Contribution of ruderal herbaceous vegetation to supporting services in Mediterranean urban greenspaces

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Abstract

In the current global context of increasing urbanization, urban greenspaces are expected to play a key role in supporting ecosystem services. Spontaneous ruderal vegetation has an important function in urban greenspaces, but more in-depth studies are needed to increase our knowledge of its contribution to providing supporting ecosystem services. We aimed to uncover the contribution to biodiversity maintenance, primary production and nutrient cycling of four selected plant communities that are widely distributed in Mediterranean urban greenspaces, namely the perennial herb communities of Malva spp., roadside vegetation with Diplotaxis virgata, annual grasslands of Hordeum murinum subsp. leporinum and perennial grasslands of Dactylis glomerata. We determined the floristic composition, species richness, species density, abundance, alpha diversity (Shannon index, Simpson index), beta diversity (Sørensen coefficient), plant species cover, cover of growth forms and cover of functional groups. Macronutrient content was analysed in the leaves and roots of six plant species corresponding to the faithful taxa of each vegetation type. We used the generalized linear model to relate vegetation type to compositional and structural features supporting ecosystem services. Our results showed that Mediterranean urban greenspaces have a high plant biodiversity. Roadside vegetation had the highest species richness and alpha diversity, with a high cover of a S-accumulator plants (Diplotaxis virgata) showing a high N content in their leaves. Annual grasslands had the highest abundance and cover of silica-accumulator plants. The greatest floristic similarity was found between roadside communities and annual grasslands. Primary production was high in perennial herbs of Malva species, which are rich in mucilage and leaf N content. Dactylis glomerata, the dominant species in perennial grasslands, showed a higher C content in leaves, so this vegetation type can be expected to make a higher contribution to C cycling. We conclude that ruderal vegetation provides a range of supporting ecosystem services according to the community type, which should be considered in the conservation and management of Mediterranean urban greenspaces.

Introduction

About 57% of the world population lives in urban areas (The World Bank 2022) and the continued expansion of these areas (Seto et al., 2011) is expected to produce major transformations of habitats and the plant landscape. Urban greenspaces include a variety of permeable green patches such as parks, gardens and others (Swanwick et al. 2003). In a context of global change, well-planned urban green areas are expected to be an excellent agent for sustaining the underlying processes of supporting services such as biological diversity maintenance, nutrient cycling and primary production (Dana et al. 2002; Zara et al. 2021).

A lower availability of greenspaces has been recorded in southern European cities (Kabisch et al. 2016); in addition, in cities under a Mediterranean climate the maintenance of certain types of high water-consuming greenspaces such as lawns represents an important challenge due to their considerable maintenance costs (Castro and Ponte-e-Sousa 2012). In a context of global change, and with a greater scarcity of water resources in certain areas such as the Mediterranean Basin where the effects of

climate change are expected to be harsh (IPCC 2014), the increase in water consumption will be unsustainable. Thus the maintenance of sustainable urban greenspaces and the knowledge of their ecosystem services are especially important.

Urban areas are spaces with highly dynamic and heterogeneous structures; this is also true of the services they supply (Sukopp and Werner 1983; Zipperer 2011; Vieira et al. 2018). The role of ruderal vegetation, namely spontaneous plant communities associated with urbanized environments and not intentionally propagated by humans (Sukopp and Werner 1983), is gaining special relevance in urban environments since it provides significant ecosystem services without any maintenance (Robinson and Lundholm 2012; Bianco et al. 2014; Guo et al. 2018). The presence of ruderal vegetation in cities allows plant cover in areas with high levels of N and organic matter (Chocholoušková and Pyšek 2003; Tredici 2010; Guo et al. 2018; Kalarus et al. 2019). But far from being a homogeneous vegetation, ruderal vegetation includes numerous plant communities that are distributed along soil disturbance gradients (Molina et al. 2023; Bretzel et al. 2012), and are good descriptors and indicators of ecosystem services (Vieira et al. 2018; Molina et al. 2023).

One of the most important ecosystem services supplied by urban spontaneous vegetation is the maintenance of biodiversity (Robinson and Lundholm 2012; Bianco et al. 2014). The loss of urban biodiversity may harm global biodiversity in the future, firstly because there will be an increasing proportion of diversity in urban areas; and secondly, because the loss of connection with nature causes the population to lose interest in its conservation (Dearborn and Kark 2010; Solecki and Marcotullio 2013). There is thus a need for a greater knowledge of spontaneous ruderal vegetation and its contribution to maintaining biodiversity in cities (Zhao et al. 2022). Supporting services other than biodiversity maintenance such as primary production and nutrient cycling and their relationships with biodiversity are poorly known and present a promising field of research. The process of the matter-biomass building and circulation, along with energy flow depends on many factors, including the crucial vegetation species composition (Ryś et al. 2023). We aimed to determine the contribution to biodiversity maintenance, primary production and nutrient cycling of four selected plant communities that are widely distributed in urban habitats. The results of this work provide useful information to serve as a basis for conservation and management policies in Mediterranean urban greenspaces.

Materials And Methods

Study area

This study was carried out in peri-urban areas of the city of Madrid (Spain) (Fig. 1). Madrid is located in the centre of the Iberian Peninsula, at an average altitude of 655 m.a.s.l. The average annual temperature is 15º C and the average annual precipitation is 421 mm (AEMET 2023). The bioclimate is Mediterranean semi-continental, with cold wet winters and hot dry summers (Rivas-Martínez et al. 2017). The soils in the study area can be classified as Anthrosols or Technosols (FAO 2014; Quintana et al. 2022). The city has almost 3,300,000 inhabitants in an area of 604.5 km2 (INE 2023).

Four greenspaces were selected on the outskirts of the city centre (Fig. 1), excluding the south of the metropolitan area to avoid the gypsum substrates. These greenspaces are established on wastelands, abandoned crop fields and landfills, where trees – often pine – and shrubs have been planted, and some areas are irrigated to maintain lawns. Nevertheless, the main vegetation matrix comprises spontaneous ruderal herbaceous plants, distributed in different habitats along gradients of soil disturbance (Molina et al. 2023; Molina et al. 2024). These non-irrigated green areas are subjected to annual mowing to prevent fires, which tend to occur in the dry summer season.

Sampling design and laboratory procedure

In each of the four greenspaces we studied four vegetation types to describe different ruderal habitats that are common in Mediterranean cities. We selected two perennial and two annual communities (Dana et al. 2002; Molina 2022). Sampling was carried out in the spring of 2023 (March-April) when the communities reached their maximum development. The following communities were studied: (1) tall perennial herbs (communities of Malva species, alliance Hordeion leporini); (2) annual medium-tall herb communities on roadsides (association Papaveri rhoeas-Diplotaxietum virgatae, alliance Hordeion leporini); (3) low annual grasslands (association Bromo scoparii-Hordeetum leporini, alliance Hordeion leporini; and (4) low perennial grasslands (community of Dactylis glomerata, class Lygeo-Stipetea) (RivasMartínez 1978; RivasMartínez et al. 2002). Hereafter these communities are called (1) perennial herb communities, (2) roadside communities, (3) annual grasslands and (4) perennial grasslands.

Three 1 m2 quadrats of each vegetation type at least 100 metres apart were surveyed in each greenspace, thus resulting in a study of 48 1m2 quadrats across four greenspaces. In each quadrat, plant species cover was estimated visually, always by the same observer to avoid bias, and the number of individuals (abundance) in each plant species were counted. To determine the productivity, the aboveground biomass of each plant species was collected, dried in an oven at 80°C until its mass was stable, then weighed.

Plant species were identified following Flora iberica (Castroviejo 2012). Each species was also assigned to a biotype (Raunkiaer 1934), identifying the following four biotypes: therophytes, hemicryptophytes, geophytes and chamaephytes. Species were also assigned to a functional group according to the biogeochemical classification established in Valverde et al. (2020). The following functional groups were identified: sulphur accumulators, N-fixers, N-compound-bearing, mucilage accumulators, terpenoid accumulators and silica accumulators. Species were also classified as native or naturalized alien species based on their geographical origin (Bot Mad et al. 2023). Nomenclature of plants used in the text is according to World Flora Online (WFO, 2023).

All the above-mentioned data were used to determine the following variables for each plant community: species density, abundance, alpha diversity (Shannon and Simpson indices), cover of biotypes and cover of functional groups in each plant community. Beta diversity (Sørensen index) was calculated for each pair of communities.

The quantitative content of carbon, hydrogen, nitrogen and sulphur was determined by combustion in a LECO CHNS-932, in leaves and roots of the most abundant plant species in each quadrat. Samples were processed in the Elemental Microanalysis Unit at the Complutense University in Madrid.

