ISSN 2623-6575
UDK 63

GLASILO FUTURE

PUBLIKACIJA FUTURE - STRUČNO-ZNANSTVENA UDRUGA ZA PROMICANJE ODRŽIVOG RAZVOJA, KULTURE I MEĐUNARODNE SURADNJE, ŠIBENIK

VOLUMEN 6 BROJ 2-3
LIPANJ 2023.

Glasilo Future

Stručno-znanstveni časopis

Nakladnik:
FUTURA
Sjedište udruge: Šibenik

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Grafička priprema: Ančica Sečan, mag. act. soc.
Objavljeno: 30. lipnja 2023. godine.
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(2023) 6 (2-3) 01–58

SADRŽAJ:

Ground-ivy (*Glechoma hederacea* L., Lamiaceae) habitats in NE Slovenia: floristic, chorological and syntaxonomic diversity

Mirjana Šipek[1]

stručni rad (professional paper)

doi: 10.32779/gf.6.2-3.5

Citiranje/Citation[2]

Abstract

Ground-ivy (*Glechoma hederacea* L.) is a widespread stoloniferous plant that grows in several ecologically diverse habitats: in the open, at the forest edge, and in understorey. The vegetation of ground-ivy habitats was studied in NE Slovenia in terms of floristic richness and diversity, biological spectrum, phytogeography and syntaxonomy. We identified five clusters of ecologically distinct habitats with the occurrence of ground-ivy, differentiated according to environmental conditions and flora composition: eutrophic forest edges, trampled habitats, forests, which are divided into two groups with different soil moisture, and meadows. The habitats were assessed using Ellenberg indicator values, thus confirming the ecological differentiation of ground-ivy habitats. Ground-ivy coexists with 169 plant species from 49 families. The highest plant species richness and Shannon diversity is found in meadows (100 plant species), while the lowest diversity is found in trampled habitats (12 plant species). Plant species coexisting with ground-ivy belong to 10 geoelements of which circumboreal, sub-cosmopolitan, Euro-Caucasian and Eurasian geoelements are represented in all habitats. The most represented life form is the hemicryptohytes with up to 88 % of all species per relevé. The syntaxon *Molino-Arrhenatheretea* dominates in the meadows, the shrub species of the forest edges belong to the syntaxon *Rhamno-Prunetea*, while *Querco-Fagatea* predominates in the forests. Ruderal species of the syntaxon *Stellarietea mediae* occurred in all habitats except in the understorey where light is a limiting factor. A non-negligible proportion of species belongs to *Galio-Urticetea*, a community characteristic of eutrophic forest edges, an optimal habitat for ground-ivy.

Key words: community composition, Ellenberg indicator values, life form, geoelement, syntaxon.

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[2] Šipek, M. (2023). Ground-ivy (*Glechoma hederacea* L., Lamiaceae) habitats in NE Slovenia: floristic, chorological and syntaxonomic diversity. *Glasilo Future*, *6*(2-3), 44–55.

Introduction

Ground-ivy (*Glechoma hederacea* L.) is a common European perennial creeping plant. In English, it is known by various names, such as ground-ivy, gill-over-the-ground, creeping Charlie, creeping Jenny, alehoof, tunhoof, catsfoot, field balm, haymaids and run-away-robin (CABI, 2023; Mahr and Stier, 2008). The kidney-shaped leaves with wavy margins are opposite on a square creeping stem that could root at the nodes. They are green and turn slightly purple in the colder months. Purple flowers In appear in spring, arranged in clusters. The flowers are two-lipped, open, tubular corollas with five-lobed bell-shaped calyxes (Figure 1). Each flower may produce up to four dry nutlets each containing one seed (Hutchings and Price, 1999).

Figure 1. *(a) Ground-ivy in the meadow and (b) flowering upright shoots. (Photo: M. Šipek).*

The native range of ground-ivy includes the temperate regions of Europe and Asia (Hutchings and Price, 1999). In North and South America, Southeast Asia, South Australia, and New Zealand, it is considered an alien and invasive plant (Figure 2).

Because of its medicinal and ornamental value, the ground-ivy was introduced to North America in the 19th century. Its ability to tolerate shade and the rapid growth of its creeping stems made the plant very suitable for horticulture as a groundcover (Middleton, 2001; Mahr and Stier, 2008). These characteristics also contribute to the invasive potential of the ground-ivy, which is expressed by high phenotypic plasticity and rapid growth that allows the plant to establish itself in a variety of habitats (Šipek and Šajna, 2021).

