in the urban areas (e.g., [1–4]). However, it is also beginning to appear in regions considered as zones of silence and rest [5–7]. According to numerous authors [8–16], valuable natural areas are increasingly struggling with the problem of mass tourism. The negative consequences of the excessive tourist traffic represented, among others, by excessive water intake and sewage production, waste generation, noise, increased probability of fire initiation, synanthropisation of flora and fauna, scaring away of animals, as well as changes in the structure of biocoenoses were repeatedly noted in protected areas. Another consequence of excessive tourist traffic is trampling, which leads to the creation of informal trails. The trampling might contribute to changes in vegetation through mechanical damage of plants and species loss [17,18], as well as the influence on seed germination, seedling establishment, growth functions after establishment, vigour and biomass production, as well as flowering and fruiting [19]. Moreover, the trampling might improve the dissemination of diaspores over long distances [20,21], particularly the dispersal of non-native taxa [22].

To date, investigations of the impact of intensity, frequency and season of human trampling on vegetation properties and traits of selected plants have been the main focus of numerous experimental research on sustainable use of natural habitats for recreation in many different habitat types around the world e.g., [23–30]. In the last decades, an increase in the number ofstudies focusing on the impact of trampling and tourist dispersion on the surrounding environment has been observed. Generally, such studies have been carried out in areas protected by law or in hot spots of biodiversity e.g., [29,31–34], and mostly they concentrated on the causes and consequences of tourist dispersion around the trails. At the same time, investigations of the impact of pathway dimensions and/or distance from pathway edge on adjacent vegetation traits e.g., species richness and diversity, height of plants and proportions of species representing different life forms were carried out in forests [35–40] and scrublands [41], as well as in open habitats such as mires and feldmark vegetation [42], heaths [38,43], meadows [38] and dunes [44]. Despite the growing interest in the aforementioned issue, the current state of knowledge is still insufficient, especially in the case of semi-natural calcareous grasslands (*Festuco-Brometea*), which are nowadays considered as one of the most endangered plant communities in Europe, covered by the Natura 2000 network [45].

In this study, we focused on the impact of width of tourist pathways and distance from pathways on (i) plant cover features i.e., height of the tallest plant shoot, species abundance, damaged plant cover percentage by trampling, total plant cover percentage, cover-abundance degree of particular species, and (ii) occurrence of species presenting different habitat affiliations, dispersal modes, life forms and origin (native or alien status in the flora). We aimed to test the hypotheses that (i) the height of plants is lower in plots located near pathways than that in plots located away from pathways, (ii) the percentage of plant cover damaged by trampling is higher in plots located near pathways than that in plots located away from pathways, (iii) the percentage of plant cover damaged by trampling is higher along narrow pathways than that along wide pathways, (iv) the number of species is higher in plots located near pathways than that in plots located away from pathways, and (v) the spectra of habitat affiliation, life form, dispersal mode, and origin of species occurring in plant cover vary significantly among plots situated along pathways with different width, as well as among plots located in diverse distance from tourist trails.

2. Materials and Methods

2.1. Location of the Study Sites

Seven study sites located in the southwest part of Cracow (southern Poland) have been selected: Bogucianka, Fort Bodzów, Górka Pychowicka, Tyniec, Uroczysko Kowadza, Uroczysko Wielkanoc and Zakrzówek. All the study sites are situated on limestone hills within the Bielańsko-Tyniecki Landscape Park (BTPK), a part of the Jurassic Landscape Parks Complex, which constitutes a valuable area protected by law due to its excellent natural, cultural and historical properties.

The vegetation is mainly represented by beech and hornbeam forests from the *Querco-Fagetea* class and by calcareous grasslands from the *Festuco-Brometea* class. In calcareous grasslands the following vascular plants are commonly found: *Achillea millefolium* L., *Coronilla varia* L., *Dianthus carthusianorum* L., *Echium vulgare* L., *Euphorbia cyparissias* L., *Fragaria viridis* Weston, *Plantago media* L., *Plantago lanceolata* L., *Potentilla arenaria* Borkh, *Thymus austriacus* Bernh. and *T. glabrescens* Willd. In most of the study sites, the plants did not create the continuous cover and gaps in the turf were observed. The study sites are influenced by similar climatic conditions. According to Matuszko and Piotrowicz [46], the mean annual air temperature achieves 8.6 °C, while the average annual sum of actual sunshine duration amounts to 1539.3 h. The average annual relative humidity amounts to 78%, the highest average monthly values during the year occur in autumn and winter, during spring the humidity drops quickly and achieves the minimum in April. The average annual number of dry days reaches 17.8 and they occur mainly in the warm half-year as single days or two-day periods. The atmospheric precipitation achieves ca. 690 mm and the peak of precipitations occurs in July.

Due to their location within the border of Cracow and easy access by public transport, all the study sites are exposed to the recreational activities of citizens and tourists. "The Cracow City Forest Trail" is a marked walking and cycling route leading, among others, through Bogucianka, Górka Pychowicka, Uroczysko Kowadza and Uroczysko Wielkanoc. Moreover, Perzanowska [47] pointed out that Fort Bodzów and Uroczysko Kowadza are perfect places suitable for outdoor recreation (Table 1).

Table 1. The Characteristics of Study Sites.

Study Site	Tourist/Recreation Infrastructure		Width of Pathway (cm)		Coordinates and Elevation of Pathway	
	within the Study Area	**in the Vicinity of the Study Area**	**Narrow**	**Wide**	**Narrow**	**Wide**
Bogucianka	Vantage point, information board	Football stadium	46	150	50°00.555′ N/19°48.909′; 244 m a.s.l. [1]	50°00.675′ N/19°48.914′; 251 m a.s.l.
Fort Bodzów	Vantage points, benches, bins, shelters, motor sports paths	Rope park	50	240	50°02.031′ N/19°52.576′; 250 m a.s.l.	50°01.978′ N/19°51.891′; 238 m a.s.l.
Górka Pychowicka	Vantage points, benches, bins, shelters, fire circles, information board	Motor sports paths, bike paths	50	180	50°01.823′ N/19°52.996′; 225 m a.s.l.	50°01.850′ N/19°52.996′; 225 m a.s.l.
Tyniec	Vantage point, motor sports paths,	-	36	335	50°00.301′ N/19°49.095′; 256 m a.s.l.	50°00.313′ N/19°49.125′; 254 m a.s.l.
Uroczysko Kowadza	Vantage point, benches	-	35	131	50°00.884′ N/19°46.638′; 268 m a.s.l.	50°00.880′ N/19°49.648′; 266 m a.s.l.
UroczyskoWielkanoc	Vantage point, benches, bins, information board	-	30	115	50°00.959′ N/19°48.850′; 264 m a.s.l.	50°00.938′ N/19°48.840′; 260 m a.s.l.
Zakrzówek	Vantage points, climbing walls, information board	Lagoon created inthe lime quarry, bike paths	33	120	50°02.365′ N/19°54.987′; 203 m a.s.l.	50°02.415′ N/19°54.752′; 213 m a.s.l.

[1] above sea level.

2.2. The Overview of the Study Design and Characteristics of the Study Plots

In each location, two visitor-created (informal) pathways were selected: a narrow one (up to 50 cm in width) and a wide one (at least 115 cm in width) based on the assumption that the width of the path is positively correlated with the intensity of tourist traffic (Table 1). The narrow trail can be used by one person, while the wide trail allows at least two people to pass in one direction or to pass each other. The pairs of 1 × 1 m research plots were established along each pathway. The pairs were systematically distributed every 2 m (alternately on both sides of the pathway). Each pair consisted of a plot labelled CL situated close to the edge of the pathway at a distance of 10 cm, and a plot labelled FU located much further at a distance of 150 cm from the plot CL (Figure 1). The distance from the edge of the trail was chosen arbitrarily on the basis of the behavior of tourists. Plots CL were established in places often trampled by tourists to avoid the trail after rainfalls, when the surface is muddy and slippery. Plots FU were established at a greater distance from the trail where descending from the pathway is due to willingness of taking photographs, curiosity, repose, or other causes.

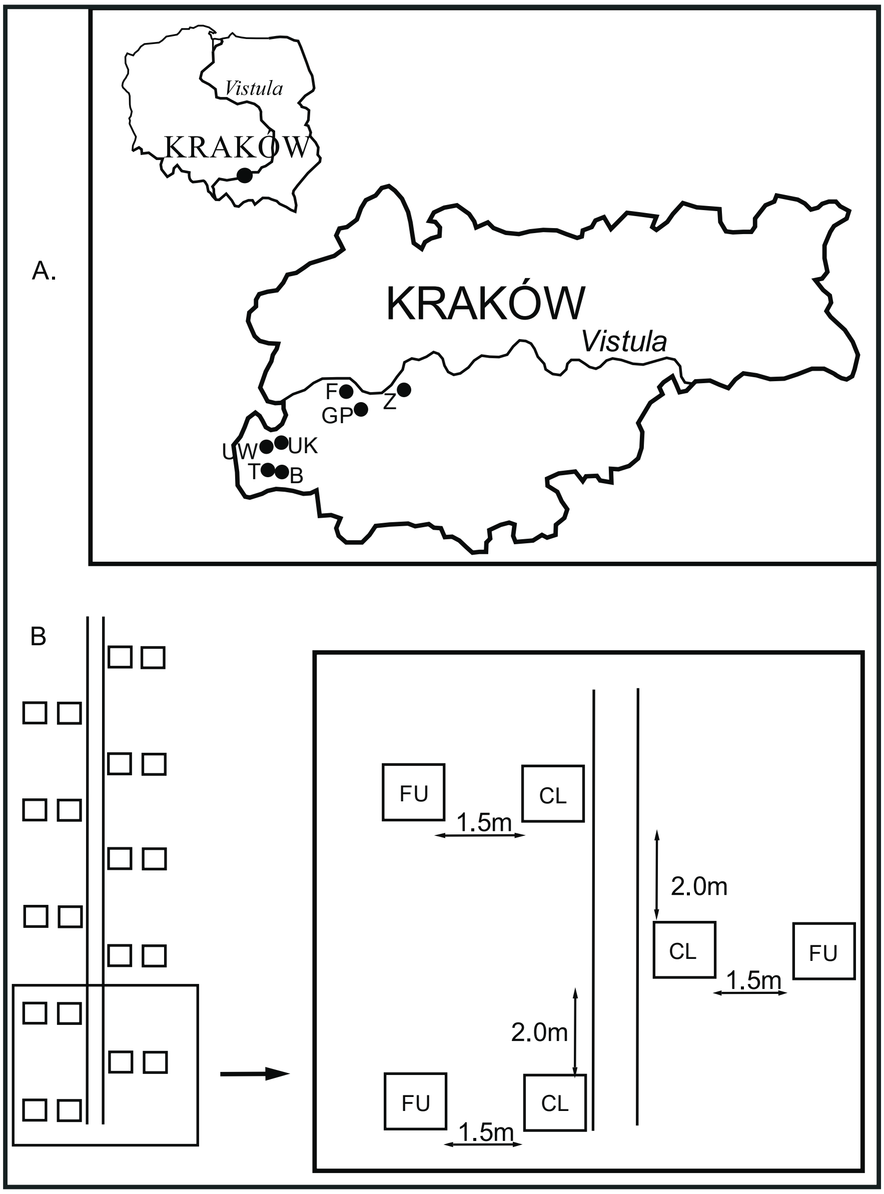

Figure 1. The localisation of the study sites (**A**) and the plot sampling design (**B**). Abbreviations of study sites:B—Bogucianka, FB – Fort Bodzów, GP—Górka Pychowicka, T—Tyniec, UK—Uroczysko Kowadza, UW—Uroczysko Wielkanoc; Z—Zakrzówek; abbreviations of plots: CL—located close to the edge of tourist trail, FU—located away from the tourist trail.