Statistical analysis

We used generalized linear models (GLM) to relate vegetation type, here considered as a habitat descriptor, to compositional and structural features related to ecosystem services such as biodiversity, productivity and nutrient cycling. All analyses were performed with R: a language and environment for statistical computing (R Core Team 2022), using the multcomp (v1.4-25, Bretz et al. 2023) and DHARMa (v 0.4.6, Hartig and Lohse 2022) packages for the analyses. The figures were prepared with ggplot2 package (v3.5.0, Wickham et al. 2024) for graphics.

Results

Plant biodiversity

We recorded a total of 153 species belonging to 22 families. *Asteraceae* (39 species), *Fabaceae* (26 species), *Poaceae* (22 species), *Caryophyllaceae* (13 species) and *Brassicaceae* (8 species) were the families with the highest number of species. Overall, 91% of the recorded species were native and only 2% were naturalized exotics.

Considering all the quadrats sampled, the most frequent plants were *Hordeum murinum* subsp. *leporinum* (88% of samples present), *Bromus rubens* (67%) and *Plantago lagopus* (60%). The species with the highest cover were *Hordeum murinum* subsp. *leporinum* (hereinafter referred to as *Hordeum leporinum*) (21% average cover), *Diplotaxis virgata* (11%), *Malva sylvestris* (11%) and *Dactylis glomerata* (9%). The percentage of cover of these species increased when considered in relation to the type of community in which they dominate. Thus, *Hordeum murinum* subsp. *leporinum* reached an average of 53% cover in annual grasslands, *Diplotaxis virgat*a 41% in roadside communities, *Malva sylvestris* 41% in perennial herbs and *Dactylis glomerata* 34% in perennial grasslands.

Roadside communities had the highest species richness with 82 species, closely followed by perennial grasslands with 81 and annual grasslands with 79. Perennial herb communities had the lowest richness, with 59 species. GLM showed that perennial herbs had a significantly lower species density compared to all the other communities (Fig. 2a). Significant differences in abundance were found between all plant communities. Annual grasslands had the highest abundance followed by perennial grasslands, roadside communities and finally perennial herbs with the lowest scores (Fig. 2b). Regarding diversity indices, roadside communities showed significantly higher values for the Shannon index than perennial herb communities, with the other two communities having intermediate values (Fig. 2c). In contrast, the Simpson index showed a significantly higher value in perennial herb communities than in roadside communities and perennial grasslands (Fig. 2d). The Sørensen index showed the highest similarity

between roadside communities and annual grasslands, and a greater differentiation in diversity between perennial herb communities with roadside communities and perennial grasslands (Table 1).

Table 1. Sørensen similarity index values for pairs of four plant-community types (roadside communities, annual grasslands, perennial herb communities, perennial grasslands). A total of 12 plots were sampled per plant community

Sørensen index	Roadside communities	Annual grasslands	Perennial herb communities	Perennial grasslands
Roadside communities	1			
Annual grasslands	0.65	1		
Perennial herb communities	0.50	0.58	1	
Perennial grasslands	0.53	0.55	0.50	1

Biotype cover and plant biomass

Roadside communities showed a significantly lower cover in species than the rest, which can reach 100% cover (Fig. 3a). Perennial grasslands presented a significantly lower cover than annual grasslands, while perennial herbs had intermediate values. As expected, therophytes had a significantly higher cover in annual grasslands and roadsides compared to perennial communities (Fig. 3b). Perennial communities were characterized by an important contingent of hemicryptophyte cover (Fig. 3c). Chamaephytes had a significantly higher cover in roadside communities compared to perennial grasslands (Fig. 3d). Plant biomass, a key regulating service, was significantly higher in perennial herbs compared to perennial grasslands, with annual communities – roadside communities and annual grasslands – reaching intermediate values (Fig. 4). This was similar to the pattern followed in the Simpson index (Fig. 2d).

Cover of functional groups and plant C, N, S content

Regarding functional groups, perennial herbs had a significantly higher cover of plants with mucilage than the others (Fig. 5a). Annual grasslands had a higher cover of N-fixing species compared to perennial herb communities (Fig. 5b). Silica accumulator cover increased progressively from roadside communities to perennial herbs, perennial grasslands and annual grasslands (Fig. 5c). Roadside communities had a significantly greater cover of sulphur-accumulating plants than the other communities (Fig. 5d).

Elemental leaf analysis of macronutrients revealed that C content increased progressively and significantly from *Malva* species to *Diplotaxis virgata*, *Hordeum leporinum* and finally *Dactylis glomerata*

(Fig. 6a). Leaf N content was significantly higher in *Malva* species and *Diplotaxis virgata* compared to *Hordeum leporinum* and *Dactylis glomerata* (Fig. 6b). Leaf sulphur content was significantly higher in *Diplotaxis virgata* than in *Malva* species and *Dactylis glomerata*, while *Hordeum leporinum* had intermediate values (Fig. 6c). The gramineous species – *Hordeum leporinum*, *Dactylis glomerata* – showed a higher leaf C/N ratio than *Malva* species and *Diplotaxis virgata* (Fig. 6d).

Root C content was significantly higher in herbaceous species – *Diplotaxis virgata*, *Malva* spp. – than in gramineous species – *Hordeum leporinum*, *Dactylis glomerata* (Fig. 7a). *Dactylis glomerata* had a lower root N content than *Malva* species and *Hordeum leporinum* (Fig. 7b). Root sulphur content was significantly higher in *Diplotaxis virgata* than in the other species (Fig. 7c). The roots of *Hordeum leporinum* also had a higher sulphur content than *Dactylis glomerata,* while *Malva* species had intermediate values between *Hordeum leporinum* and *Dactylis glomerata*. The roots of *Diplotaxis virgata* had a significantly higher C/N ratio than those of *Malva* species and *Hordeum leporinum*, with *Dactylis glomerata* showing intermediate values.

Discussion

Urban biodiversity will comprise an increasing proportion of the world's repository of biodiversity in the future (Faeth et al. 2011). Our study revealed that 5.9 x 10-7% of Madrid's regional area, which we sampled for our study, hosted 5.6% of its plant species richness (cf. López Jiménez 2007), and 2.4% of the Iberian flora (cf. Aedo et al. 2017). This finding reveals the importance of Mediterranean urban greenspaces in supporting the ecosystem service of biodiversity maintenance, and highlights the importance of conserving urban biodiversity (Dearborn and Kark 2010; Beauvais et al. 2016; Panitsa et al. 2020). The five largest families found in our study are consistent with those of the total Iberian vascular flora (Aedo et al. 2017), and the urban local taxonomic composition at the family level was consistent with the regional taxonomic pool. We also found a high proportion of native species, indicating the high plant diversity present in Mediterranean urban grasslands (Kantsa et al. 2013; Filibeck et al. 2016). Therophytes were the most abundant life form with the highest cover (79% of species, 74.7% average cover) throughout the study area. This growth form is best adapted to the Mediterranean climate and its droughts (Benvenuti 2004; Midolo et al. 2024) and the best strategist in disturbed habitats (Midolo et al. 2023).

The most common species throughout the study area (*Hordeum leporinum*, *Plantago lagopus* and *Bromus rubens*) are characteristic of so-called sub-nitrophilous Mediterranean annual grasslands (Rivas-Martinez and Izco 1977). The high cover of nutrient-demanding species such as *Malva* spp. and *Diplotaxis virgata* in certain habitats (perennial herb communities, roadside communities) is related to the greater availability of certain macronutrients such as N and P in the soil in comparison to other ruderal habitats such as those dominated by *Hordeum leporinum* (Molina et al. 2023; Molina et al. 2024). These differences between ruderal habitats support the various phytosociological order units, namely *Brometalia* for ruderal vegetation on soils that are not excessively nitrified, and Chenopodietalia muralis for ruderal nitrified soils (Rivas-Martinez and Izco, 1977; Mucina et al. 2016). Perennial grasslands

characterized by *Dactylis glomerata* are not only considered a common plant species in natural environments (San Miguel et al. 2009) but also in synanthropic habitats (Gros et al. 2023). Dactylis glomerata is a widely distributed and taxonomically complex taxon (Horjales et al. 2008), pointing to the interest of studying the taxonomic elucidation of urban populations.

Cities under a Mediterranean climate host a greater urban floristic diversity than those in other temperate climates (Lubarda et al. 2023). A high heterogeneity in species composition is a key feature of urban and peri-urban areas, as local spatial variation depends on factors such as land use and management, parent material and land cover (Lorenz and Lal 2009; Norton et al. 2016). According to our results, sub-nitrophilous annual grasslands supported the highest abundance (density of individuals), and perennial herb communities had the lowest abundance and species density. A decreasing species richness from annual grasslands to perennial herbs has previously been reported in Mediterranean cities (Filibeck et al. 2016). Perennial herbs of *Malva* species have been associated with highly disturbed habitats (Dana et al. 2002; Güler 2020), particularly with the high availability of soil nutrients and a rapid and high demand for nutrients (Molina et al. 2023).