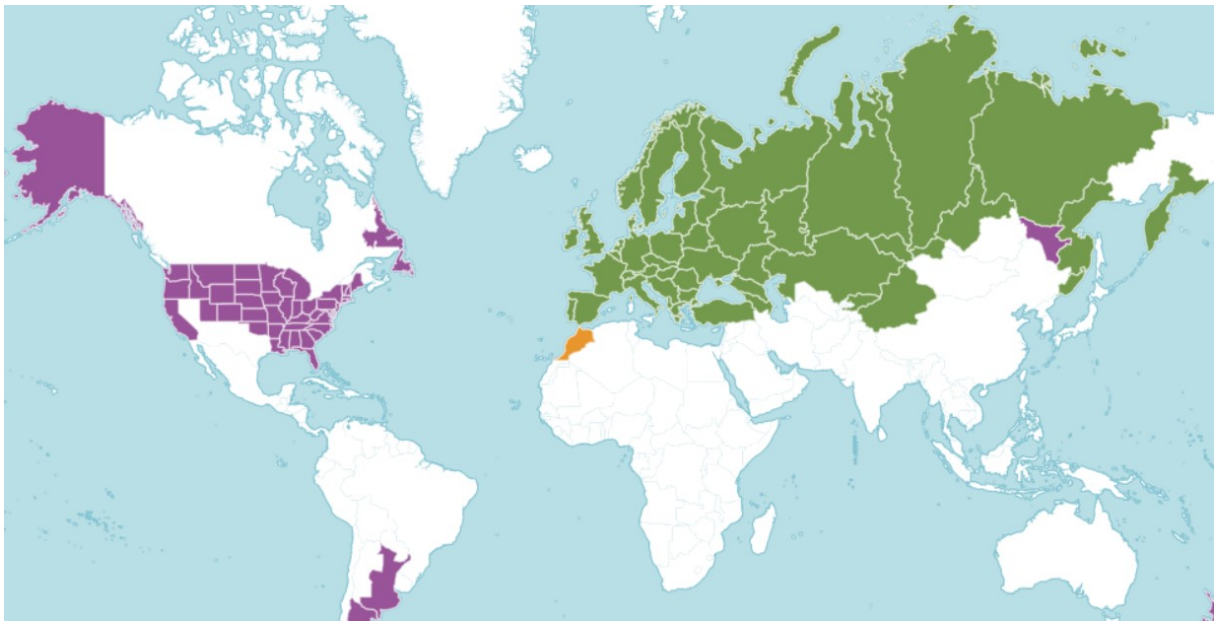

Figure 2. *Ground-ivy global distribution map retrieved from POWO (2023; http://www.plantsoftheworldonline.org/). Green colour indicates native range, purple introduced and orange doubtful presence.*

In addition to its medicinal properties and horticultural value, ground-ivy is also interesting from an ecological point of view as the plant tolerates a wide range of ecological conditions and grows in various habitats with different light and nutrient conditions. Ground-ivy grows in completely open habitats such as meadows and lawns, in semi shaded edge habitats and in shade such as in the forest understorey (Šipek and Šajna, 2021). In response to given environmental conditions, the morphological and reproductive characteristics of ground-ivy are highly variable (Hutchings and Price, 1999; Šipek and Šajna, 2021). In open habitats, ground-ivy cover is usually rather low but seed production is high. In nutrient-rich, partially shaded or shaded habitats, ground-ivy cover increases and can become a dominant component of the community, while seed production decreases as light availability decreases (Šipek and Šajna, 2021).

In the following, an analysis of plant communities in which ground-ivy occurs in northeastern Slovenia is conducted. Communities are analysed in terms of ecological conditions, which are assessed using Ellenberg indicator values, floristic richness and diversity, biological spectrum, phytogeography and syntaxonomy.

Methods

Study site

The study was conducted in northeastern Slovenia, in the Dravsko polje plain and Slovenske gorice hills. The study area belongs to the sub-Pannonian region with a moderate continental climate typical

of the lowland and hilly landscape in the eastern and northeastern parts of Slovenia. The average annual temperatures measured at the weather station in Starše on Dravsko polje (240 m above sea level) from 1961 to 2015 are 10.1 °C (ARSO, 2023). The average precipitation in Starše in the same period was 966 mm per year. Although the precipitation regime is favourable, drought is frequent in the summer months.