The measurements of the abiotic habitat conditions, which were tested in particular plots by using the handheld device BIOWIN, evidenced that light intensity ranged from 740.0 Lx to 2000.0 Lx, soil moisture ranged from 1.0 to 6.7, whereas soil pH was from 7.1 to 7.8 (Table 2). The ANOVA analysis of main effects evidenced that the values of light intensity were similar in both the narrow and wide patches, the soil moisture was significantly greater in the plots CL than in the plots FU (F = 9.85, $p < 0.01$), and the soil reaction achieved greater values in the plots located along the wide pathways than in the narrow ones (F = 10.30, $p < 0.01$).

Table 2. The mean light intensity (Lx) (± SD), soil moisture (± SD) and soil pH (± SD) noted in closer (CL) and further (FU) plots located along the narrow (width ≤ 50 cm) and wide (width ≥ 115 cm) pathways situated within the investigated study site.

			Study Sites						
			Górka Pychowicka	**Fort Bodzów**	**Bogucianka**	**Uroczysko Wielkanoc**	**Zakrzówek**	**Uroczysko Kowadza**	**Tyniec**
Light intensity	Narrow	CL	2000 (±0.0)	1150 (±400.6)	2000 (±0.0)	2000 (±0.0)	1720 (±489.4)	2000 (±0.0)	740 (±508.1)
		FU	2000 (±0.0)	1020 (±498.4)	2000 (±0.0)	2000 (±0.0)	1690 (±499.8)	2000 (±0.0)	690 (±499.8)
	Wide	CL	1820 (±423.73)	1850 (±337.4)	2000 (±0.0)	1950 (±158.1)	1460 (±614.9)	2000 (±0.0)	1090 (±502.1)
		FU	1680 (±474.6)	1680 (±518.1)	2000 (±0.0)	1800 (±421.6)	1270 (±551.8)	1900 (±316.2)	830 (±447.3)
Soil moisture	Narrow	CL	2.5 (±0.6)	1 (±0.0)	1.3 (±0.3)	6.7 (±2.1)	4 (±1.0)	3.7 (±2.3)	4.5 (±2.2)
		FU	1.7 (±0.8)	1 (±0.0)	1.2 (±0.3)	4.3 (±2.3)	3.6 (±1.1)	3.5 (±1.5)	4.6 (±2.2)
	Wide	CL	1 (±0.0)	1 (±0.0)	1.2 (±0.2)	5.8 (±1.9)	4.9 (±1.6)	3.7 (±1.8)	5.5 (±1.8)
		FU	1 (±0.0)	1 (±0.0)	1.1 (±0.2)	5.4 (±1.8)	3.9 (±1.1)	3 (±0.7)	4.4 (±1.7)
Soil pH	Narrow	CL	7.4 (±0.2)	7.5 (±0.0)	7.5 (±0.0)	7.3 (±0.4)	7.3 (±0.3)	7.4 (±0.2)	7.2 (±0.3)
		FU	7.5 (±0.2)	7.5 (±0.0)	7.5 (±0.0)	7.4 (±0.2)	7.4 (±0.2)	7.2 (±0.3)	7.1 (±0.2)
	Wide	CL	7.8 (±0.3)	7.5 (±0.2)	7.5 (±0.0)	7.3 (±0.3)	7.4 (±0.2)	7.2 (±0.3)	7.3 (±0.3)
		FU	7.7 (±0.3)	7.5 (±0.0)	7.5 (±0.0)	7.5 (±0.2)	7.4 (±0.3)	7.4 (±0.2)	7.4 (±0.2)

2.3. The Field Trial

Field study was conducted in July 2019. The height of the tallest plant shoot from the ground level to the top of the stem was measured in each study plot using a folder tape. Within each plot, the total percentage of plant cover and the percentage of plant cover damaged by trampling were visually estimated using a cover-abundance scale with an interval of 5%. Furthermore, the vascular plant species growing in the herbaceous layer within each plot were inventoried. The seedlings and saplings were removed and determined according to Csapodý [48] and Muller [49]. The degree of cover-abundance of each species was visually estimated according to a scale of Braun-Blanquet [50]. The explication of particular points of scale is as follows:

- -"+"- species covers less than 1% of the studied area,
- -"1"- species covers 1–5% of the studied area,
- -"2"- species covers 6–25% of the studied area,
- -"3"- species covers 26–50% of the studied area,
- -"4"- species covers 51–75% of the studied area,
- -"5"- species covers 76–100% of the studied area.

2.4. The Species Groups

To assess the species response to tourist activities, we selected four traits (i.e., habitat affiliation, life form, native or alien status in the flora and mode of seed dispersal) that were "ecologically meaningful" in accordance with the ability to persist in the stressful conditions caused by man (trampling) and accompanying animals (ground browning, wallowing). The traits of particular vascular plant species evidenced in the plots are presented in Table A1.

Habitat affiliation was assigned according to Matuszkiewicz [51]. The species were assigned to (i) grassland species (occurring in calcareous grasslands from the *Festuco-Brometea* class, thermophilic fringe communities representing the *Rhamno-Prunetea* and *Trifolio-Geranietea sanguinei* classes, grasslands and heaths from the *Nardo-Callunetea* class, pioneering communities on mobile or poorly fixed screes *Thlaspietea rotundifolii*, rocky grasslands *Seslerio-Festucion duriusculae, calamine* grasslands *Violetea calaminariae*, sandy grasslands *Koelerio glaucae-Corynephoretea canescentis*), (ii) meadow species (occurring in communities representing the *Molinio-Arrhenatheretea* class), (iii) forest species (occurring in communities from the *Querco-Fagetea* class), and (iv) ruderal species (occurring in ruderal communities of perennial plants from the *Artemisietea vulgaris* class, nitrophilous communities of logging, trampled and ruderal areas from the *Epilobietea angustifolii* class, semi-ruderal xerothermic pioneer communities from the *Agropyretea intermedio-repentis* class, communities of arable fields *Stellarietea mediae*, segetal weeds community *Papaveretum argemones*, and annual plant and biennial ruderal plant communities *Sisymbrietalia*).

The life form of species proposed by Raunkiaer [52] was assigned according to the database "Ecological Flora of the British Isles" [53]. The following life forms were distinguished: phanerophytes, chamaephytes, hemicryptophytes, geophytes and therophytes. In the case of missing data the publication of Ellenberg et al. [54] was included.

The dispersal mode of species was assigned based on the database "Pladias" [55]. The following dispersal types were distinguished: *Allium* (mainly autochory, as well as anemochory, endozoochory, epizoochory), *Bidens* (mainly autochory and epizoochory, as well as endozoochory), *Cornus* (autochory and endozoochory), *Epilobium* (mainly anemochory and autochory, as well as endozoochory, epizoochory). The detailed description of dispersal modes can be found in the publication of Sádlo et al. [56].

The origin of species was assigned based on the database "Alien species in Poland" [57]. The alien species was understood as a species or lower taxon, introduced outside its natural past or present range that might survive and subsequently reproduce. The native species to a given area is a species that has been observed in the form of a naturally occurring and self-sustaining population from historical times.

Data concerning habitat affiliation and life form of *Erigeron acris* ssp. *serotinus* (Weihe) Greuter, which are lacking in the aforementioned sources, were taken from the publication of Pliszko [58]. Plants identified solely to the rank of a genus (e.g., *Carex* sp.) were excluded from the analyses. Moreover, the cultivated plants such as *Cerasus vulgaris* Mill. and *Malus domestica* Borkh. were excluded from the analysis of habitat affiliation.

2.5. The Data Analysis

The mean height of the tallest plant shoot, number of species, percentage of aboveground biomass damage by trampling, total plant cover percentage, as well as degree of cover-abundance of a particular species (±SD) were calculated in the research plots CL and FU, as well as in the plots located along narrow and wide pathways in each study site.

The normal distribution of the untransformed data was tested using the Kołmogorov-Smirnov test, whereas the homogeneity of variance was verified using the Levene test at the significance level of $p < 0.05$. The ANOVA analysis of main effects followed by the post-hoc Tukey HSD test was applied to check the statistical significance of the effect of pathway width and plot distance from the pathway on (i) the height of the tallest plant shoot, (ii) the number of species, (iii) total plant cover percentage, (iv) percentage of plant cover damaged by trampling, as well as (v) degree of cover-abundance of a particular species within the study plots. The aforementioned analyses were computed using a STATISTICA software (version 13). The chi-square test with Yates correction for continuity was applied to check whether there were significant differences among the plots located along the narrow and wide pathways, as well as in the plots situated at a diverse distance from the border of trails in cover-abundance degree of species showing various habitat affiliation, life form, seed dispersal mode and species origin. The chi-square test was conducted using the interactive calculation tool [59].

3. Results

3.1. The Plant Cover and Richness

The mean height of the tallest plant ranged from 66.2 cm to 123.7 cm (Figure A1) and it was similar in the plots situated along the narrow and wide pathways (F = 0.08, $p = 0.77$), at the same time it was significantly greater in the plots FU than in the plots CL (F = 31.64, $p < 0.001$). The mean number of species per plot amounted from 11.1 to 17.6 (Figure A1) and it did not differ in the plots situated along the narrow and wide pathways (F = 0.17, $p = 0.67$) but it was greater in the plots CL than FU (F = 5.39, $p \leq 0.05$).The mean percentage of total plant cover achieved from 43.0 to 85.0 (Figure A2). The statistical analysis evidenced, that the values noted in the plots located along the narrow pathways were significantly lower than along the wide ones (F = 5.19, $p \leq 0.05$) and they were similar in the plots CL and FU (F = 0.22, $p = 0.63$). The mean percentage of plant cover damaged by trampling achieved from 0.0 to 82.5 (Figure A2). It was similar in plots located along narrow and wide pathways (F = 0.01, $p = 0.90$) and remarkably greater in the plots CL than in the plots FU (F = 145.93, $p < 0.001$). The mean cover-abundance degree of particular species per plot according to the Braun-Blanquet scale ranged from 0.1 to 0.7 (Figure A3). The values recorded along the narrow pathways were greater than along the wide ones (F = 12.00, $p < 0.001$), whereas values noted in the plots CL and FU were similar (F = 0.15, $p = 0.69$).