Cities are places with a high potential to address questions of evolutionary biology (Diamond and Martin 2021), and where the natural ecological succession can be studied to determine how the response of ruderal vegetation relates to the disturbances caused by urbanization (Rivas-Martínez 1978, Zipperer 2011). Our study revealed that ruderal communities dominated by nutrient-demanding species are at the opposite ends of the range of alpha diversity: specifically roadside communities with the highest value, and perennial herb communities with the lowest. These communities also had a lower floristic similarity. Annual grasslands showed a higher similarity value with the rest of the plant communities, as they shared a higher number of species. We therefore hypothesize that annual grasslands constitute a general herbaceous matrix in Mediterranean urban greenspaces, whereas perennial herb communities and roadside vegetation correspond to successional stages related to different soil disturbances. Since perennial grasslands showed a higher floristic dissimilarity with perennial herbs and roadside vegetation, which are most closely related to more disturbed soils (Molina et al. 2023; Molina et al. 2024), we also assume that perennial grasslands correspond to a successional stage towards a more established soil (Fig. 8).

On a global scale, productivity is a poor predictor of plant species richness in herbaceous-dominated plant communities (Adler et al. 2011). The effect of species composition diversity on the biomass level is complex (Ryś et al. 2023). In the study of Mediterranean ruderal vegetation, we found that perennial herbs of Malva species tended to have a higher biomass and lower species density. Vegetation type influences the relationship between plant biomass and plant diversity with soil nutrients (Fayiah et al. 2019). Malva communities are constituted by an assemblage of dense tall herbs developed on soils with a large amount of organic matter and nutrient availability (Molina et al. 2023, Molina et al. 2024), which supports the positive correlation between soil nutrients and plant biomass, and the inverse relationships between species richness and productivity at higher production levels found by Vermeer and Berendse (1983). In contrast, the other perennial vegetation in the study, perennial grasslands, tended to have a

lower biomass. They are dominated by the tufted grass *Dactylis glomerata*, and form open grasslands, which may explain their lower biomass. The structure of the vegetation type, the plant habit of the dominant plant species in the plant community and the soil nutrients may thus help to explain why perennial herbs were found to be the main contributors to supporting ecosystem services related to primary production.

According to our results, species participate differently in macronutrient cycles due to their different macronutrient composition. Specifically, *Malva* species and *Diplotaxis virgata* showed higher N content in their leaves than the other plants. Malva species have been mentioned as having a high N and protein content (Ben-Simchon et al. 2019; Özbakır Özer and Aksoy 2019), and high levels of nitrate accumulation have been reported in *Diplotaxis* spp. (Bianco et al. 1998). These physiological features may be associated with a high availability of soil macronutrients where they develop (Molina et al. 2023), which justifies their qualification as nitrophilous species (Gómez and Alcaraz 1993; Norton et al. 2016). The high sulphur content we found in the leaves and roots of *Diplotaxis virgata* is due to the fact that *Diplotaxis* species are major producers of glucosinolates, organic compounds containing sulphur and nitrogen (D'Antuono et al. 2008; Branca and Cartea 2011). *Diplotaxis* communities have been related to higher soil arylsulfatase activity (Molina et al. 2023). Since sulphate and nitrate ions in soils have been suggested to have an inhibitory effect on soil arylsulfatase activity (Siwik-Ziomek and Koper 2010), it can be inferred that arylsulfatase activity may be responsible for ensuring that there is enough sulphur fraction available to plants. *Malva* and *Diplotaxis* species are thus important contributors in the N and S cycles. Ruderal perennial grasslands of *Dactylis glomerata* develop on carbon-rich soils (Quintana et al. in press). Based on our results, the dominant Gramineae species in both perennial and annual grasslands had a higher C and C/N content in leaves and a lower C content in roots. Thus, a higher plant contribution to the C cycle is likely to occur in these habitats.

Conclusions

Supporting ecosystem services provided by ruderal urban vegetation were related to the plant-community type. We found that Mediterranean urban greenspaces maintain a high plant biodiversity in ruderal vegetation. Specifically, roadside communities had the highest species richness and alpha diversity; and annual grasslands showed the highest abundance. The greatest similarity was specifically found between roadside communities and annual grasslands, highlighting the important contribution of these habitats to maintaining biodiversity in Mediterranean cities. According to our results, perennial herb communities accounted for the main contribution to primary production. The contribution of ruderal vegetation to macronutrient cycles may be related to that of the dominant species. Thus, perennial forbs of *Malva* species and roadside communities of *Diplotaxis virgata* were the main contributors to the N cycle, and the latter also to the S cycle. Perennial grasslands of *Dactylis glomerata* and annual grasslands of *Hordeum leporinum* showed a greater contribution to the C cycle.

Declarations

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References

1. Adler PB, Seabloom EW, Borer ET et al. (2011) Productivity is a poor predictor of plant species richness. Science 333(6050):1750–1753. https://doi.org/10.1126/science.1204498
2. Aedo C, Buira A, Medina L, Fernández-Albert M (2017) The Iberian Vascular Flora: Richness, Endemicity and Distribution Patterns. In: Loidi J (ed) The Vegetation of the Iberian Peninsula. Plant and Vegetation. Springer, Cham, pp 101–130 https://doi.org/10.1007/978-3-319-54784-8_4
3. AEMET (2023) Valores climatológicos normales. Madrid. https://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=3195&k=undefined. Accessed 25 Mar 2024
4. Beauvais MP, Pellerin S, Lavoie C (2016) Beta diversity declines while native plant species richness triples over 35 years in a suburban protected area. Biol Conserv 195:73–81. https://doi.org/10.1016/j.biocon.2015.12.040
5. Ben-simchon E, Sapir E, Vaknin Y, Shelef O (2019) Malvaceae spp. leaves as a novel crop for food. International Journal of Agriculture Forestry and Life Sciences 3:279–286
6. Benvenuti S (2004) Weed dynamics in the Mediterranean urban ecosystem: Ecology, biodiversity and management. Weed Res 44(5):341–354. https://doi.org/10.1111/j.1365-3180.2004.00410.x
7. Bianco PM, Pignatti S, Bianco PM, et al (2003) Ruderalization in a Roman Park as a Result of Changing Management. Urban habitats 1
8. Bianco VV, Santamaria P, Elia A (1998) Nutritional value and nitrate content in edible wild species used in southern Italy. Acta Hortic 71–90. https://doi.org/10.17660/ActaHortic.1998.467.7
9. Bot Mad et al. (2023) Madrid Flora Urbana. Catálogo de la flora silvestre urbana, Lista Roja y recomendaciones para la gestión del patrimonio botánica de la ciudad. Doce calles, Aranjuez
10. Branca, F., Cartea, E. (2011). Brassica. In: Kole, C. (eds) Wild Crop Relatives: Genomic and Breeding Resources. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-14871-2_2
11. Bretz Frank, Hothorn Torsten, Westfall PH (2023) Package 'multcomp' L http://multcomp.R-forge.R-project.org Accessed 15 Oct 2023
12. Bretzel F, Malorgio F, Paoletti L, Pezzarossa B (2012) Response of sowed, flowering herbaceous communities suitable for anthropic Mediterranean areas under different mowing regimes. Landsc Urban Plan 107(2):80–88. https://doi.org/10.1016/j.landurbplan.2012.05.002
13. Castro, M. C.M.L., & Ponte-EeSousa, C.M.C. (2012). Lawns and ornamental meadows as an alternative in the South Europe. Dissertation, Congressos Científicos Internacionais.