Vegetation survey

In May 2018, we conducted vegetation surveys in several habitats where ground-ivy occur, in a total of 20 relevés that include covering forests, forest edges, and meadows. Vegetation surveys were conducted using the standard Central European phytosociological method (Braun-Blanquet, 1964). The size of the relevé was smaller than prescribed if the homogeneous area where ground-ivy grows was smaller (Table 1).

Table 1. *List of relevés with size, latitude, longitude and altitude of the site, clusters according to plant species composition, plant species richness and ground-ivy cover.*

Relevé	Relevé size (m^2)	Latitude	Longitude	Altitude (m)	Site	Cluster	Species richness	Ground-ivy cover (%)
I	12	46.53869	15.69907	261	Zrkovci	1	14	37.5
II	8	46.53962	15.69403	246	Brezje	1	16	62.5
III	8	46.54011	15.6913	254	Brezje	1	14	62.5
IV	2.8	46.54028	15.69167	256	Brezje	2	9	5
V	8	46.54025	15.69152	262	Brezje	2	6	15
VI	12	46.5807	15.87603	274	Sv. Trojica	5	38	15
VII	10	46.58291	15.87216	281	Sv. Trojica	5	46	5
VIII	100	46.58816	15.8701	260	Sv. Trojica	3	26	5
IX	10	46.62437	15.88247	267	Drvanja	5	26	15
X	8	46.62218	15.87911	268	Benediški vrh	5	31	37.5
XI	10	46.59192	15.89638	240	Osek	5	40	5
XII	15	45.55508	15.89008	238	Senarska	5	40	5
XIII	10	46.61727	15.88623	304	Benedikt	5	38	15
XIV	8	46.62431	15.8823	260	Drvanja	1	8	87.5
XV	10	46.62451	15.88227	295	Drvanja	5	41	1
XVI	8	46.6227	15.88125	299	Drvanja	1	29	87.5
XVII	100	46.58816	15.87022	261	Sv. Trojica	3	23	37.5
XVIII	6	46.58027	15.64301	389	Ribniško selo	4	17	5
XIX	100	46.5993	15.64226	378	Ribniško selo	4	30	15
XX	100	46.58785	15.86904	340	Sv. Trojica	3	24	15

Environmental conditions in the sampled sites (relevés) were evaluated using average Ellenberg ecological indicator values for light, temperature, continentality, soil moisture, soil reaction, and nutrients calculated from indicator values of plant species growing at each site (relevé).

The nomenclature of plant species and the classification of species into higher taxonomic groups (families) and biological spectrum (Raunkiaer life forms) follow Mala Flora Slovenije (Martinčič et al., 2007). Geoelements were determined according to Pignatti (2005) and syntaxons according to Oberdorfer (1994) and Mucina et al. (1993).

Statistical analysis

Sampled relevés were analyzed using non-metric multidimensional ranking (NMDS), a method for indirect gradient analysis that creates an ordination based on distances or an inequality matrix. Differences between clusters at $P < 0.05$ were tested with one-way ANOVA (F test) when parametric test assumptions were met, otherwise, the nonparametric Kruskal-Wallis test was used. Significant differences in environmental conditions were determined with the permutation test ($P.perm < 0.05$). Analyzes were performed using JUICE 7.0.208 software and Microsoft Excel.

Results with discussion

Ecological differentiation of ground-ivy habitats in NE Slovenia

Ground-ivy grows in a wide range of habitats in northeastern Slovenia, including open (meadows, lawns), semi shaded (orchards, vineyards, forest edges), and shaded habitats (nutrient-rich and moist forests). Five clusters of ecologically distinct habitats with ground-ivy occurrence were identified, differentiated by ecological conditions and flora diversity (Figure 3). Eutrophic forest edges are placed in cluster 1 and trampled habitats in cluster 2. Clusters 3 and 4 include moist, nutrient-rich forest habitats, which are most ecologically distinct from cluster 5, which includes meadows. Meadows are habitats with the highest amount of light and the highest temperatures compared to the other clusters. Forests in cluster 3 have higher soil moisture than forests in cluster 4, which is reflected in plant composition, such as the presence of black alder, which grows on moist to wet soils.