3.2. The Species Groups Characteristics

Along the narrow and wide pathways, meadow and grassland species prevailed over ruderal plants, while forest taxa occurred sporadically. The statistical analysis showed a lack of differences in most study areas (Figure 2). The similar spectra of habitat affiliations were observed in the plots CL and FU in the majority of the study sites. Only in one study area, in closer plots, was the considerable dominance of ruderal taxa evidenced (Figure 3). The statistical analysis proved significant differences in life form spectra among the narrow and wide pathways (Figure 4), as well as among the plots CL and FU (Figure 5) regardless of the dominance of hemicryptophytes and chamaephytes, slight presence of phanerophytes and therophytes, as well as the lowest cover-abundance degree of geophytes in the majority of the study areas. The cover-abundance degrees of species with particular dispersal mode occurring in plots situated along pathways with different width varied significantly (Figure 6). In the majority of plots situated along the narrow pathways, the lowest cover-abundance degree showed species with dispersal type *Bidens,* while taxa with *Allium, Cornus* or *Epilobium* dispersal type prevailed in at least one study site. In the plots located along the wide pathways, different patterns of dispersal mode spectra were noticed. The statistical analysis showed that also the cover-abundance degrees of species with particular dispersal mode occurring in the plots CL and FU differed significantly (Figure 7). In most plots CL, species with *Bidens* type occurred sporadically, whereas in plots FU species with type *Cornus* dominated in the majority of places. Despite the prevalence of native species over alien species, the statistical analysis showed significant differences among the narrow and wide pathways (Figure 8), as well as among the plots CL and FU (Figure 9).

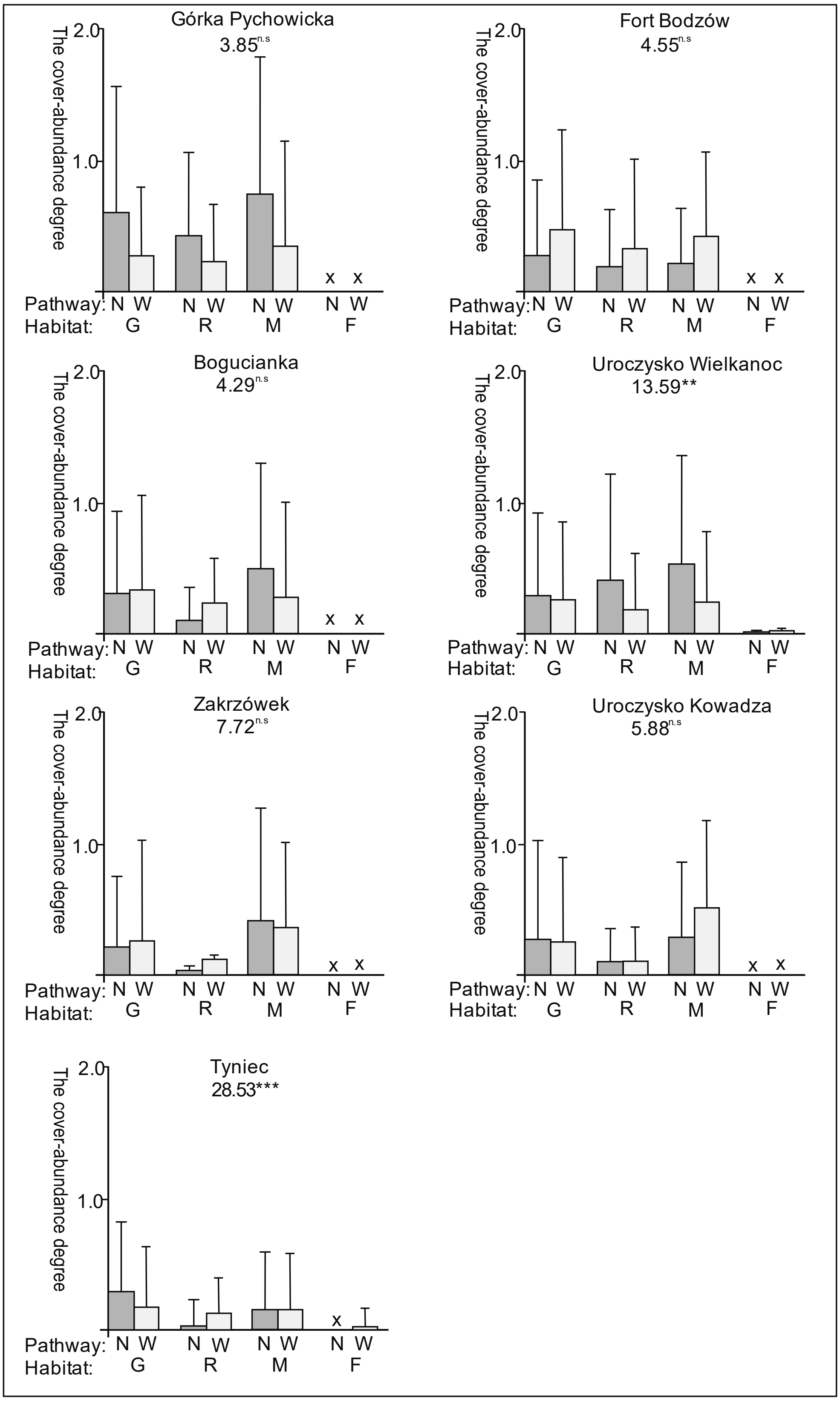

Figure 2. The mean cover-abundance degree of a species (± SD) affiliated to the forest (F), meadow (M), grassland (G), and ruderal habitats (R) per plot located along the narrow-N (width ≤ 50 cm) and wide-W (width ≥ 115 cm) pathways situated within the investigated study sites. The statistical significance level of χ^2 test (df = 3): ns – not significant, * $p \leq 0.05$, ** $p < 0.01$, *** $p < 0.001$.

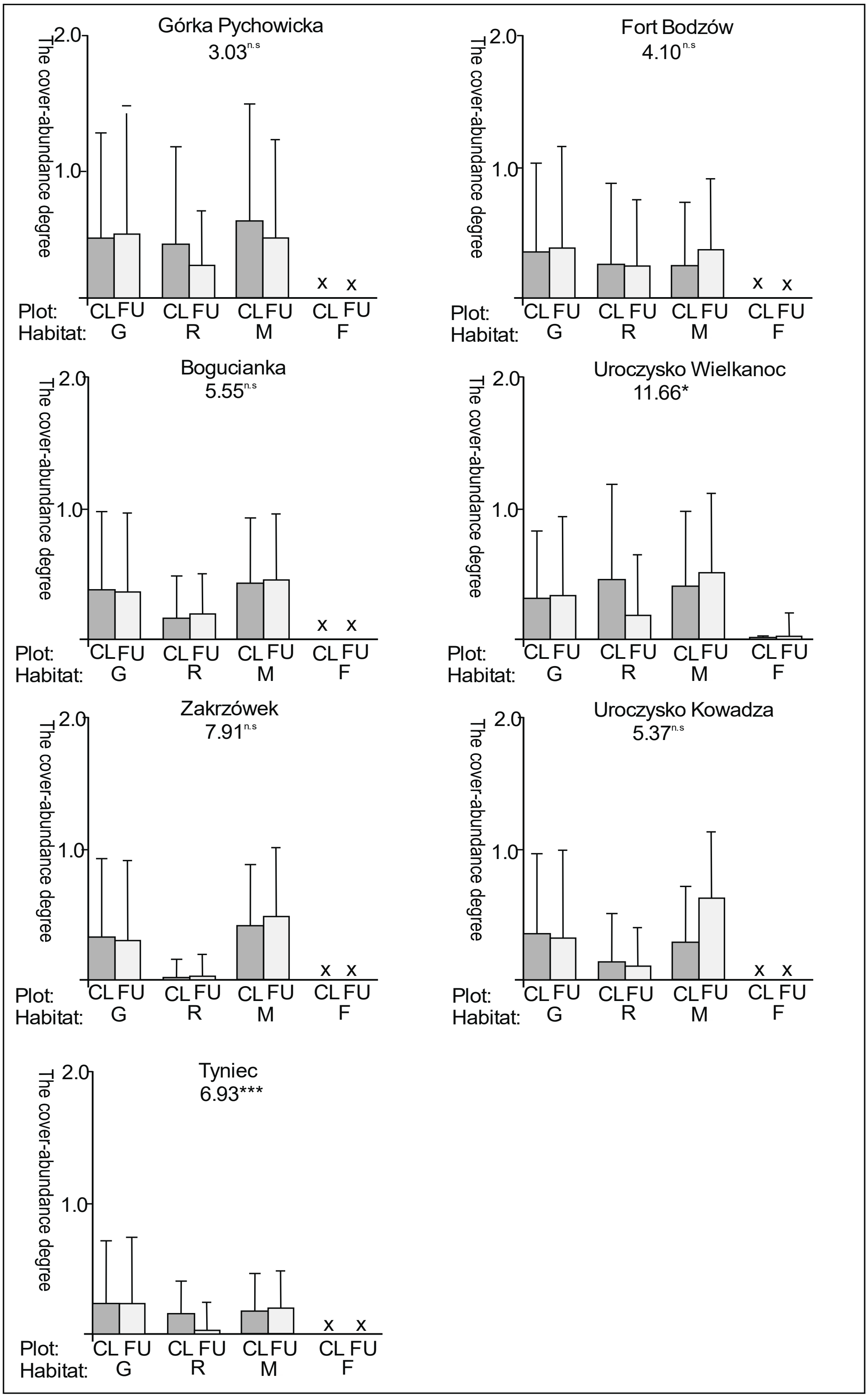

Figure 3. The mean cover-abundance degree of a species (± SD) affiliated to forest (F), meadow (M), grassland (G), and ruderal habitats (R) per closer (CL) and further (FU) plot within the investigated study sites. The statistical significance level of χ^2 test (df = 3) is given in Figure 2.