14. Castroviejo, S. (coord. gen.). 1986-2012. Flora iberica 1-8, 10-15, 17-18, 21. Real Jardín Botánico, CSIC, Madrid.
15. Castroviejo, S., Aedo, C., Cirujano, S., Laínz, M., Montserrat, P., Morales, R., Muñoz Garmendia, F., Navarro, C., Paiva, J. & Soriano, C. (eds.). 1993. Flora iberica 3. Real Jardín Botánico, CSIC, Madrid.
16. Chocholoušková Z, Pyšek P (2003) Changes in composition and structure of urban flora over 120 years: a case study of the city of Plzeň. Flora - Morphology, Distribution, Functional Ecology of Plants 198:366–376. https://doi.org/10.1078/0367-2530-00109
17. Cooke J, Leishman MR (2012) Tradeoffs between foliar silicon and carbon-based defences: evidence from vegetation communities of contrasting soil types. Oikos 121(12):2052–2060. https://doi.org/10.1111/j.1600-0706.2012.20057.x
18. Dana ED, Vivas S, Mota JF (2002) Urban vegetation of Almería City - a contribution to urban ecology in Spain. Landsc Urban Plan 59(4), 203–216. https://doi.org/10.1016/S0169-2046(02)00039-7
19. D'Antuono, L & Elementi, Simona & Neri, Roberta (2008) Glucosinolates in Diplotaxis and Eruca leaves: Diversity, taxonomic relations and applied aspects. Phytochemistry 69, 187-99. https://doi.org/10.1016/j.phytochem.2007.06.019
20. Dearborn, D. C., & Kark, S. (2010). Motivations for conserving urban biodiversity. Conserv Biol 24(2): 432–440. https://doi.org/10.1111/j.1523-1739.2009.01328.x
21. Diamond SE, Martin RA (2021) Evolution in Cities. https://doi.org/10.1146/annurev-ecolsys-012021
22. Faeth SH, Bang C, Saari S (2011) Urban biodiversity: patterns and mechanisms. Ann. N. Y. Acad. Sci, 1223(1), 69–81. https://doi.org/10.1111/J.1749-6632.2010.05925.X
23. FAO (2014) World reference base for soil resources 2014: international soil classification system for naming soils and creating legends for soil maps. https://www.fao.org/3/i3794en/I3794en.pdf Accessed 20 Dic 2023
24. Fayiah M, Dong S, Li Y, Xu Y, Gao X, Li S, Shen H, Xiao J, Yang Y, Wessell K (2019) The relationships between plant diversity, plant cover, plant biomass and soil fertility vary with grassland type on Qinghai-Tibetan Plateau. Agric. Ecosyst. Environ, 286, 2019, 106659. https://doi.org/10.1016/j.agee.2019.106659
25. Filibeck G, Petrella P, Cornelini P (2016). All ecosystems look messy, but some more so than others: a case-study on the management and acceptance of Mediterranean urban grasslands. Urban For Urban Greening 15:32–39. https://doi.org/10.1016/j.ufug.2015.11.005
26. Gros C, Bulot A, Aviron S, et al (2023) Both management practices and landscape influence plant communities in urban grasslands. Front Ecol Evol 11:. https://doi.org/10.3389/fevo.2023.1151913
27. Güler B (2020) Plant species diversity and vegetation in urban grasslands depending on disturbance levels. Biologia (Bratisl) 75:1231–1240. https://doi.org/10.2478/s11756-020-00484-0
28. Guo P, Su Y, Wan W, et al (2018) Urban plant diversity in relation to land use types in built-up areas of Beijing. Chin Geogr Sci 28:100–110. https://doi.org/10.1007/s11769-018-0934-x

29. Hartig F, Lohse L (2022) Package “DHARMa” https://cran.r-project.org/web/packages/DHARMa/index.html Accessed 15 Oct 2023
30. Horjales M, Laso G, Redondo & N (2008) Dactylis glomerata L. (Poaceae) en la Península Ibérica
31. IPCC (2014) Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge
32. Kabisch N, Strohbach M, Haase D, Kronenberg J (2016) Urban green space availability in European cities. Ecol Indic 70:586–596. https://doi.org/10.1016/j.ecolind.2016.02.029
33. Kalarus K, Halecki W, Skalski T (2019) Both semi-natural and ruderal habitats matter for supporting insect functional diversity in an abandoned quarry in the city of Kraków (S Poland). Urban Ecosyst 22:943–953. https://doi.org/10.1007/s11252-019-00869-3
34. Kantsa A, Tscheulin T, Junker RR, et al (2013) Urban biodiversity hotspots wait to get discovered: The example of the city of Ioannina, NW Greece. Landsc Urban Plan 120:129–137. https://doi.org/10.1016/j.landurbplan.2013.08.013
35. López-Jiménez, Nicolás. (2007). Las plantas vasculares de la comunidad de madrid. Doctoral thesis (2007).
36. Lorenz K, Lal R (2009) Biogeochemical C and N cycles in urban soils. Environ Int 35:1–8. https://doi.org/10.1016/j.envint.2008.05.006
37. Lubarda B, Rat M, Petronić S, et al (2024) Urban floristic diversity in Bosnia and Herzegovina—the reflection of nature. Urban Ecosyst. https://doi.org/10.1007/s11252-024-01509-1
38. Midolo G, Axmanová I, Divíšek J, et al (2024) Diversity and distribution of Raunkiær’s life forms in European vegetation. Journal of Vegetation Science 35:. https://doi.org/10.1111/jvs.13229
39. Midolo G, Herben T, Axmanová I, et al (2023) Disturbance indicator values for European plants. Global Ecology and Biogeography 32:24–34. https://doi.org/10.1111/geb.13603
40. Molina JA (2022) Biodiversidad de los Campus UCM: vegetación y flora. In: Rescia Perazzo A, Lucas Olegario MGSM (eds) Trabajos en sostenibilidad y resiliencia socio-ecológica en la Universidad Complutense de Madrid. Ediciones Complutense, Madrid, pp 99–121
41. Molina JA, Martín-Sanz JP, Casermeiro MÁ, Quintana JR (2023) Spontaneous urban vegetation as an indicator of soil functionality and ecosystem services. Appl Veg Sci 26: https://doi.org/10.1111/avsc.12728
42. Molina JA, Martín-Sanz JP, Casermeiro MÁ, Quintana JR (2024) Soil depth and vegetation type influence ecosystem functions in urban greenspaces. Applied Soil Ecology 194:105209. https://doi.org/10.1016/j.apsoil.2023.105209
43. Mucina L, Bültmann H, Dierßen K, et al (2016) Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Appl Veg Sci 19:3–264. https://doi.org/10.1111/avsc.12257

44. Norton BA, Evans KL, Warren PH (2016) Urban biodiversity and landscape ecology: patterns, processes and planning. Current Landscape Ecology Reports 1:178–192. https://doi.org/10.1007/s40823-016-0018-5
45. Özer MÖ, Aksoy M (2019) Mineral composition and nutritional properties of Malva neglecta and Malvella sherardiana consumed as vegetable in Central Black Sea region of Turkey. Turkish Journal of Food and Agriculture Sciences 18–23
46. Panitsa M, Iliadou E, Kokkoris I, et al (2020) Distribution patterns of ruderal plant diversity in Greece. Biodivers Conserv 29:869–891. https://doi.org/10.1007/s10531-019-01915-4
47. Quintana, J. R., de la Cruz Caravaca, M. T., & Martínez, M. A. C. (2022). Suelos de la Ciudad Universitaria. In: Trabajos en sostenibilidad y resiliencia socio-ecológica en la Universidad Complutense de Madrid (pp. 91-97). Ediciones Complutense.
48. R Core Team (2022) R: A language and environment for statistical computing
49. Raunkiaer C (1934) The life forms of plants and statistical plant geography. Oxford University Press, London
50. Rivas-Martínez S (1978) La vegetación de Hordeion leporini en España. Documents Phytosociologiques 9:377–392
51. Rivas-Martínez S, Díaz TE, Fernández-González F, et al (2002) Vascular plant communities of Spain and Portugal. Addenda to the syntaxonomical checklist of 2001. Itinera Geobotanica
52. Rivas-Martinez S, Izco J (1977) Sobre la vegetacion terofitica subnitrofila mediterranea (Brometalia rubenti tectori). Anales 34:355–381
53. Robinson SL, Lundholm JT (2012) Ecosystem services provided by urban spontaneous vegetation. Urban Ecosystems 15(3):545–557. https://doi.org/10.1007/s11252-012-0225-8
54. Ryś K, Chmura D, Prostański D, Woźniak G (2023) Biomass amounts of spontaneous vegetation on post-coal mine novel ecosystem in relation to biotic parameters. Energies 16:7513. https://doi.org/10.3390/en16227513
55. San Miguel Ayanz A, Roig Gómez S, Alzueta Lusarreta C, et al. (2009). Los pastos de la Comunidad de Madrid, tipología, cartografía y evaluación. Dirección General de Medio Ambiente. Consejería de Medio Ambiente, Vivienda y Ordenación del Territorio. Editorial Solitario.
56. Sánchez Gómez P, Alcaraz Ariza F (1993) Flora, vegetación y paisaje vegetal de las sierras de segura orientales. Albacete
57. Seto KC, Fragkias M, Güneralp B, Reilly MK (2011) A Meta-Analysis of Global Urban Land Expansion. PLoS ONE 6(8): e23777. https://doi.org/10.1371/journal.pone.0023777
58. Siwik-Ziomek, Anetta & Koper, Jan (2010) Changes in the content of sulphate sulphur and arylsulphatase activity in soil under potato caused by fertilization. Journal of Elemntology 15. https://doi.org/10.5601/jelem.2010.15.1.171-176
59. Solecki, William & Marcotullio, Peter. (2013). Climate Change and Urban Biodiversity Vulnerability. Cities and Biodiversity Outlook: Urbanization, Biodiversity and Ecosystem Services: Challenges and