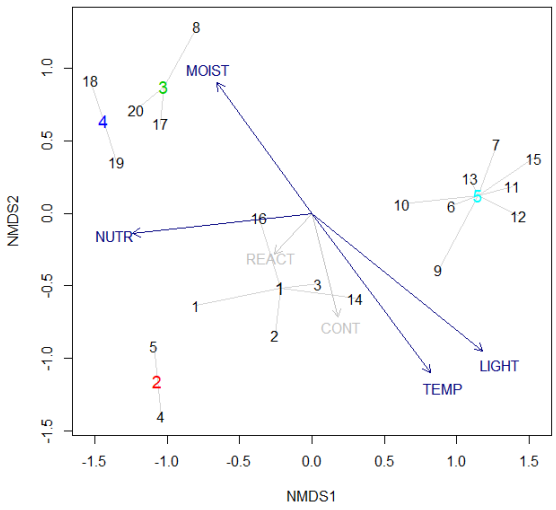

Figure 3. *Nonmetric multidimensional scaling of 20 relevés according to environmental gradient estimated from Ellenberg indicator values, resulting in 5 clusters.*

The clusters identified above were further analyzed to confirm ecological differentiation of ground-ivy habitats. Ellenberg values for light differ significantly among clusters (Figure 4a). Cluster 5 (meadows) has the highest light values, while clusters 3 and 4 (forests) have the lowest values. Ellenberg values for temperature show a similar pattern (Figure 4b). The continentality values differ between clusters: the highest value is obtained in cluster 1, and the lowest in cluster 4 (Figure 4c). The highest soil moisture is obtained in the habitats of clusters 3 and 4 (forests), while the lowest soil moisture is found in cluster 5 (meadows; Figure 4d). The soil reaction is similar in all clusters (Figure 4e). Nutrients are statistically lower in cluster 5, while there are no differences between the other clusters (Figure 4e).