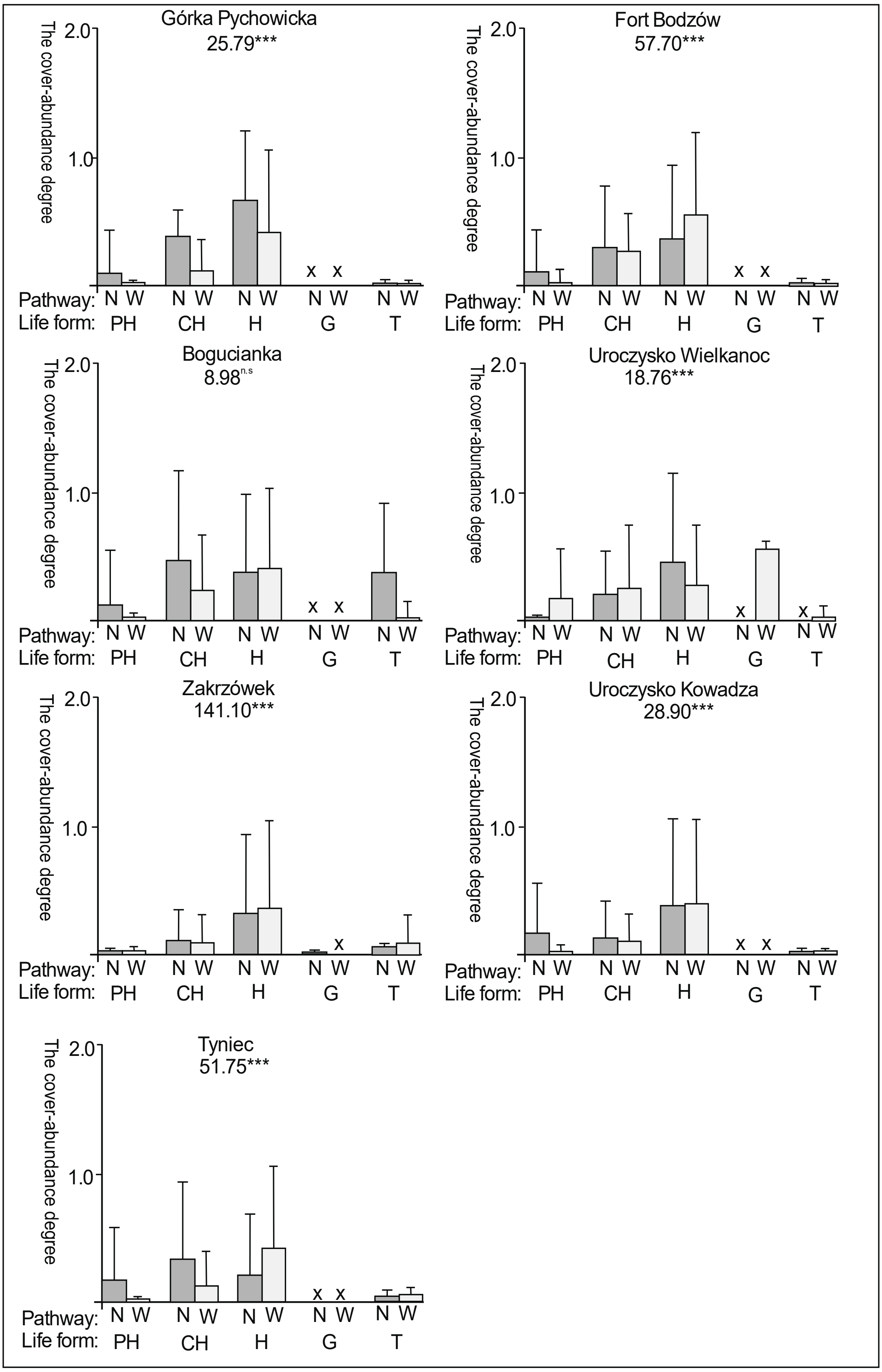

Figure 4. The mean cover-abundance degree of a species (± SD) representing phanerophytes (PH), chamaephytes (CH), hemicryptophytes (H), geophytes (G) and therophytes (T) per plot located along the narrow-N (width ≤ 50 cm) and wide-W (width ≥ 115 cm) pathways within the investigated study sites. The statistical significance level of χ^2 test (df = 4) is given in Figure 2.

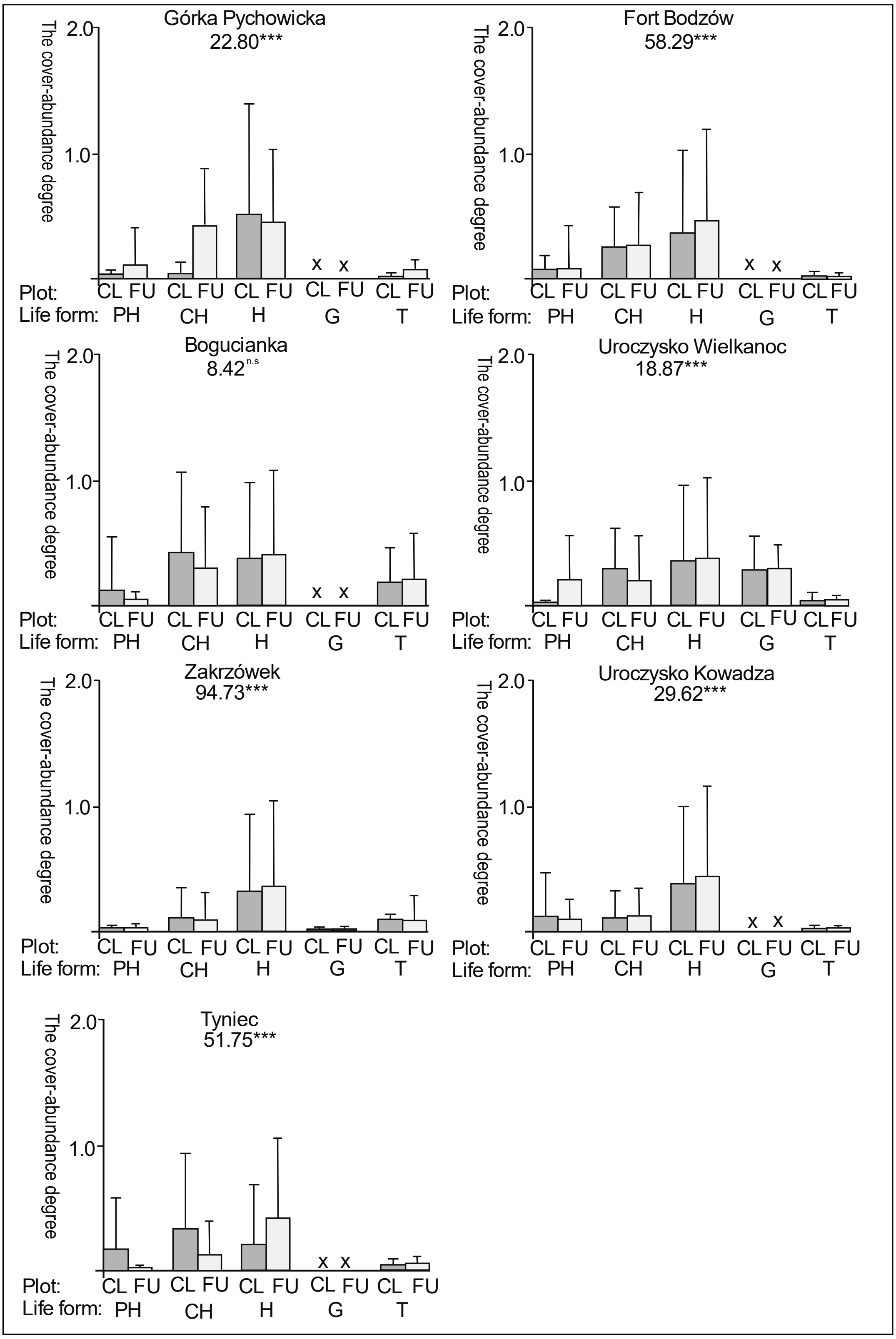

Figure 5. The mean cover-abundance degree of a species (± SD) representing phanerophytes (PH), chamaephytes (CH), hemicryptophytes (H), geophytes (G) and therophytes (T) per closer (CL) and further (FU) plot within the investigated study sites. The statistical significance level of χ^2 test (df = 4) is given in Figure 2.

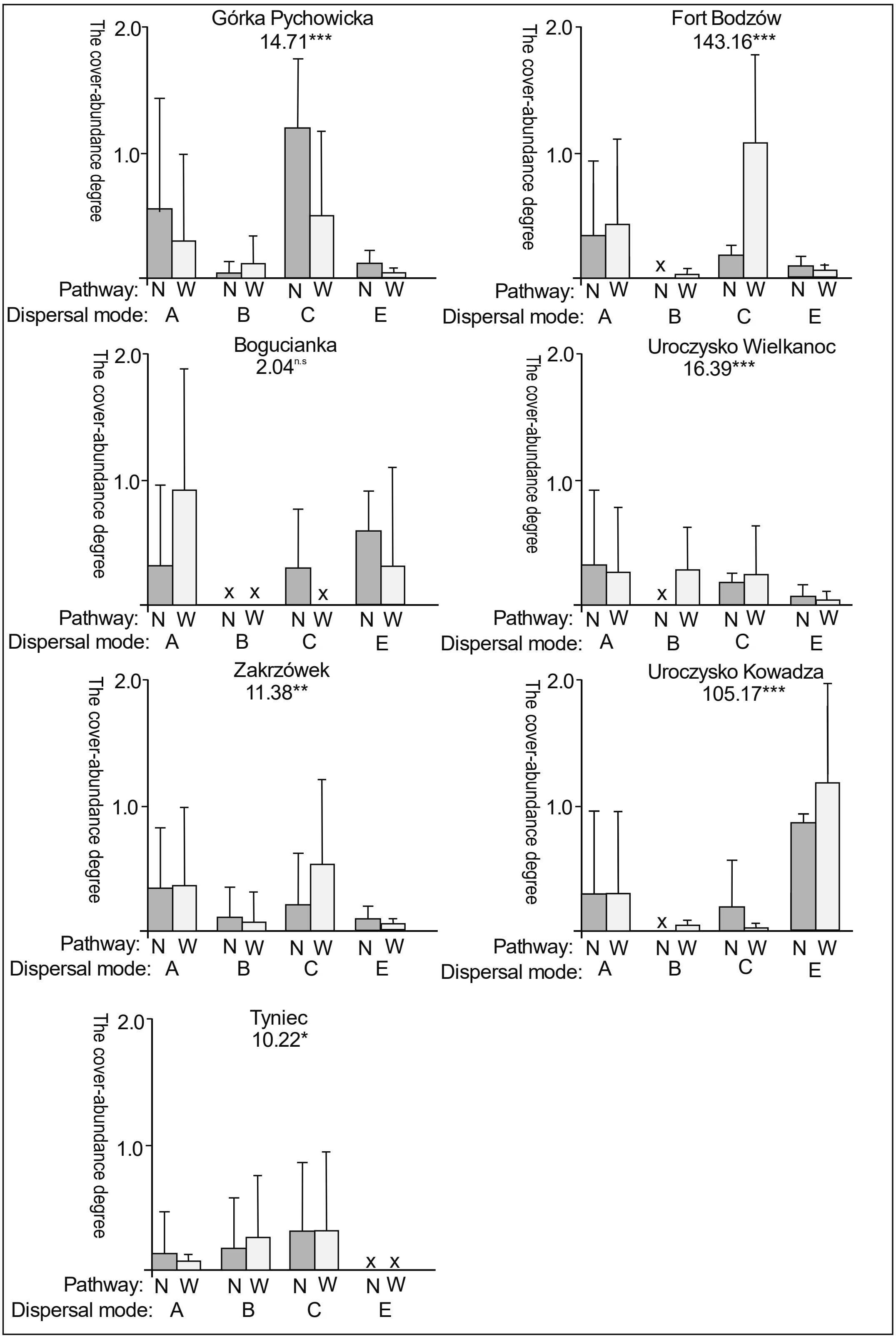

Figure 6. The mean presence of a species (± SD) representing dispersal mode *Allium* (A), *Bidens* (B), *Cornus* (C) and *Epilobium* (E) per plot located along narrow-N (width ≤ 50 cm) and wide-W (width ≥ 115 cm) pathways situated within the investigated study sites. The statistical significance level of χ^2 test (df = 3) is given in Figure 2.