Opportunities. 85-504. https://doi.org/10.1007/978-94-007-7088-1_25

60. Sukopp H, Werner P (1983) Urban environments and vegetation. In: Man's impact on vegetation. Springer Netherlands, Dordrecht, pp 247–260
61. Swanwick C., Dunnett N., Woolley H. (2003) Nature, Role and Value of Green Space in Towns and Cities: An Overview. Built Environ 29:94–106. https://doi.org/10.2148/benv.29.2.94.54467
62. Tredici P Del (2010) Spontaneous urban vegetation: Reflections of change in a globalized world. Nature and Culture 5:299–315. https://doi.org/10.3167/nc.2010.050305
63. Valverde-Asenjo I, Diéguez-Antón A, Martín-Sanz JP, et al (2020) Soil and vegetation dynamics in a chronosequence of abandoned vineyards. Agric Ecosyst Environ 301:107049. https://doi.org/10.1016/j.agee.2020.107049
64. Vermeer JG, Berendse F (1983) The relationship between nutrient availability, shoot biomass and species richness in grassland and wetland communities. Vegetatio 53:121–126. https://doi.org/10.1007/BF00043032
65. Vieira J, Matos P, Mexia T, et al (2018) Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks. Environ Res 160:306–313. https://doi.org/10.1016/j.envres.2017.10.006
66. WFO (2023) Plant List | World Flora. https://wfoplantlist.org/plant-list/ Accessed 5 Dec 2023
67. Wickham H, Chang W, Henry L, et al (2024) Package "ggplot2" https://cran.r-project.org/web/packages/ggplot2/ggplot2.pdf Accessed 15 Oct 2023
68. Zara L, Tordoni E, Castro-Delgado S, et al (2021) Cross-taxon relationships in Mediterranean urban ecosystem: A case study from the city of Trieste. Ecol Indic 125:107538. https://doi.org/https://doi.org/10.1016/j.ecolind.2021.107538
69. Zhao X, Li F, Yan Y, Zhang Q (2022) Biodiversity in urban green space: A bibliometric review on the current research field and its prospects. International Journal of Environmental Research and Public Health. 2022; 19(19):12544. https://doi.org/10.3390/ijerph191912544
70. Zipperer WC (2011) The process of natural succession in urban areas. In: Douglas, Ian; Goode, David; Houck, Mike; Wang, Rusong (Eds.). (2010). The Routledge Handbook of Urban Ecology. Routledge. https://doi.org/10.4324/9780203839263

Figures

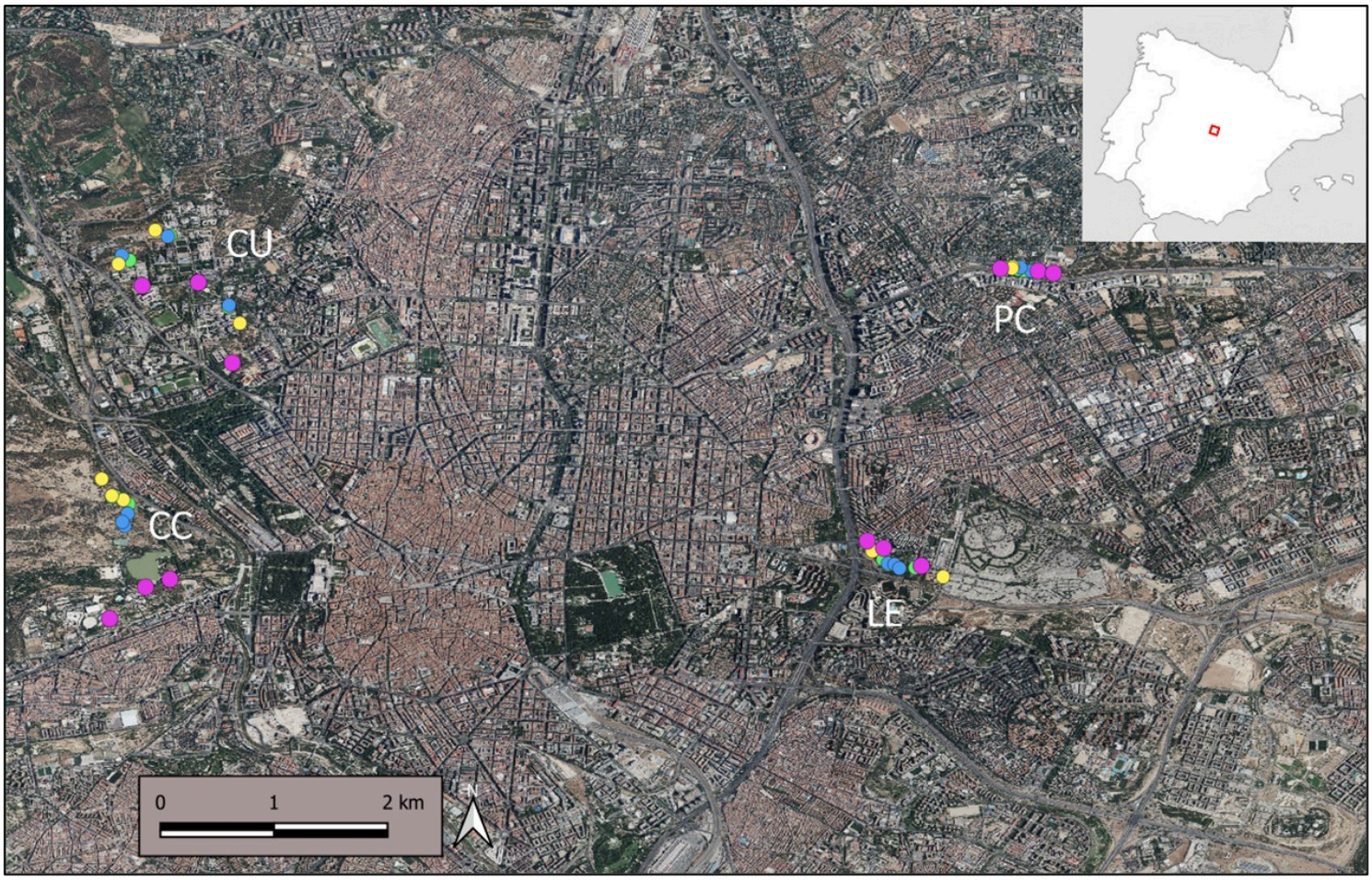

Figure 1

Location of the study area (Spain) (upper right square). Location of the sampling plots in four study greenspaces in Madrid city: Ciudad Universitaria (CU), Pinar Conde de Orgaz (PC), Parque de La Elipa (LE) and Casa de Campo (CC). Each colour represents a community: perennial herb communities (pink), roadside communities (yellow), annual grasslands (green) and perennial grasslands (blue)