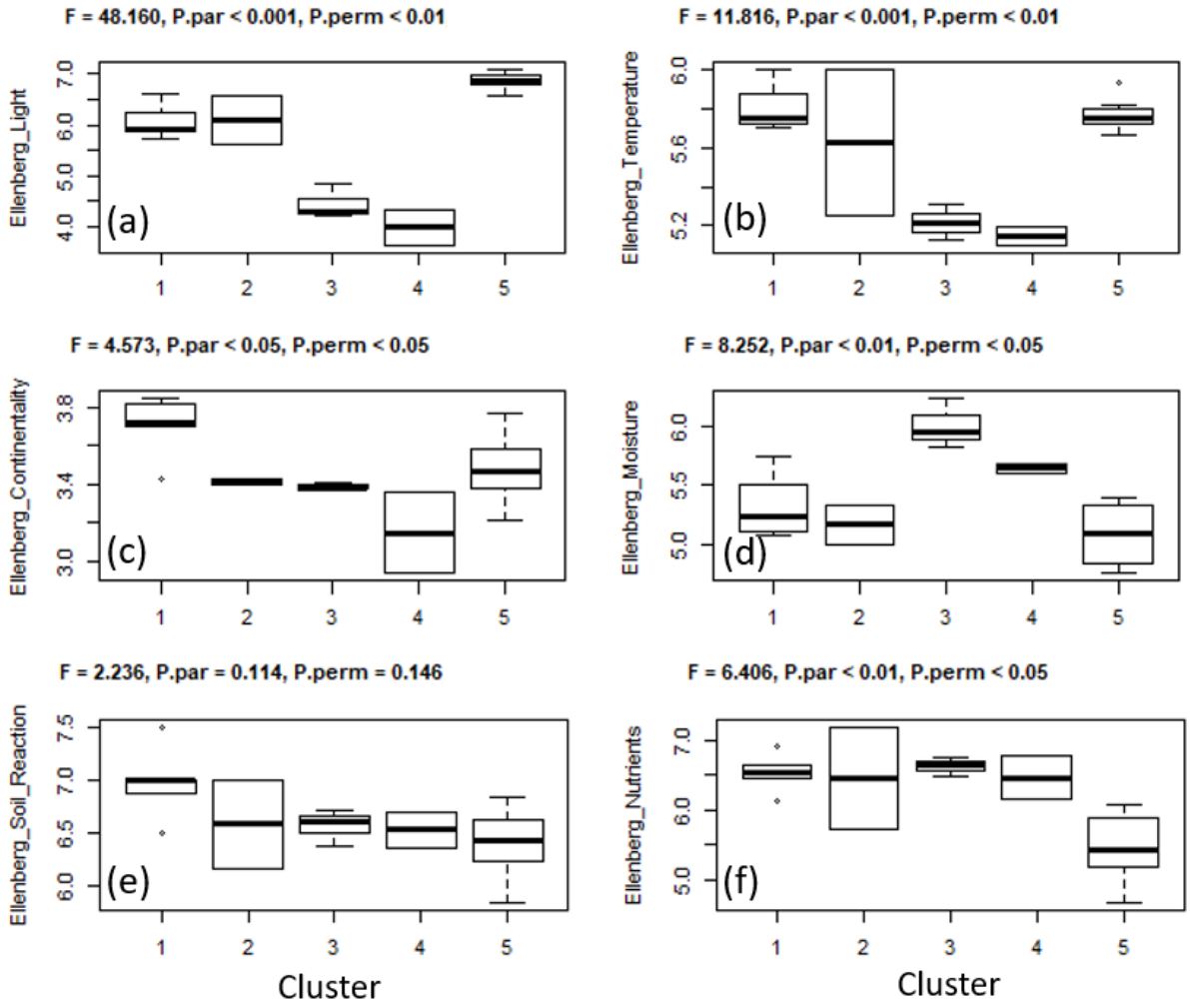

Figure 4. *Ellenberg ecological indicator values for (a) light, (b) temperature, (c) continentality, (d) soil moisture, (e) soil reaction and (d) nutrients in five clusters (habitats). The values above the graphs show the results of the ANOVA and the significance assessed with the permutation test (P.perm).*

Floristic diversity

Floristic analysis of the vegetation of the ground-ivy habitats in NE Slovenia resulted in 169 coexisting plant species, classified into 49 families, of which Poaceae (25), Lamiaceae (10) Fabaceae (10), Caryophyllaceae (10), Asteraceae (9) and Rosaceae (9) contained the highest number of species (Table 2; Figure 5).

Trampled habitats have the lowest species richness and diversity with 12 listed plant species, while meadows are the most species rich and diverse habitats with 100 listed plant species (Table 2).

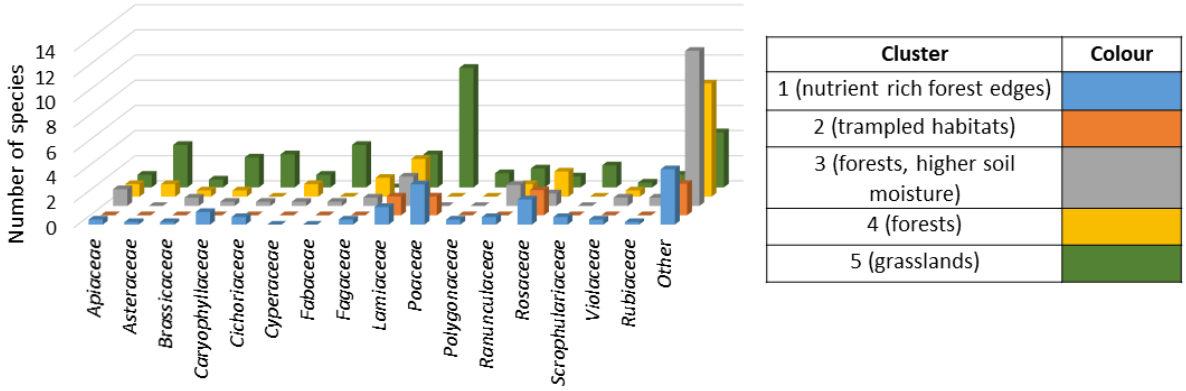

Figure 5. *Phylogenetic diversity of ground-ivy coexisting plant species according to five clusters (habitats).*

Table 2. *Ground-ivy habitat clusters with the average number of species per relevé, total number of species in a cluster, and the average Shannon diversity per relevé.*

Cluster	Average number of species/ relevé	Total number of species	Shannon diversity
1 (nutrient-rich forest edges)	16.2	54	1.602
2 (trampled habitats)	7.5	12	1.310
3 (forests, higher soil moisture)	24	40	2.440
4 (forests)	23	36	2.380
5 (meadows)	37.5	100	2.815

Biological spectrum

The proportion of chamaephytes (ANOVA; $F_{4, 15} = 1.06$, $P = 0.41$; Figure 6a) and therophytes (ANOVA; $F_{4, 15} = 1.70$, $P = 0.30$; Figure 6e) was similar between clusters. Geophytes dominated in the forests (Kruskal-Wallis test; $\chi 2 = 12.49$, $P < 0.05$; Figure 6b). Hemicryptophytes were represented with the lowest proportion in forests, while their proportion was comparable in other clusters (ANOVA; $F_{4, 15} = 4.56$, $P < 0.05$; Figure 6c). Phanerophytes dominated in forests, but were also abundant in forest edges, while they were absent in meadows (ANOVA; $F_{4, 15} = 7.33$, $P < 0.01$; Figure 6d).