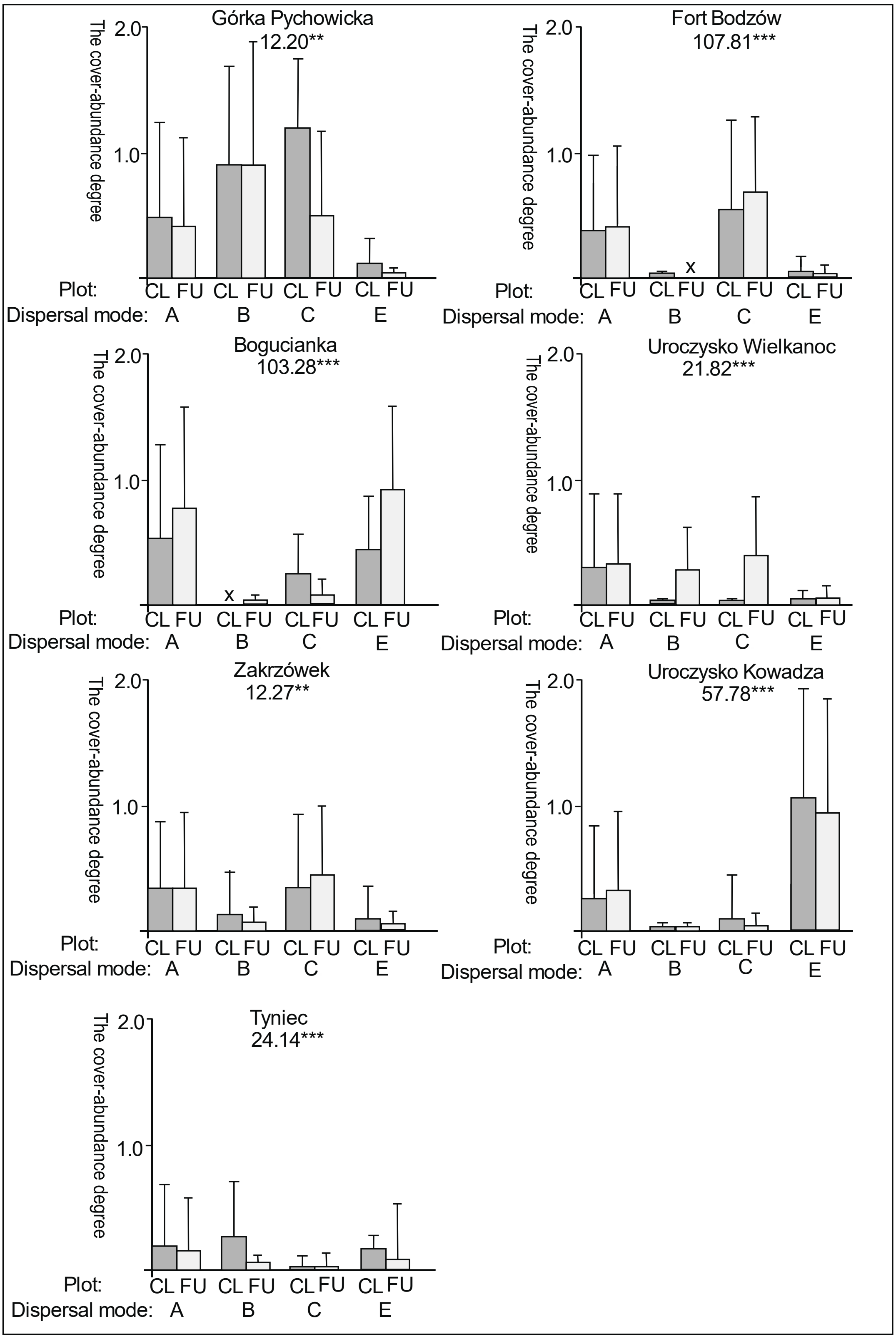

Figure 7. The mean presence of a species (±SD) representing dispersal mode *Allium* (A), *Bidens* (B), *Cornus* (C) and *Epilobium* (E) per closer (CL) and further (FU) plot within investigated study sites. The statistical significance level of χ^2 test (df = 3) is given in Figure 2.

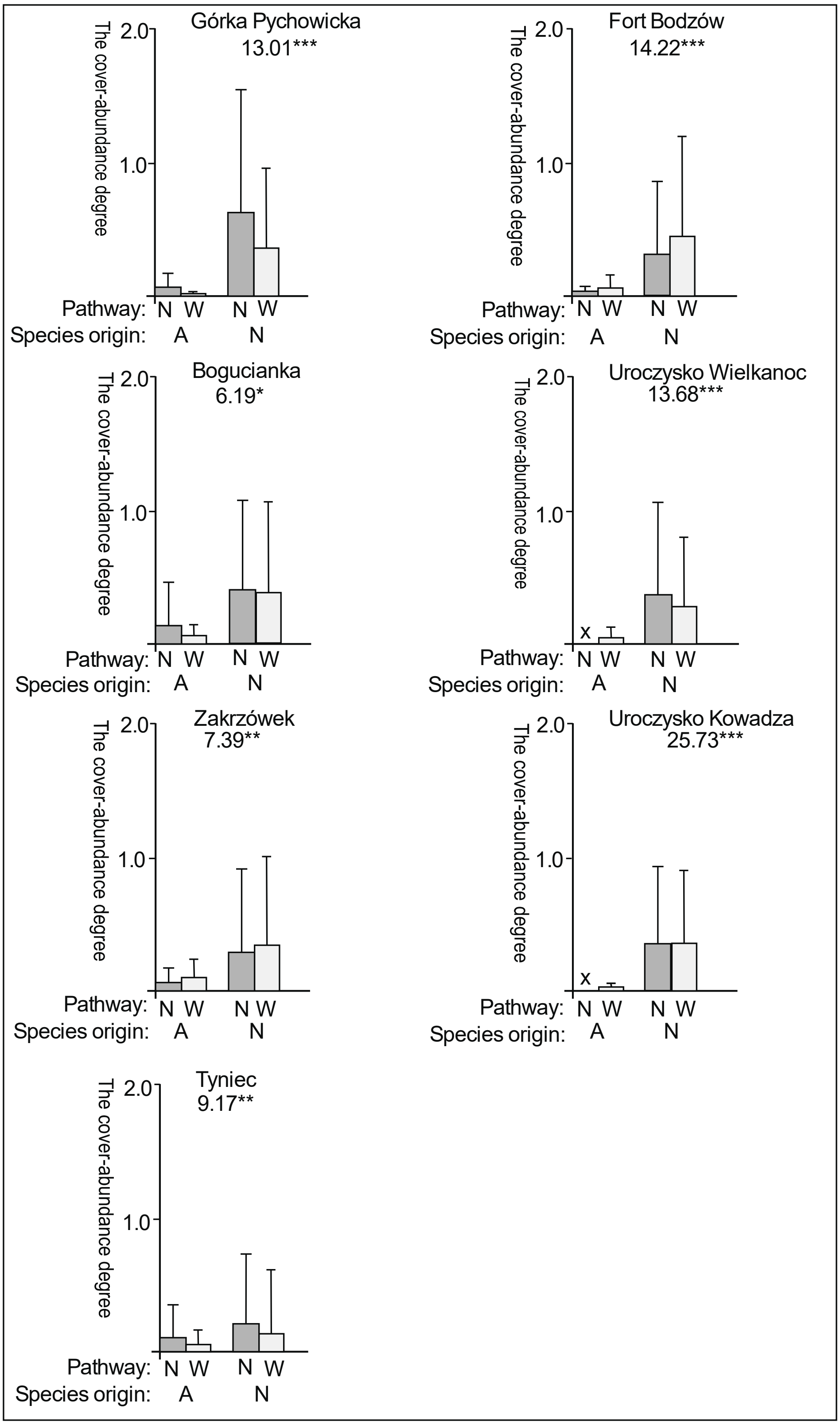

Figure 8. The mean cover-abundance degree of alien (A) and native (N) species (± SD) per plot located along the narrow-N (width ≤ 50 cm) and wide-W (width ≥ 115 cm) pathways within the investigated study sites. The statistical significance level of χ^2 test (df = 1) is given in Figure 2.

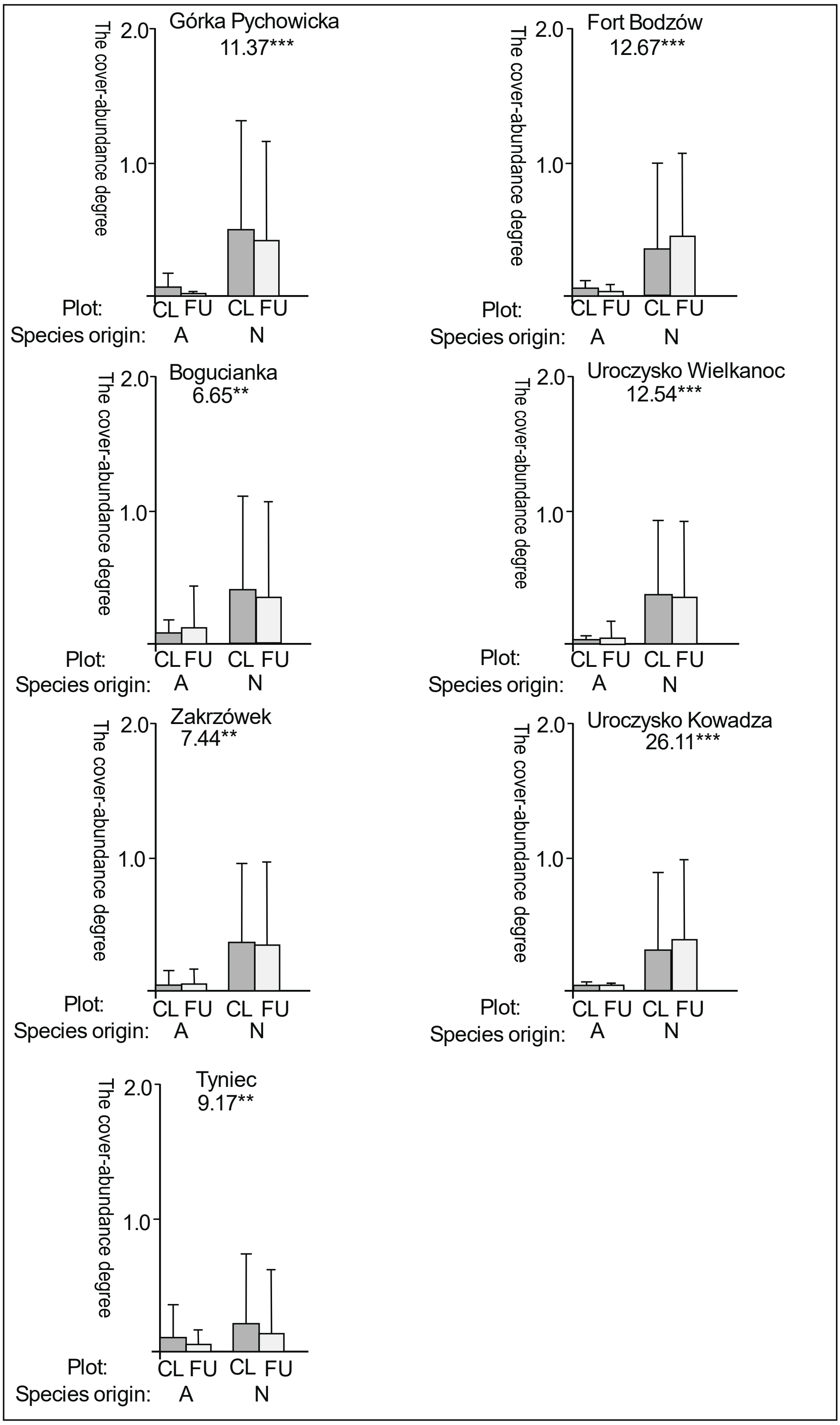

Figure 9. The mean cover-abundance degree of alien (A) and native (N) species (± SD) per closer (CL) and further (FU) plot within the investigated study sites. The statistical significance level of χ^2 test (df = 1) is given in Figure 2.