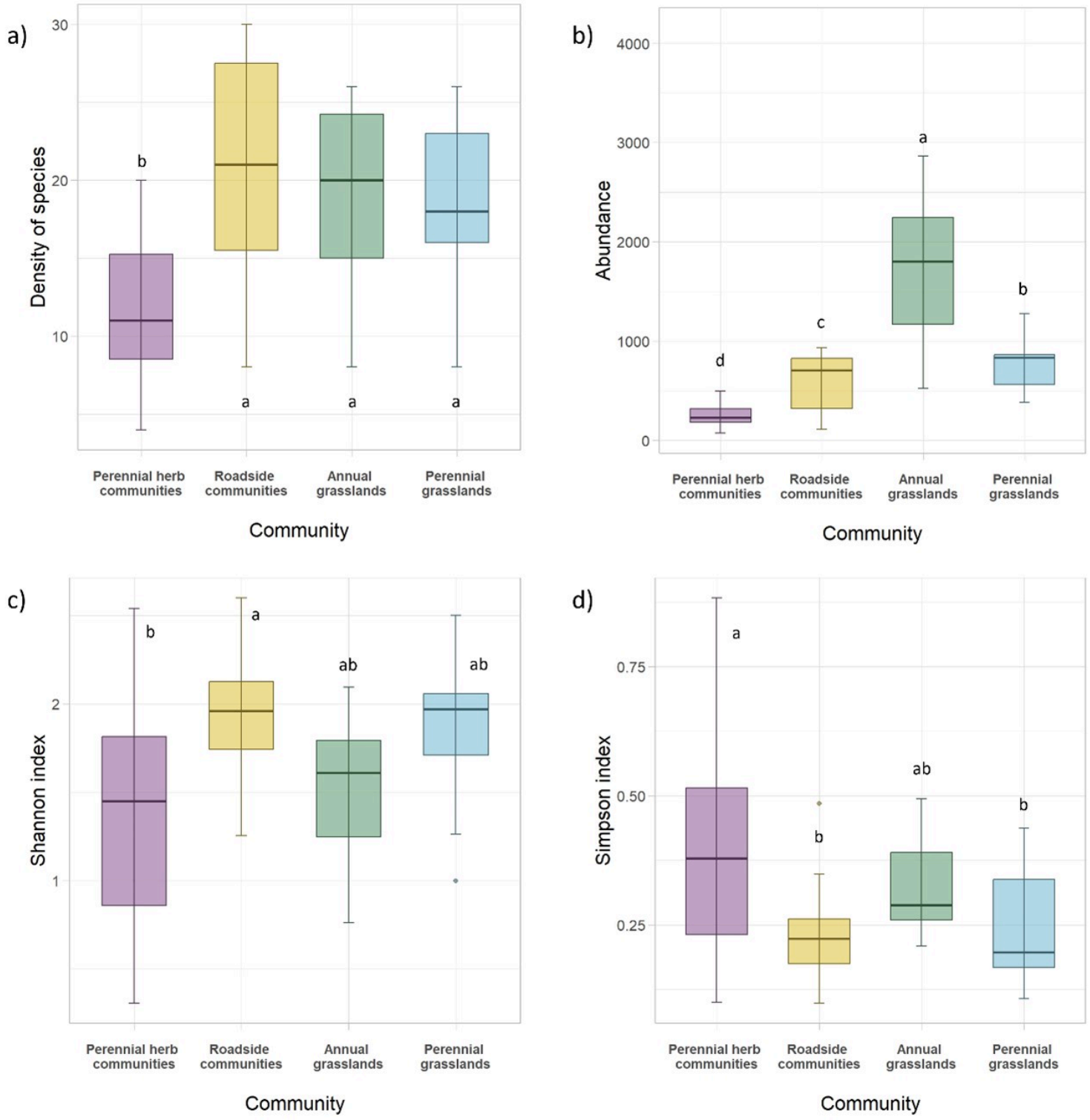

Figure 2

Species density (a), abundance (b), Shannon index (c) and Simpson index (d) in four community types (perennial herb communities, roadside communities, annual grasslands and perennial grasslands). Letters indicate significant differences between communities (GLM with a Tukey test, $P<0.05$)

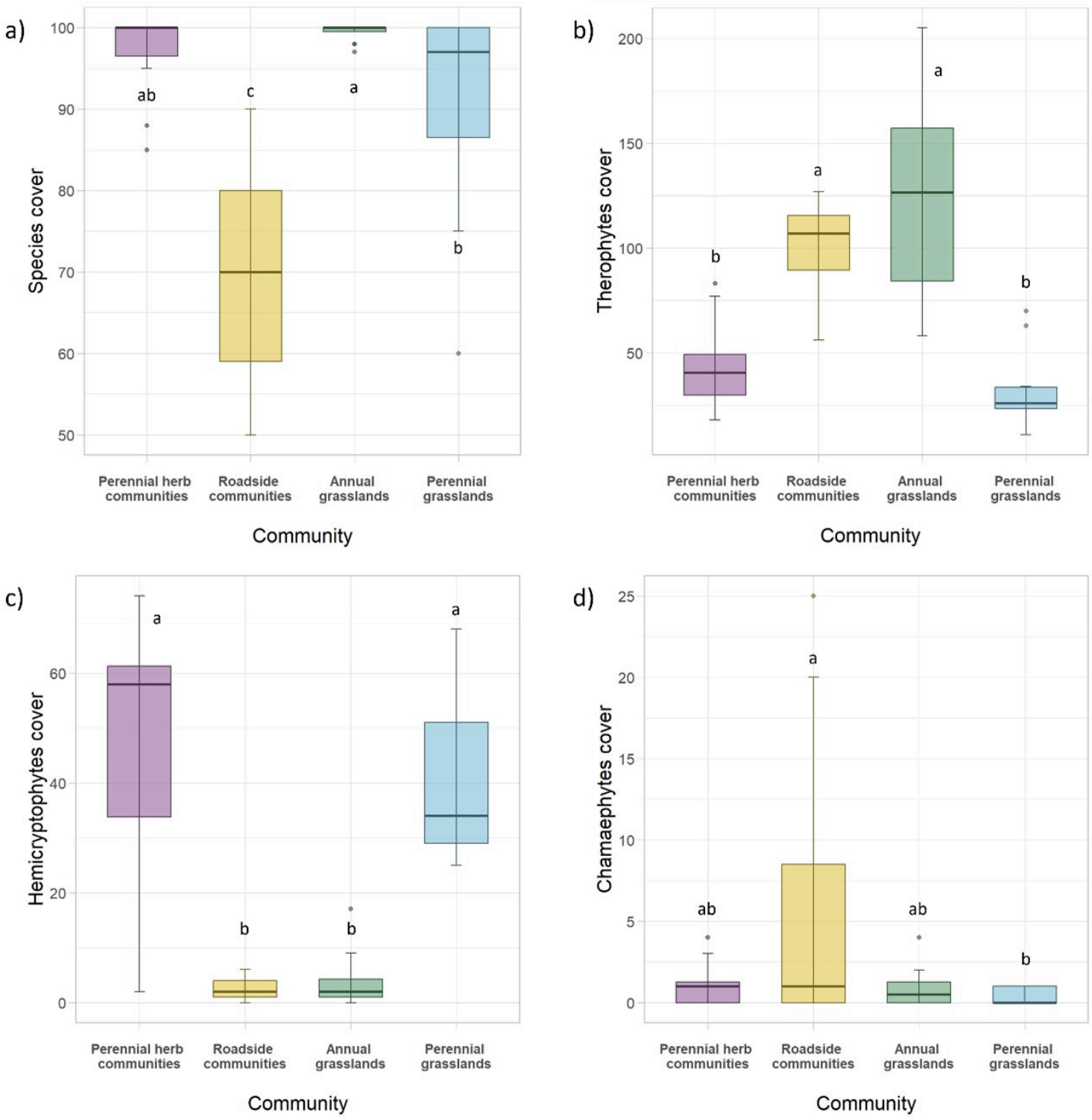

Figure 3

Total vegetation cover (a) and cover per biotype: therophytes (b), hemicryptophytes (c) and chamaephytes (d) in four community types (perennial herb communities, roadside communities, annual grasslands and perennial grasslands). Letters indicate significant differences between communities (GLM with a Tukey test, $P<0.05$)

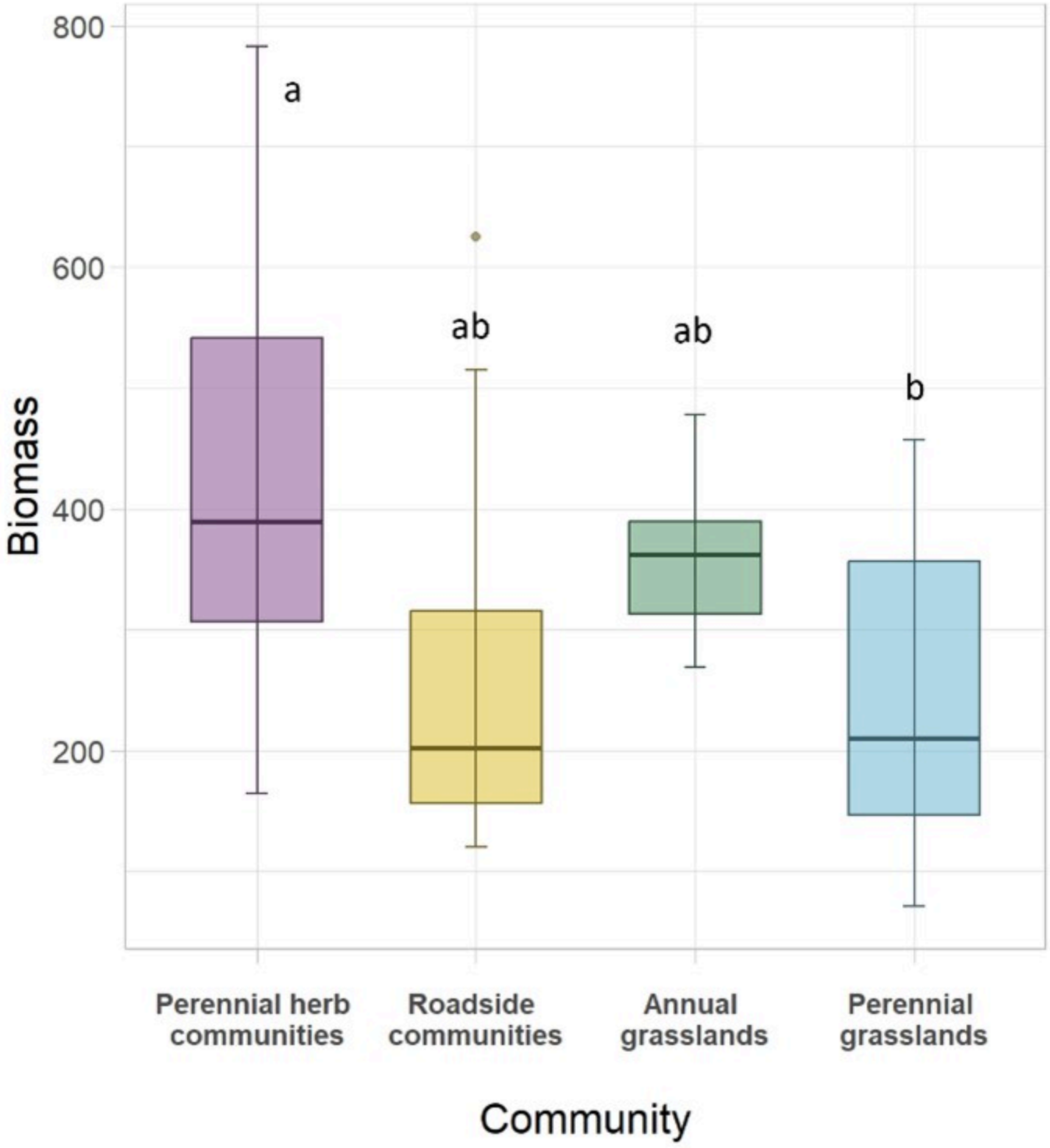

Figure 4

Biomass in four community types (perennial herb communities, roadside communities, annual grasslands and perennial grasslands). Letters indicate significant differences between communities (GLM with a Tukey test, $P<0.05$)