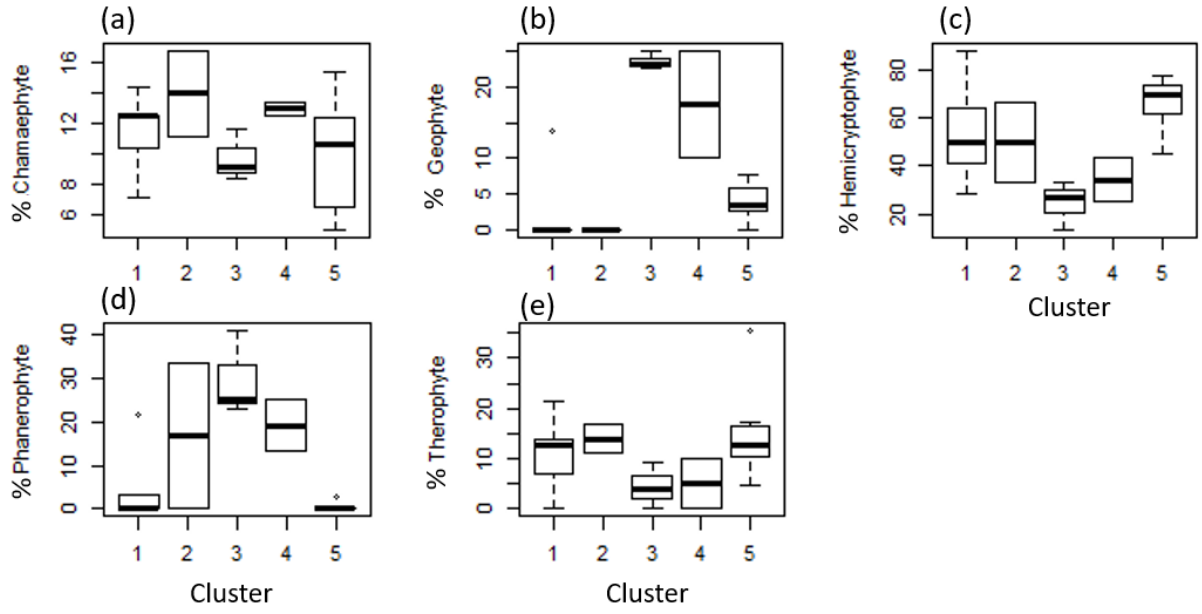

Figure 6. *Percentage incidence of life forms: (a) chamaephytes, (b) geophytes, (c) hemicryptopytes, (d) phanerophytes and (e) therophytes in five clusters (habitats).*

Phytogeographic diversity

Phytogeographic analysis has shown the presence of 10 floral elements, among which the following geoelements were recognized: Eurasian, Euro-Caucasian, circumboreal, paleotemperate, sub-cosmopolitan, cosmopolitan, Central-European, Euro-Siberian, Euromediterranean and adventive (Figure 7).

Species with circumboreal, sub-cosmopolitan, Euro-Caucasian and Eurasian distributions are represented in all clusters. Adventive and cosmopolitan species dominate eutrophic forest edges and trampled habitats, while only a small proportion are found in forests and meadows. Central-European species are represented to a lesser extent in forests. Most Eurimediterranean species are found in meadows, but they also occur in forests in a proportion of less than 5 %.