4. Discussion

4.1. The Plant Cover Characteristics

The performed observations evidenced that the values of height of the tallest plant shoots, species richness, as well as the percentage of plant cover damaged by trampling did not differ in the narrow and wide pathways. The height of the tallest plants achieves greater values in the distant plots than in the plots situated closely to the pathways, while species richness and percentage of plant cover damaged by trampling show an inversed trend. Therefore, our hypotheses that (i) the height of plants is lower in plots located near pathways than that in plots located away from pathways, (ii) the percentage of plant cover damaged by trampling is higher in plots located near pathways than that in plots located away from pathways, and (iv) the number of species is higher in plots located near pathways than that in plots located away from pathways can be fully accepted. At the same time, the hypothesis (iii) that the percentage of plant cover damaged by trampling is higher along narrow pathways than that along wide pathways must be rejected.

The lower height of the tallest plant in plots situated close to the tourist trails might be an effect of damage to plant tissue, especially shoot fractures by passers-by. Also, a much greater percentage of damaged plant cover by trampling in the close plots might be linked with the activity of visitors bypassing the pathways or descending from them due to the taking of photographs, curiosity, repose or other causes. Such tourist dispersion was frequently observed in trails by numerous authors e.g., [32,34].

The obtained results proving much greater species richness close to tourist trails correspond with the findings of Root-Bernstein and Svenning [60], while other investigators observed an inversed tendency [61]. A higher number of plant species near the tourist/recreation pathways within the calcareous grasslands can be explained by the fact that plant diaspores are easily transported on shoes, clothes and vehicles. Similarly, it was evidenced by Tikka et al. [62] that road verges serve as dispersal corridors for grassland species. It is also worth mentioning that some plants such as *Lolium perenne* L. and *Trifolium repens* L. tolerate trampling and often occur on roadside verges [23,63]. However, their abundance in the examined plots was rather low (except some plots with *L. perenne*). Moreover, tourist trails are often used for migration by wild animals (e.g., [64]), which may also promote the plant dispersal along the pathways.

The performed observations evidenced that the distance from the trails does not have an influence on total plant cover percentage, as well as the cover-abundance degree of a particular species per plot. The obtained results are not consistent with the studies of Jägerbrand and Alatalo [43], who noted that due to the decrease in understory cover, the abundance of litter, rock and soil increased with the proximity to the trail in alpine heath. The noted in the present studies lower values of total plant cover in the plots situated along the narrow pathways might indicate the occurrence of a greater number of gaps where bare substratum is visible. It is worth mentioning that such openings in continuous turf are considered as safe sites for seedling recruitment *sensu* Harper [65], regeneration niche *sensu* Grubb [66] and space "free from competition" [67]. The beneficial role of small-scale gaps enabling spontaneous recruitment and establishment of seedlings in calcareous grasslands was repeatedly proved in naturally originated [68], as well as experimentally made openings [69,70]. In the present study, the recorded greater mean cover-abundance degree of a species along the narrow pathways than along the wide ones might suggest the successful generative propagation and/or undisturbed vegetative spread, leading to the multiplication of individuals and/or ramet number, as well as an area of individuals presumably owing to the non-intensive use of trails by visitors. The increase of pathway width as the result of the augmentation of the intensity of tourist traffic, as well as the frequency of passes, was previously recorded among others by Kiszka [16].

4.2. The Species Groups Characteristics

Our study, showing that regardless of pathway width and distance from the trail, meadow and grassland species prevailed over ruderal plants, while forest taxa occurred sporadically, suggest that hypothesis (v) about the variability of habitat affiliation spectra must be rejected. Moreover, we evidenced the dominance of native species over alien species irrespective of pathway width and distance from the edge of the trail. Although the area of calcareous grasslands in Cracow has significantly decreased over the last decades [71], their semi-natural value is still high [72]. However, the presence of some alien species such as *Erigeron annuus* (L.) Desf., *E. canadensis* L., *Robinia pseudoacacia* L., *Solidago canadensis* L. and *Vicia grandiflora* Scop., which are invasive in Poland [73], suggests the negative effect of human activities on calcareous grasslands in the area of the city. These species can be easily introduced to calcareous grasslands from nearly located roadside verges, abandoned allotment gardens and waste ground. Nevertheless, it might be stated that despite the significant statistical differences regarding the presence of native and alien species along the narrow and wide pathways, as well as among the plots CL and FU, the dominance of native taxa suggests the rejection of hypothesis (v) about the variability of species origin spectra.

Also, in spite of recorded differences in the degree of cover-abundance of species representing particular life forms, depending on trail width and plot location, the similar patterns of life form spectra noticed in the majority of the study areas indicate the rejection of hypothesis (v) about the variability of species life form spectra. The performed investigations evidencing a dominance of hemicryptophytes and chamaephytes supports the findings of Dobay et al. [74], arguing that the species representing the aforementioned life forms are often found in grassland areas. Roovers et al. [38] observed the dominance of hemicryptophytes regardless of level recreational use in meadows, heaths, and forests, whilePescott and Stewart [75] added that vegetation dominated by hemicryptophytes recovers from trampling to a greater extent than vegetation dominated by other life forms. The observed in the present studies scarce number of phanerophytes is not remarkable considering the occurrence of forests in the vicinity of the study sites, whereas the slight abundance of therophytes seems to be very surprising and might be an effect of slight occurrence of diaspores in the soil seed bank and/or unsuitable conditions for seedling recruitment. Additionally, it is worth mentioning, that Skłodowski et al. [39], as well as Zdanowicz and Skłodkowski [40], found the greater number of therophytes along wide pathways than along narrow ones in forests. Apart from this, other researchers recorded a considerably greater share of therophytes in the borders of trails than in more distant sites in forests [37] and meadows [38].

According to Sádlo et al. [56], the dispersal strategies of *Allium*, *Bidens*, *Cornus*, *Epilobium* and *Lycopodium* are found within the plants occupying dry grasslands. In our study, we evidenced the presence of species with the strategies of *Allium*, *Bidens*, *Cornus* and *Epilobium*. The occurrence of different patterns of dispersal mode spectra among the plots located along the narrow and wide pathways, as well as among the plots CL and FU, allows confirming the hypothesis (v) about the variability of species dispersal mode spectra. Simultaneously, the results showing the lowest cover-abundance degree of species presenting *Bidens* dispersal type (mainly epizoochory and autochory, as well as endozoochory) in plots situated along narrow pathways, as well as in plots located close to the trail edge, might suggest low activity of tourist and visitors passing by pathways in the external transport of diaspores possessing mechanisms to adhere to clothes equipment, vehicles and animals. On the other hand, the prevalence of taxa with *Cornus* type (endozoochory and autochory) in plots located at a greater distance might be an effect of dung deposition by animals. The considerable recruitment of endozoochorous species seedlings from dung samples was observed in numerous habitats (e.g., [76–78]).

5. Conclusions

The height of the tallest plant shoots, species richness, as well as the percentage of plant cover damaged by trampling did not differ in the narrow and wide pathways. The significantly lower height of plants in close plots and the greater species number and percentage of plant cover damaged by trampling recorded there is the effect of passers-by contributing to the mechanical fracture of plant organs and the dissemination of diaspores. The distance from trails does not impact the total plant cover percentage, as well the cover-abundance degree of a particular species per plot. The lower value of plant cover percentage along narrow trails creates the opportunities for successful generative propagation and/or vegetative spread, resulting in a greater mean cover-abundance degree of a species.

The dominance of meadow and grassland species over ruderal plants and sporadic occurrence of forest taxa, as well as the prevalence of native species irrespective of pathway width and distance from trail edge, suggests that the composition of the examined patches of grasslands has not been drastically changed by secondary succession and human activity. The dominance of hemicryptophytes and chamaephytes, slight presence of phanerophytes and therophytes and the low cover-abundance degree of geophytes was observed in the majority of study areas regardless of path width and distance from the edge of the trail. The lowest cover-abundance degree of species presenting *Bidens* dispersal type in plots situated along narrow pathways, as well as in plots located close to the trail edge might suggest the low activity of visitors passing by pathways in the external transport of epizoochorous seeds. The prevalence of taxa with *Cornus* type in plots located at a greater distance might be an effect of deposition of dung containing endozoochorous seeds by animals.

The investigations performed enlarge the current state of knowledge about the properties of vegetation in the vicinity of visitor-created (informal) tourist trails in calcareous grasslands - areas of high conservation value. Our results can be applied in further studies to evaluate the temporal changes of species composition and plant traits, as well as for comparison with other popular semi-natural areas, where trampling is also an issue.

According to assumptions of plans of protection [79], to preserve the calcareous grasslands in the Natura 2000 areas, it is important to make awareness-raising efforts among the local population and tourists through educational campaigns. Moreover, the monitoring of frequently visited patches, enabling the identification of existing and potential threats caused by visitor activities, is desired.

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Appendix A

Table A1. The characteristics of species found in the plant cover of the studied calcareous grasslands regarding habitat affiliations according to Matuszkiewicz [61], life form according to Fitter and Peat [63], dispersal type according to Pladias [55]. Database of the Czech flora and vegetation [65], and origin according to Alien species in Poland [67].

Taxon	Habitat	Life Form	Dispersal Type	Origin
Acer platanoides L.	Forest	Phanerophyte	*Epilobium*	Native
Acer pseudoplatanus L.	Forest	Phanerophyte	*Epilobium*	Native
Achilleamillefolium L.	Meadow	Chamaephyte	*Allium*	Native
Acinosarvensis (Lam.) Dandy	Grassland	Therophyte	*Allium*	Native
Aegopodium podagraria L.	Forest	Hemicryptophyte	*Allium*	Native
Agrimonia eupatoria L.	Grassland	Hemicryptophyte	*Bidens*	Native