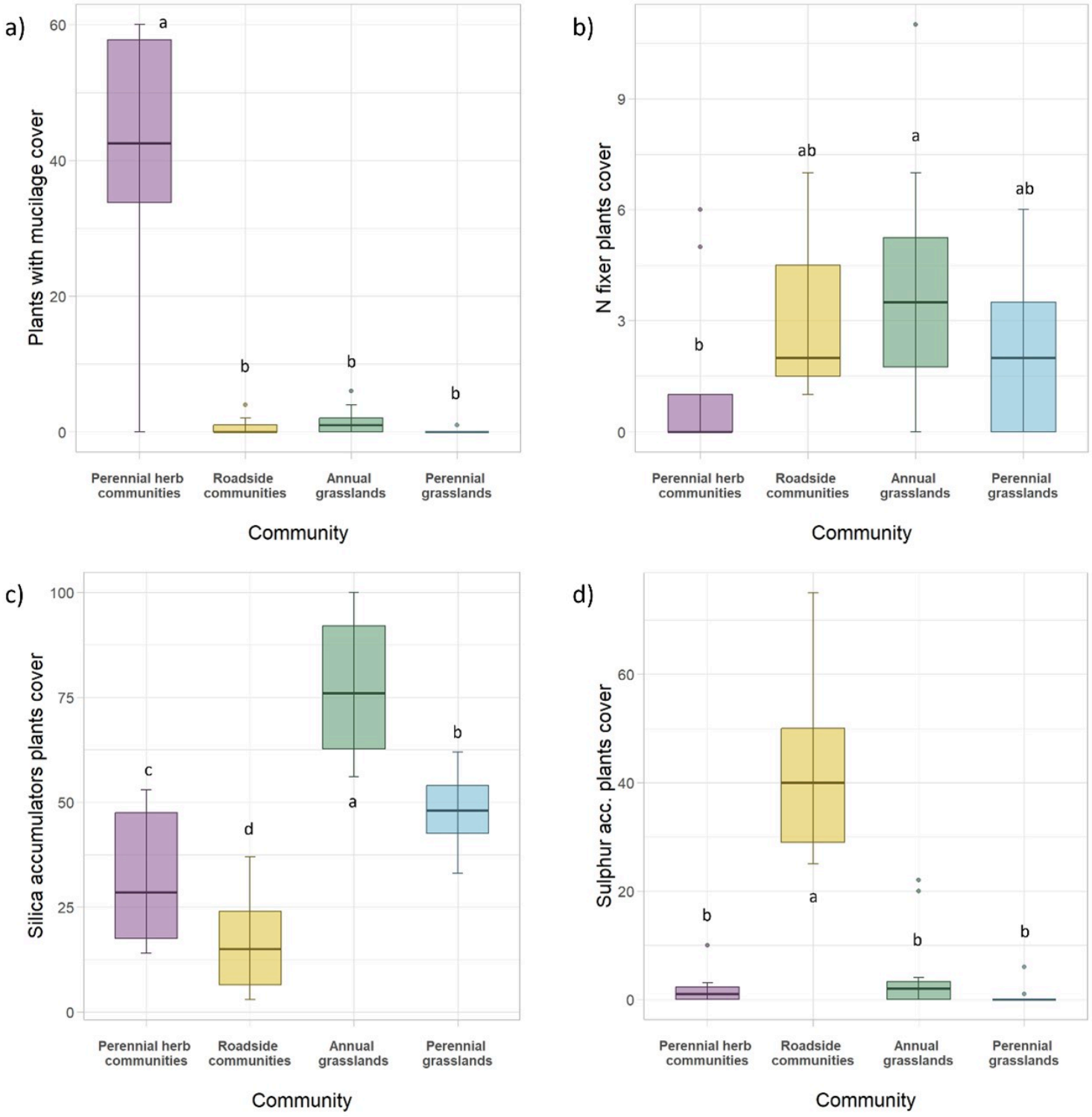

Figure 5

Cover of (a) mucilage-accumulating species, (b) N-fixer species, (c) phenolic compound accumulators, (d) silica-accumulating species and (e) sulphur-accumulating species in four community types (perennial herb communities, roadside communities, annual grasslands and perennial grasslands). Letters indicate significant differences between communities (GLM with a Tukey test, $P<0.05$)

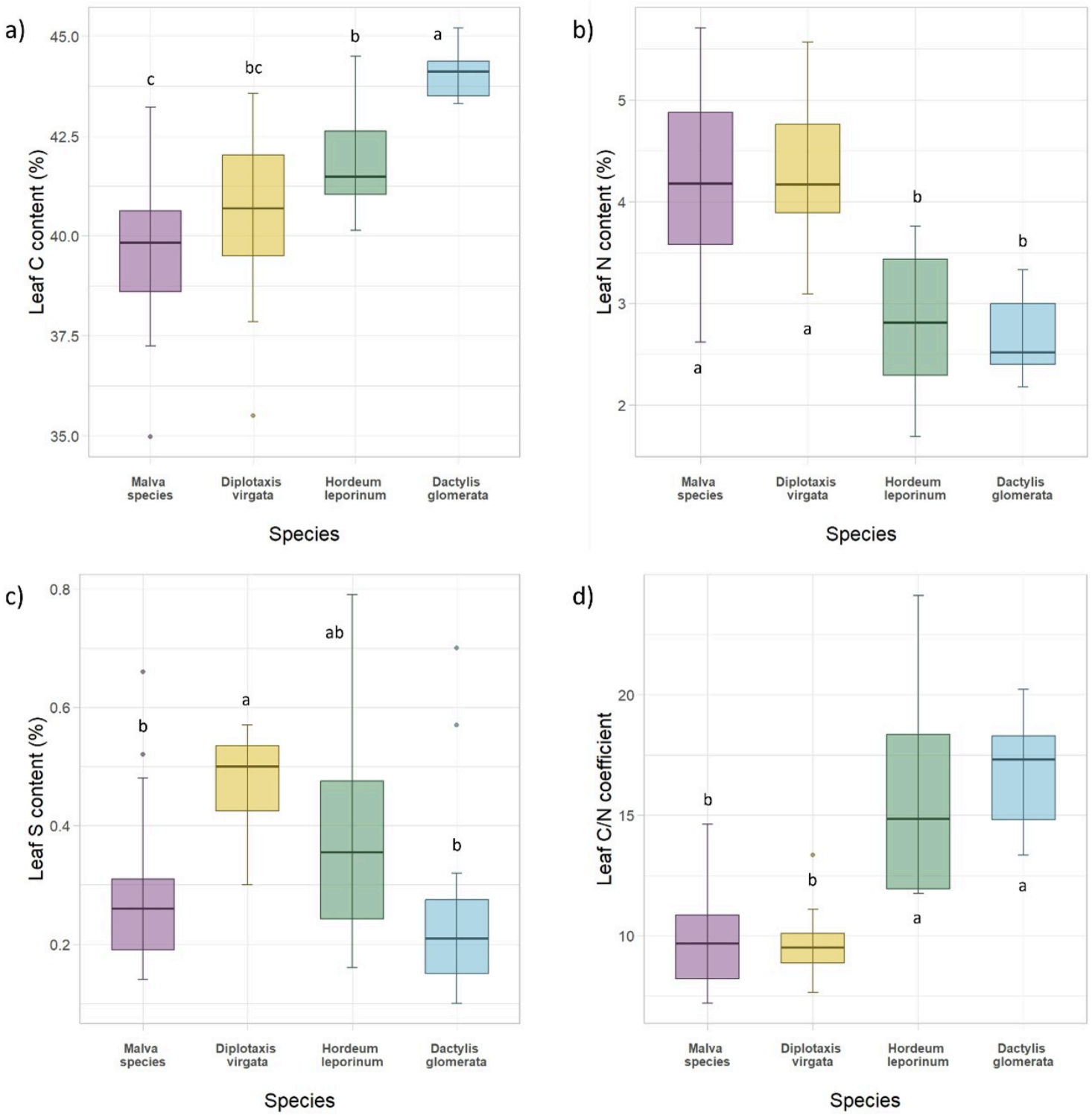

Figure 6

Carbon (a), nitrogen (b), sulphur (c) content (%) and C/N ratio (d) in leaves of the four most common species: *Malva*spp., *Diplotaxis virgata*, *Hordeum murinum* subsp. *leporinum*and *Dactylis glomerata*. Letters indicate significant differences between communities (GLM with a Tukey test, P<0.05)