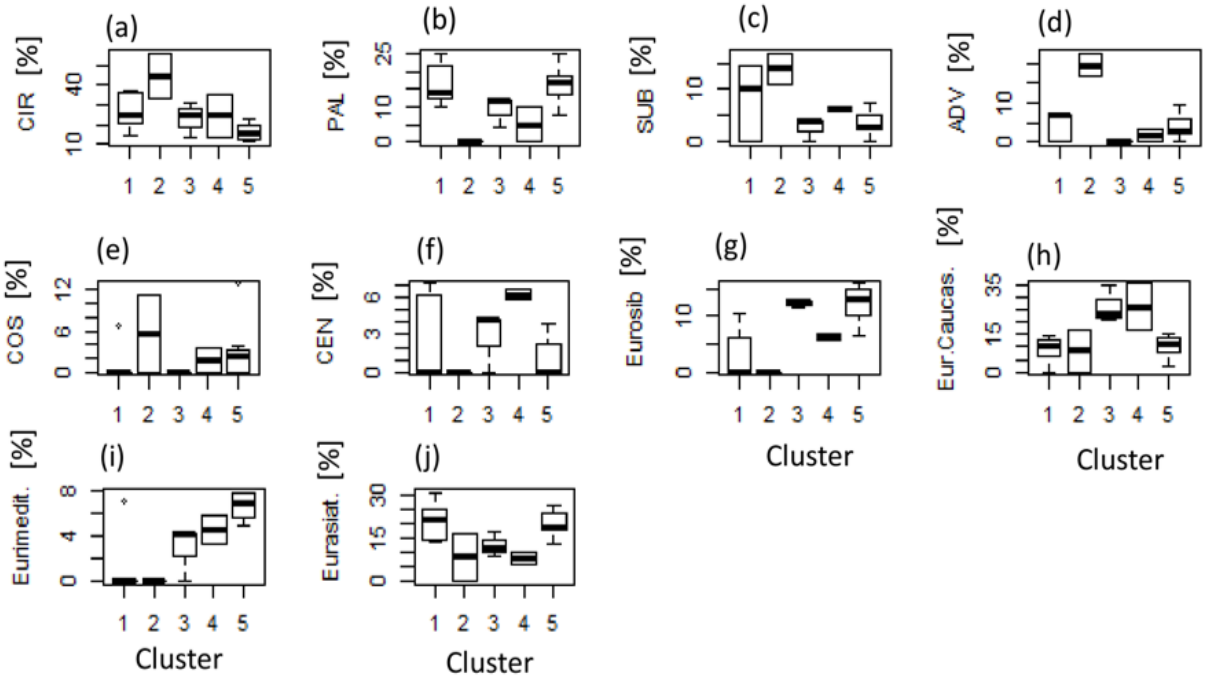

Figure 7. *Chorological spectrum of the ground-ivy habitats: (a) circumboreal, (b) paleotemperate, (c) sub-cosmopolitan, (d) adventive, (e) cosmopolitan, (f) Central-European, (g) Euro-Siberian, (h) Euro-Caucasian, (i) Eurimediterranean and (j) Eurasian floral element.*

Syntaxonomic diversity

We expected the above defined clusters to be dominated by different syntaxons, because the clusters differ ecologically and floristically. The *Molino-Arrhenatheretea* syntaxon dominates cluster 5, which includes 80 % of all species in this cluster. These are typical species of meadows and pastures. In smaller proportions (less than 20 %) these species were also present in other clusters. Shrub species of syntaxon *Rhamno-Prunetea* were represented in clusters 2, 3 and 4, which include forest edges and forests. Ruderal species of syntaxon *Stellarietea mediae* were represented in all habitats except in the forest understorey (cluster 3 and 4) where light is the main limiting factor. The *Querco-Fagatea* syntaxon was defined very broadly, as we included all typical forest species in this group, including species more typical of forests with moist to wet soils. As expected, these species are only represented in clusters that include forest and forest edge habitats. Nitrophilic forest edge species of *Galio-Urticetea* dominated cluster 2, but were also represented to a lesser extent in other habitats, with the exception of meadows where they were absent. Perennial weeds of class *Artemisietea* was most represented in cluster 1, accounting for about 10 %, while it was absent in clusters 2 and 4. Forest edge species of *Trifolio-Geranietea* were found with a small proportion (> 5 %) only in clusters 4 and 5. It is somewhat surprising that the edge species were listed in clusters combining forests and meadows. In this regard, it should be noted that the vegetation survey conducted in the forests included only lighter forests, which are relatively close to the edges and where edge species can also establish. Ground-ivy

cannot tolerate conditions in a forest with a completely closed canopy, as light intensity would be too low. On the other hand, cluster 5 also contains samples (relevés) made near forest edges, which explains the occurrence of edge species of *Trifolio-Geranietea* in meadows. As expected, the syntaxon of eutrophic shrub species *Robinietea* was most represented in cluster 2, but even there it did not exceed 10 %. Syntaxon *Polygono-Plantaginetea* is characteristic of trampled habitats and was represented in the largest proportion, but still below 10 %, only in cluster 2 (Figure 8).