Table A1. *Cont.*

Taxon	Habitat	Life Form	Dispersal Type	Origin
Agrostis capillaris L.	Grassland	Hemicryptophyte	*Allium*	Native
Ajuga genevensis L.	Grassland	Hemicryptophyte	*Allium*	Native
Allium montanum F. W. Schmidt	Grassland	Geophyte	*Allium*	Native
Alyssum alyssoides L.	Grassland	Therophyte	*Allium*	Native
Anchusa officinalis L.	Ruderal	Hemicryptophyte	*Allium*	Alien
Anthyllis vulneraria L.	Grassland	Hemicryptophyte	*Allium*	Native
Anthoxanthum odoratum L.	Meadow	Hemicryptophyte	*Allium*	Native
Arabidopsis thaliana (L.) Heynh.	Ruderal	Therophyte	*Allium*	Native
Arabis hirsuta (L.) Scop.	Grassland	Hemicryptophyte	*Allium*	Native
Arenaria serpyllifolia L.	Grassland	Therophyte	*Allium*	Native
Arrhenatherum elatius (L.) P. Beauv. ex J. & C. Presl	Meadow	Hemicryptophyte	*Allium*	Native
Artemisia campestris L.	Grassland	Chamaephyte	*Allium*	Native
Artemisia vulgaris L.	Ruderal	Hemicryptophyte	*Allium*	Native
Asperula cynanchica L.	Grassland	Hemicryptophyte	*Allium*	Native
Astragalus glycyphyllos L.	Grassland	Hemicryptophyte	*Allium*	Native
Avenula pratensis (L.) Dumort.	Grassland	Hemicryptophyte	*Allium*	Native
Avenula pubescens (Huds.) Dumort.	Meadow	Hemicryptophyte	*Allium*	Native
Briza media L.	Meadow	Hemicryptophyte	*Allium*	Native
Bromus erectus Huds.	Grassland	Hemicryptophyte	*Allium*	Native
Bromus hordeaceus L.	Meadow	Hemicryptophyte	*Allium*	Native
Bromus sterilis L.	Ruderal	Therophyte	*Allium*	Alien
Calamagrostis epigejos (L.) Roth.	Ruderal	Hemicryptophyte	*Epilobium*	Native
Calystegia sepium (L.) R. Br.	Ruderal	Hemicryptophyte	*Allium*	Native
Carduus acanthoides L.	Ruderal	Hemicryptophyte	*Epilobium*	Alien
Carex caryophyllea L.	Grassland	Hemicryptophyte	*Allium*	Native
Carex hirta L.	Meadow	Hemicryptophyte	*Allium*	Native
Carex ovalis Gooden.	Grassland	Hemicryptophyte	*Allium*	Native
Carex praecox Schreb.	Grassland	Hemicryptophyte	*Allium*	Native
Carex sp.	-	-	-	-
Carlina acaulis L.	Grassland	Hemicryptophyte	*Epilobium*	Native
Centaurea stoebe Tausch	Grassland	Hemicryptophyte	*Allium*	Native
Cerastium arvense L.	Grassland	Chamaephyte	*Allium*	Native
Cerasus sp.	-	-	-	-
Cerasus vulgaris Mill.	-	Phanerophyte	*Cornus*	Alien
Cerinthe minor L.	Ruderal	Hemicryptophyte	*Allium*	Native
Cichorium intybus L.	Ruderal	Hemicryptophyte	*Allium*	Alien
Convolvulus arvensis L.	Ruderal	Hemicryptophyte	*Allium*	Native
Cornus sanguinea L.	Grassland	Phanerophyte	*Cornus*	Native
Coronilla varia L.	Grassland	Hemicryptophyte	*Allium*	Native
Crataegus sp.	-	-	-	-
Cuscuta epithymum L.	Grassland	Therophyte	*Allium*	Native

Table A1. *Cont.*

Taxon	Habitat	Life Form	Dispersal Type	Origin
Dactylis glomerata L.	Meadow	Hemicryptophyte	*Allium*	Native
Daucus carota L.	Meadow	Hemicryptophyte	*Bidens*	Native
Deschampsia caespitosa (L.) P. B.	Meadow	Hemicryptophyte	*Allium*	Native
Dianthus carthusianorum L.	Grassland	Chamaephyte	*Allium*	Native
Echium vulgare L.	Ruderal	Hemicryptophyte	*Allium*	Native
Elymus hispidus (Opiz) Melderis	Ruderal	Hemicryptophyte	*Allium*	Native
Elymus repens (L.) Gould	Ruderal	Hemicryptophyte	*Allium*	Native
Erigeron acris ssp. serotinus (Weihe) Greuter	Grassland	Hemicryptophyte	*Epilobium*	Native
Erigeron annuus (L.) Desf.	Ruderal	Hemicryptophyte	*Epilobium*	Alien
Erigeron canadensis L.	Ruderal	Therophyte	*Epilobium*	Alien
Euonymus europaeus L.	Forest	Phanerophyte	*Cornus*	Native
Euphorbia cyparissias L.	Grassland	Hemicryptophyte	*Allium*	Native
Euphrasia stricta J. P. Wolff. ex Lehmann	Grassland	Therophyte	*Allium*	Native
Fallopia convolvulus (L.) Á. Löve	Ruderal	Therophyte	*Allium*	Alien
Festuca pratensis Huds.	Meadow	Hemicryptophyte	*Allium*	Native
Festuca rubra L.	Meadow	Hemicryptophyte	*Allium*	Native
Festuca rupicola Heuff.	Grassland	Hemicryptophyte	*Allium*	Native
Festuca sp.	-	-	-	-
Fragaria viridis Weston	Grassland	Hemicryptophyte	*Cornus*	Native
Galium mollugo L.	Meadow	Hemicryptophyte	*Allium*	Native
Galium verum L.	Grassland	Hemicryptophyte	*Allium*	Native
Geranium pratense L.	Ruderal	Hemicryptophyte	*Allium*	Native
Geum urbanum L.	Meadow	Hemicryptophyte	*Bidens*	Native
Helianthemum nummularium (L.) Mill.	Grassland	Chamaephyte	*Allium*	Native
Hieracium pilosella L.	Grassland	Hemicryptophyte	*Epilobium*	Native
Holcus lanatus L.	Meadow	Hemicryptophyte	*Allium*	Native
Hypericum perforatum L.	Ruderal	Hemicryptophyte	*Allium*	Native
Knautia arvensis (L.) J. M. Coult.	Meadow	Hemicryptophyte	*Allium*	Native
Koeleria macrantha (Ledeb.) Schult.	Grassland	Hemicryptophyte	*Allium*	Native
Leontodon autumnalis L.	Meadow	Hemicryptophyte	*Epilobium*	Native
Leontodon hispidus L.	Meadow	Hemicryptophyte	*Epilobium*	Native
Leucanthemum vulgare Lam.	Meadow	Hemicryptophyte	*Allium*	Native
Ligustrum vulgare L.	Grassland	Phanerophyte	*Cornus*	Native
Linaria vulgaris Mill.	Ruderal	Hemicryptophyte	*Allium*	Native
Linum catharticum L.	Meadow	Hemicryptophyte	*Allium*	Native
Lolium perenne L.	Meadow	Hemicryptophyte	*Allium*	Native
Lotus corniculatus L.	Meadow	Hemicryptophyte	*Allium*	Native
Malus domestica Borkh.	-	Phanerophyte	Cornus	Alien
Medicago falcata L.	Grassland	Hemicryptophyte	*Allium*	Native
Medicago lupulina L.	Ruderal	Hemicryptophyte	*Allium*	Native

Table A1. *Cont.*

Taxon	Habitat	Life Form	Dispersal Type	Origin
Medicago sativa L.	Ruderal	Hemicryptophyte	*Allium*	Alien
Pastinaca sativa L.	Meadow	Hemicryptophyte	*Allium*	Alien
Peucedanum oreoselinum (L.) Moench	Grassland	Hemicryptophyte	*Allium*	Native
Phleum phleoides (L.) H. Karst.	Grassland	Hemicryptophyte	*Allium*	Native
Phleum pratense L.	Meadow	Hemicryptophyte	*Allium*	Native
Picris hieracioides L.	Ruderal	Hemicryptophyte	*Epilobium*	Native
Pimpinella saxifraga L.	Meadow	Hemicryptophyte	*Allium*	Native
Plantago lanceolata L.	Grassland	Hemicryptophyte	*Allium*	Native
Plantago major L.	Meadow	Hemicryptophyte	*Allium*	Native
Plantago media L.	Grassland	Hemicryptophyte	*Allium*	Native
Poa compressa L.	Ruderal	Hemicryptophyte	*Allium*	Native
Poa pratensis L.	Ruderal	Hemicryptophyte	*Allium*	Native
Polygonum aviculare L.	Ruderal	Therophyte	*Allium*	Native
Populus tremula L.	Ruderal	Phanerophyte	*Epilobium*	Native
Potentilla arenaria Borkh.	Grassland	Hemicryptophyte	*Allium*	Native
Potentilla argentea L.	Grassland	Hemicryptophyte	*Allium*	Native
Potentilla reptans L.	Meadow	Hemicryptophyte	*Allium*	Native
Prunella vulgaris L.	Meadow	Hemicryptophyte	*Allium*	Native
Prunus sp.	-	-	-	-
Prunus spinosa L.	Grassland	Phanerophyte	*Cornus*	Native
Rhamnus cathartica L.	Grassland	Phanerophyte	*Cornus*	Native
Ranunculus bulbosus L.	Grassland	Hemicryptophyte	*Allium*	Native
Robinia pseudoacacia L.	Forest	Phanerophyte	*Allium*	Alien
Rosa canina L.	Grassland	Phanerophyte	*Cornus*	Native
Rubus caesius L.	Grassland	Phanerophyte	*Cornus*	Native
Rumex crispus L.	Ruderal	Hemicryptophyte	*Allium*	Native
Rumex obtusifolius L.	Ruderal	Hemicryptophyte	*Allium*	Native
Rumex thyrsiflorus Fingerh.	Meadow	Hemicryptophyte	*Allium*	Native
Salvia pratensis L.	Grassland	Hemicryptophyte	*Allium*	Native
Salvia verticillata L.	Grassland	Hemicryptophyte	*Allium*	Native
Sanguisorba minor Scop.	Grassland	Hemicryptophyte	*Allium*	Native
Sarothamnus scoparius(L.) Wimm.	Grassland	Phanerophyte	*Allium*	Native
Scabiosa ochroleuca L.	Grassland	Hemicryptophyte	*Allium*	Native
Sedum acre L.	Grassland	Chamaephyte	*Allium*	Native
Sedum sexangulare L.	Grassland	Chamaephyte	*Allium*	Native
Senecio jacobaea L.	Ruderal	Hemicryptophyte	*Epilobium*	Native
Seseli annuum L.	Grassland	Hemicryptophyte	*Allium*	Native
Setaria viridis (L.) P. Beauv.	Ruderal	Therophyte	*Bidens*	Alien
Silene otites (L.) Wibel	Grassland	Hemicryptophyte	*Allium*	Native
Solidago canadensis L.	Ruderal	Hemicryptophyte	*Epilobium*	Alien
Solidago gigantea Aiton	Ruderal	Hemicryptophyte	*Epilobium*	Alien

Table A1. *Cont.*

Taxon	Habitat	Life Form	Dispersal Type	Origin
Solidago virgaurea L.	Grassland	Hemicryptophyte	*Epilobium*	Native
Sonchus oleraceus L.	Ruderal	Hemicryptophyte	*Epilobium*	Alien
Stachys recta L.	Grassland	Hemicryptophyte	*Allium*	Native
Taraxacum sp.	-	-	-	-
Thymus austriacus Bernh.	Grassland	Chamaephyte	*Allium*	Native
Thymus glabrescens Willd.	Grassland	Chamaephyte	*Allium*	Native
Thymus pulegioides L.	Grassland	Chamaephyte	*Allium*	Native
Tragopogon pratensis L.	Meadow	Hemicryptophyte	*Epilobium*	Native
Trifolium arvense L.	Grassland	Therophyte	*Allium*	Native
Trifolium campestre Schreb.	Grassland	Therophyte	*Allium*	Native
Trifolium montanum L.	Meadow	Hemicryptophyte	*Allium*	Native
Trifolium pratense L.	Meadow	Hemicryptophyte	*Allium*	Native
Trifolium repens L.	Meadow	Hemicryptophyte	*Allium*	Native
Trisetum flavescens (L.) P. Beauv.	Grassland	Hemicryptophyte	*Allium*	Native
Verbascum lychnitis L.	Grassland	Hemicryptophyte	*Allium*	Native
Verbascum thapsus L.	Ruderal	Hemicryptophyte	*Allium*	Native
Veronica arvensis L.	Ruderal	Therophyte	*Allium*	Alien
Veronica austriaca L.	Grassland	Chamaephyte	*Allium*	Native
Veronica chamaedrys L.	Ruderal	Chamaephyte	*Allium*	Native
Veronica spicata L.	Grassland	Chamaephyte	*Allium*	Native
Vicia cracca L.	Meadow	Hemicryptophyte	*Allium*	Native
Vicia grandiflora Scop.	Ruderal	Therophyte	*Allium*	Alien
Vicia hirsuta (L.) S. F. Gray	Ruderal	Therophyte	*Allium*	Alien
Vicia tetrasperma (L.) Schreb.	Ruderal	Therophyte	*Allium*	Alien
Vincetoxicum hirundinaria Medik.	Grassland	Hemicryptophyte	*Epilobium*	Native
Viola hirta L.	Grassland	Hemicryptophyte	*Allium*	Native
Viola odorata L.	Ruderal	Hemicryptophyte	*Allium*	Native