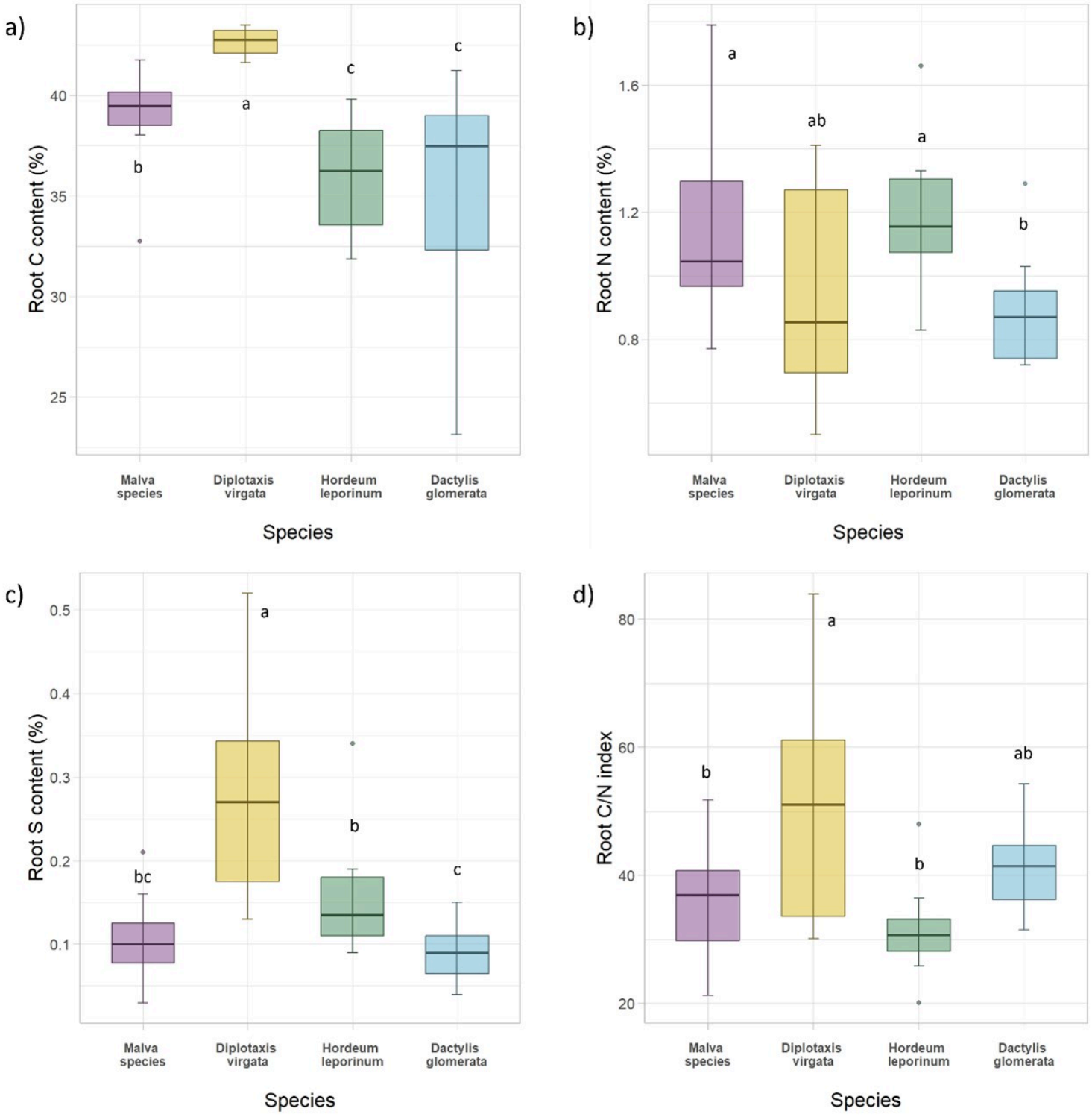

Figure 7

Carbon (a), nitrogen (b) and sulphur (c) content of roots (%) and C/N ratio of roots (d) of the four most common species: *Malva* spp., *Diplotaxis virgata*, *Hordeum murinum* subsp. *leporinum* and *Dactylis glomerata*. Letters indicate significant differences between communities (GLM with a Tukey test, P<0.05)

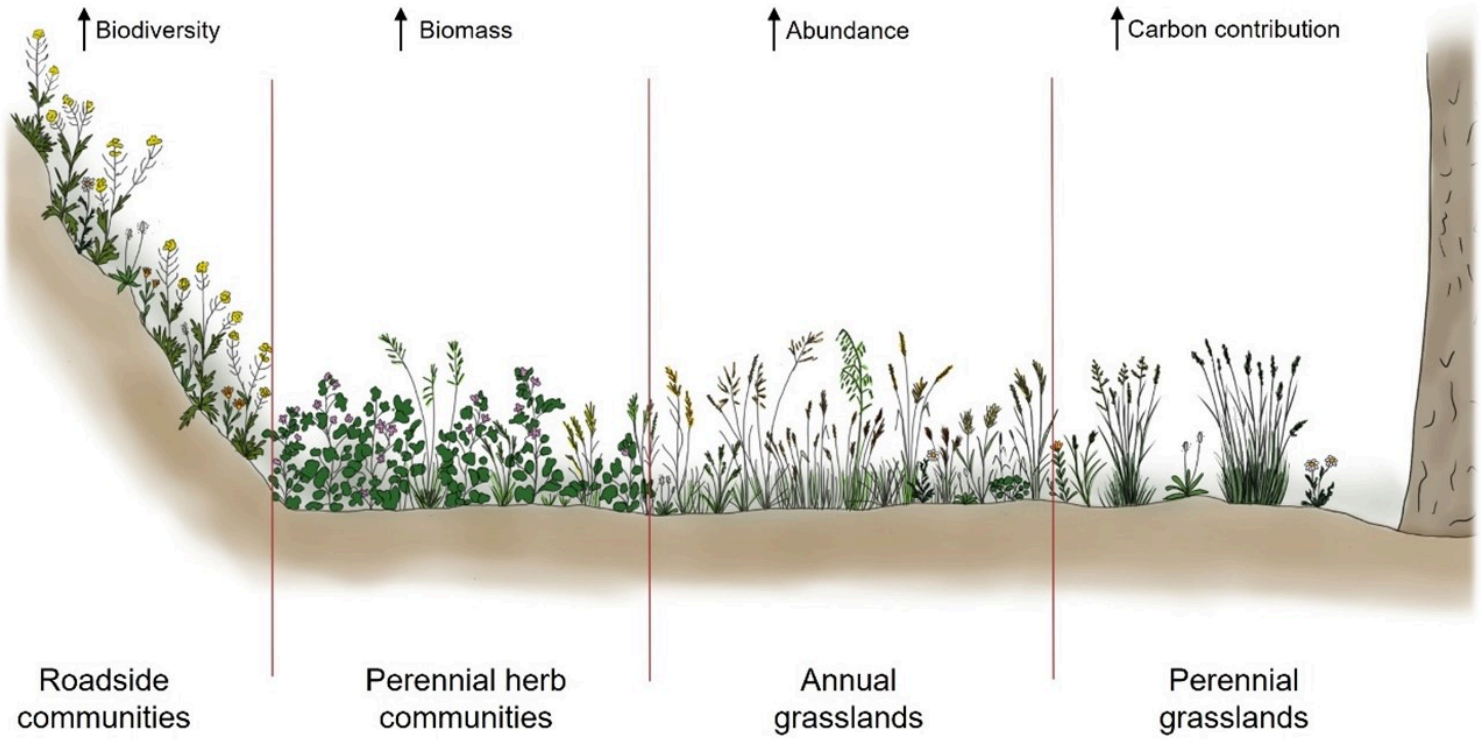

Figure 8

Representation of the four communities studied (roadside communities, perennial herb communities, annual grasslands and perennial grasslands) with the most representative species