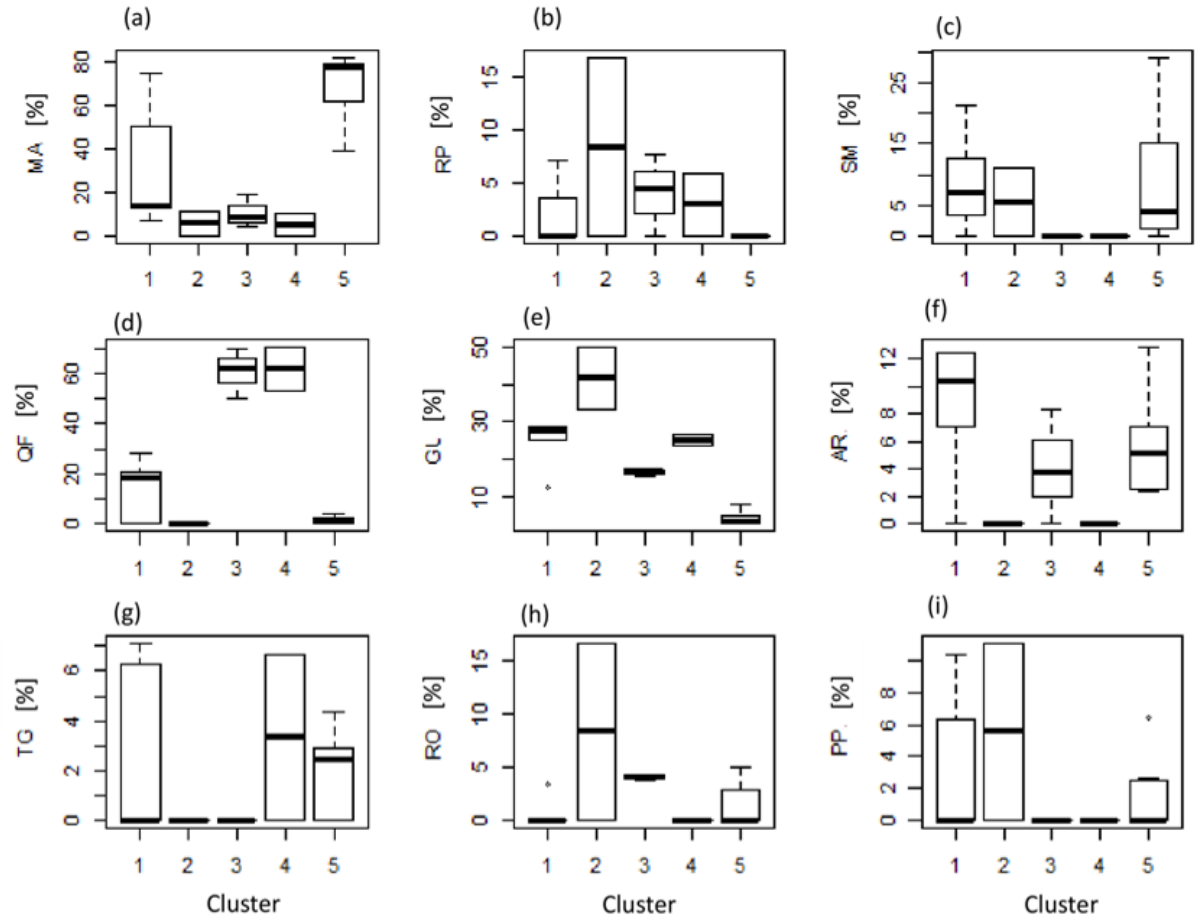

Figure 8. *Percent frequency of syntaxons (a) Molino-Arrhenatheretea, (b) Rhamno-Prunetea (Prunetalia spinose), (c) Stellarietea mediae, (d) Querco-Fagatea, (e) Galio-Urticetea, (f) Artemisietea, (g) Trifolio-Geranietea, (h) Robinietea in (i) Polygono-Plantaginetea in five clusters (habitats).*

Conclusion

Ground-ivy occurs in NE Slovenia in meadows, lawns, trampled habitats, forest edges and moist forest communities. The vegetation survey resulted in 20 relevés which were grouped into five clusters that differ ecologically and floristically. Differences between clusters recognized by floristic composition were confirmed with Ellenberg indicator values for various environmental parameters. We also showed that the proportions of individual life forms, chorotypes and syntaxons differed significantly among the recognized clusters.

Acknowledgements

The author thanks prof. dr. Andraž Čarni for his help with fieldwork and data analysis. Great thanks to assoc. prof. dr. Nina Šajna for insightful discussions about ground-ivy.

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Primljeno: 17. travnja 2023. ***Received:*** *April 17, 2023*

Prihvaćeno: 26. svibnja 2023. ***Accepted****: May 26, 2023*