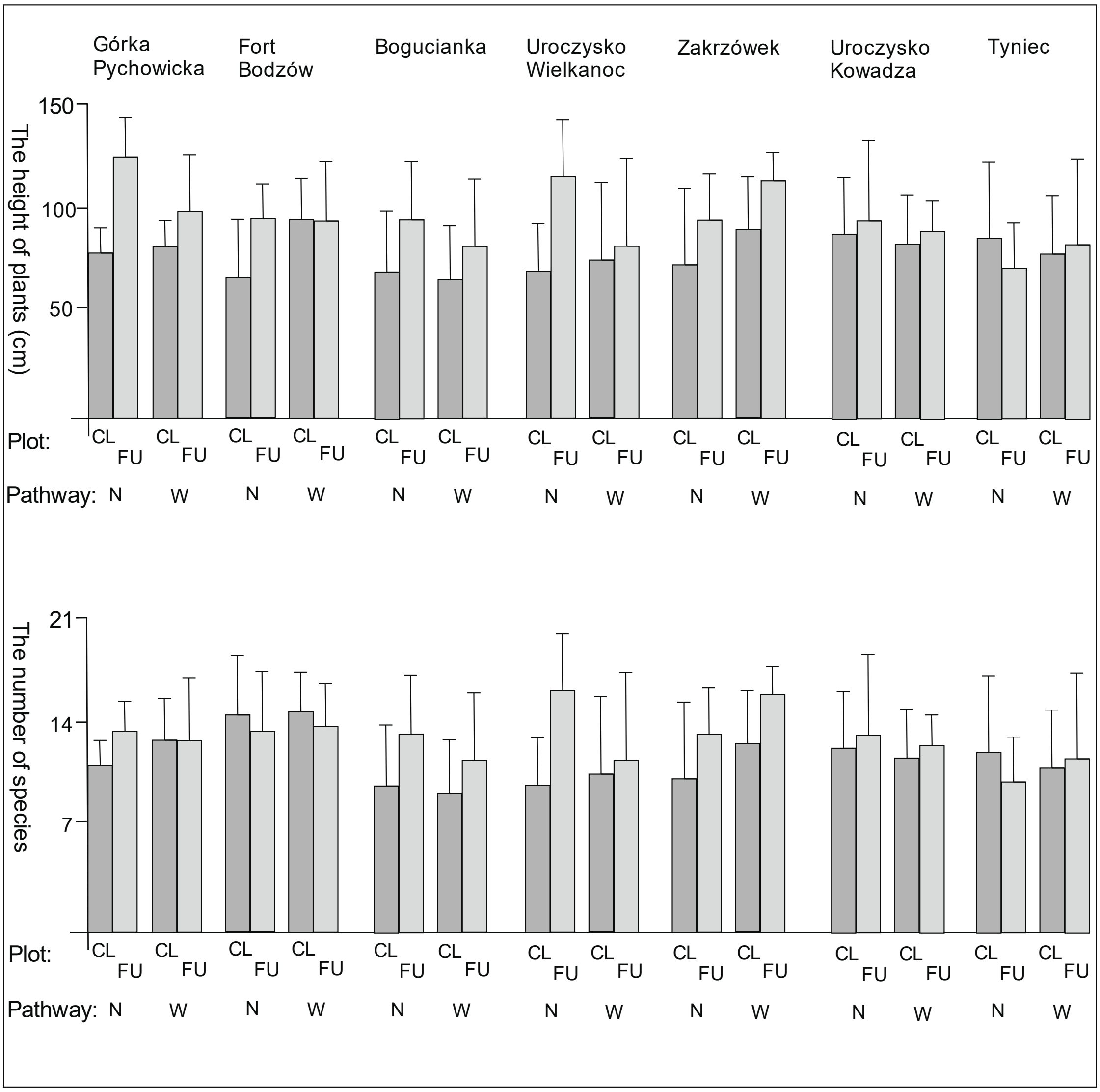

Figure A1. The mean height (cm) of the tallest plant (± SD) and number of species (± SD) in the closer (CL) and further (FU) plots located along the narrow-N (width ≤ 50 cm) and wide-W (width ≥ 115 cm) pathways situated within the investigated study sites.

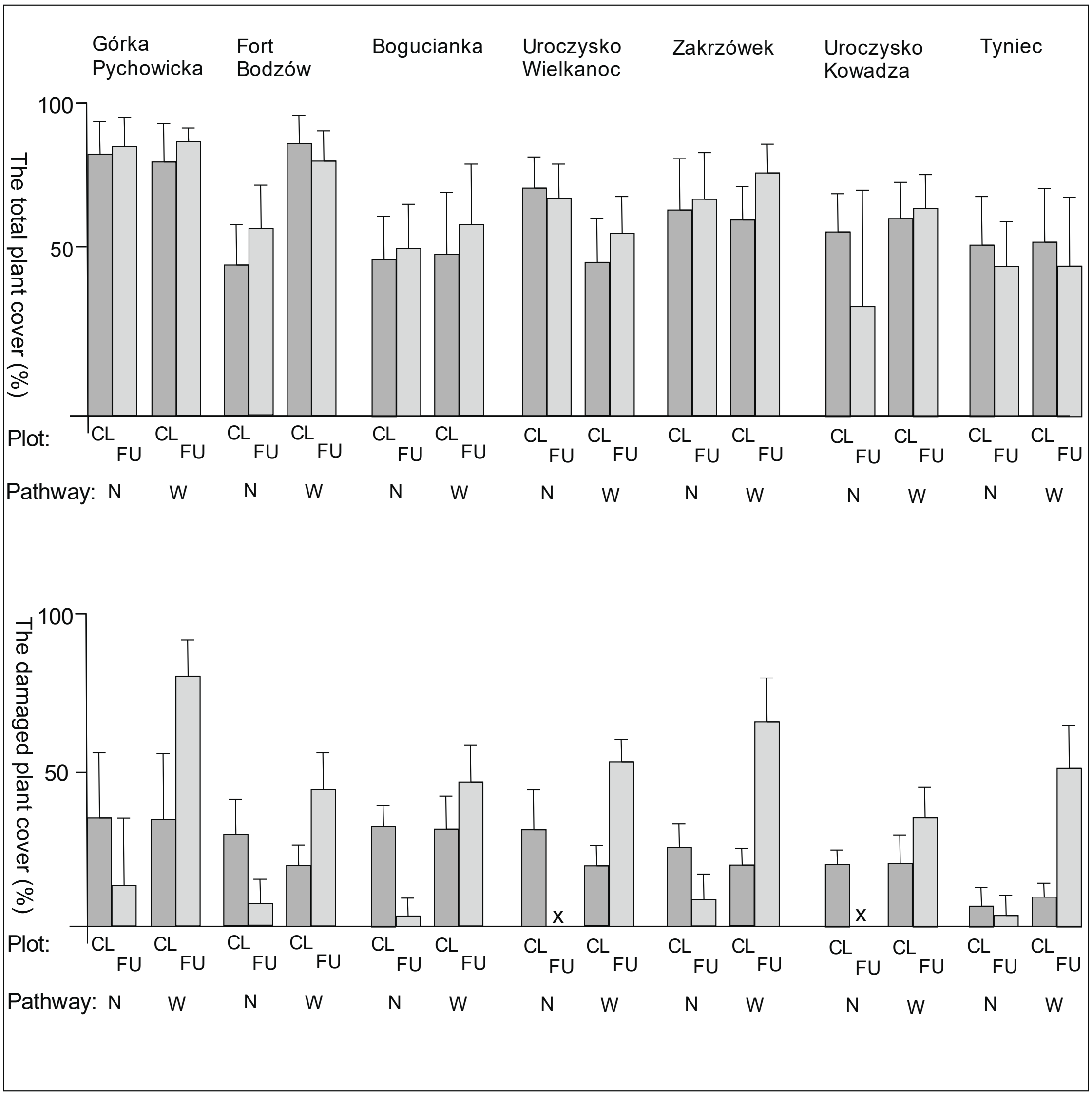

Figure A2. The mean percentage of total plant cover (± SD) and the percentage of plant cover damaged by trampling (± SD) in the closer (CL) and further (FU) plots located along the narrow-N (width ≤ 50 cm) and wide-W (width ≥ 115 cm) pathways situated within the investigated study sites.

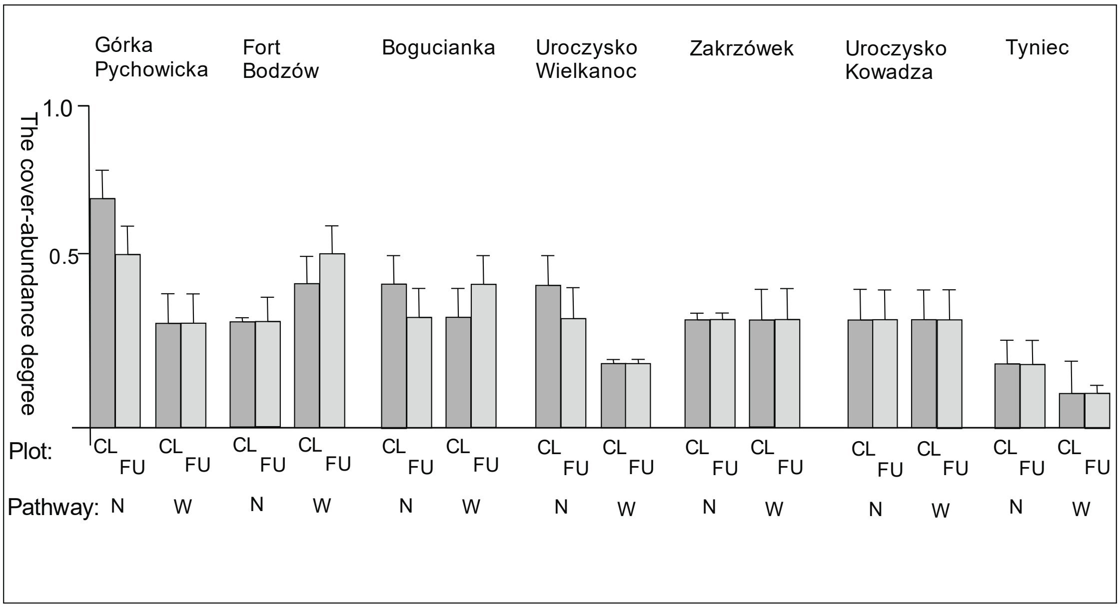

Figure A3. The mean cover-abundance degree of a particular species according to the Braun-Blanquet scale (± SD) in the closer (CL) and further (FU) plots located along the narrow-N (width ≤ 50 cm) and wide-W (width ≥ 115 cm) pathways situated within the investigated study sites.

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