

Article

Vegetation Management Changes Community Assembly Rules in Mediterranean Urban Ecosystems—A Mechanistic Case Study

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Abstract

Urban ecosystems are structurally and functionally distinct from their natural counterparts, with anthropogenic management potentially altering fundamental ecological processes such as seasonal community dynamics and impairing their sustainability. However, the mechanisms through which management filters plant diversity across seasons remain poorly understood. This study tested the hypothesis that management acts as an abiotic filter, dampening seasonal community variations and increasing biotic homogenization in urban green spaces. In this respect, through an intensive, multi-seasonal case study comparing two Mediterranean urban green spaces under contrasting management regimes, we analysed plant communities across 120 plots over four seasons. Results reveal a contingency cascade under management: while the species composition remains relatively stable (+26% variability, $p < 0.001$), the demographic success becomes more contingent (+41%, $p < 0.001$), and the ecological dominance becomes highly stochastic (+90%, $p < 0.001$). This hierarchy demonstrates that management primarily randomizes which species achieve dominance, in terms of biomass and cover, from a pool of disturbance-tolerant generalists. A 260% increase in alien and cosmopolitan species and persistent niche pre-emption dominance–diversity patterns also indicate biotic homogenization driven by management filters (mowing, trampling, irrigation, and fertilization) that favors species resistant to mechanical stresses and induces a breakdown of deterministic community assembly. These processes create spatially and temporally variable assemblages of functionally similar species, explaining both high structural variability and persistent functional redundancy. Conversely, seasonally structured, niche-based assemblies with clear dominance–diversity progressions are observed in the unmanaged area. Overall, findings demonstrate that an intensive management homogenizes urban plant communities by overriding natural seasonal filters and increasing stochasticity. The study provides a mechanistic basis for sustainable urban green space management, indicating that reduced intervention can help preserve the seasonal dynamics crucial for sustaining biodiversity and ecosystem functioning.

Keywords: urban vegetation; community seasonal dynamics; anthropogenic pressure; structural biodiversity; functional biodiversity; sustainable management; Mediterranean area



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1. Introduction

World population is rapidly increasing and concentrating in ever enlarging urban environments, 70% of which is expected to live in cities by 2050 [1]. From an ecological

point of view, urban environments represent heterotrophic and dissipative ecosystems [2], where the majority of human activities take place. The dysfunctional energy budget and organic matter cycle that characterize these ecosystems cause, irrespective of their still limited global coverage (less than 3% [3]), environmental pressures acting both at local and global scales, such as various forms of pollution, soil erosion and landscape fragmentation, ultimately impacting biodiversity and the provision of ecosystem services. Several authors have tried to quantify anthropogenic impacts on ecological systems, mainly focusing on proxies such as land use conversion [4,5], carbon dioxide emissions [6], or ecosystem processes from which we draw benefits [7,8]. Despite all these efforts, there is still no solid way to define or quantify the effects of multiple anthropogenic stressors [9] on ecological systems, especially at small spatial and temporal scales.

A way to mitigate these issues and, at the same time, improve the provision of ecosystem services by urban ecosystems, is the introduction of green areas within the urban tissue [10]. Indeed, despite their limited extension and connectivity, urban green areas are able to improve the overall functioning and stability of the urban ecosystem, support biodiversity, and provide material, non-material and control nature contributions to people [11]. However, these areas are subject to significant anthropogenic pressures [12–15], which can severely affect the biodiversity of less mobile species such as plants [16–19] and small animals [20–22]. For instance, the management of urban green areas (e.g., mowing and irrigation) can select species with specific functional traits, thus shaping plant community structure and dynamics [14,23,24].

These aspects are particularly relevant in regions such as the Mediterranean [25], where anthropogenic disturbances threaten the invaluable biodiversity comprising the 20% of global flowering plant and fern species [26], i.e., nearly 22,500 plant species, with 11,700 endemics [27,28]. In this area, wide annual oscillations in temperature and precipitations determine clear seasonal dynamics in community assemblages [29]. However, how anthropogenic disturbances modify these seasonal dynamics remains a remarkably understudied topic, despite the potential implications for trophic webs and overall diversity.

Although previous studies on urban vegetation have often focused on structural diversity at a single point in time [30,31], or on functional traits without tracking their seasonal dynamics [32,33], our study aims at going beyond this by integrating structural and functional diversity metrics throughout multiple seasons. This combined approach is crucial to fully understand how management practices alter not only the composition, but also the functional response and seasonal dynamics of plant communities [34,35].

We hypothesize that anthropogenic pressures from management practices alter the amplitude of seasonal community variations by filtering functional traits. In order to test this hypothesis, we compare the seasonal vegetation dynamics in two urban green areas subjected to different management regimes (mowing, irrigation, and fertilization) but similar in location, climate and land-use history. Through intensive seasonal sampling (120 samplings over 4 seasons), multiple abundance measures, and a wide spectrum of functional traits, this study sheds light on the complex interactions between anthropogenic activities and ecological dynamics in urban ecosystems.

2. Materials and Methods

2.1. Study Areas

The study was carried out over 4 seasons from October 2023 to July 2024, in two urban green spaces within the municipalities of Avellino (S_{AV} , Avellino province, $40^{\circ}54'22.71''$ N, $14^{\circ}48'19.73''$ E, 358 m a.s.l.) and Fisciano (S_{SA} , Salerno province, $40^{\circ}46'10.49''$ N, $14^{\circ}47'25.07''$ E, 251 m a.s.l.), Italy (Figure 1). Both areas exhibit a Mediterranean climate [36], with monthly mean temperatures of 15.9°C (S_{AV}) and 17.4°C (S_{SA}), and total

monthly precipitation of 81.8 mm (S_{AV}) and 110.2 mm (S_{SA}) over the period 1 September 2023 to 28 August 2024 (data from Avellino Genio-Civile and Serino stations for S_{AV} and from Baronissi, Mercato San Severino and Pizzolano stations for S_{SA} —<https://centrofunzionale.regione.campania.it/>, accessed on 31 August 2024). Information on landscape characteristics and history of the two areas was retrieved from aerial photogrammetry coverage and satellite imagery (<https://sit2.regione.campania.it/>, accessed on 1 January 2024, and the desktop application of Google Earth Pro v7.3.6).

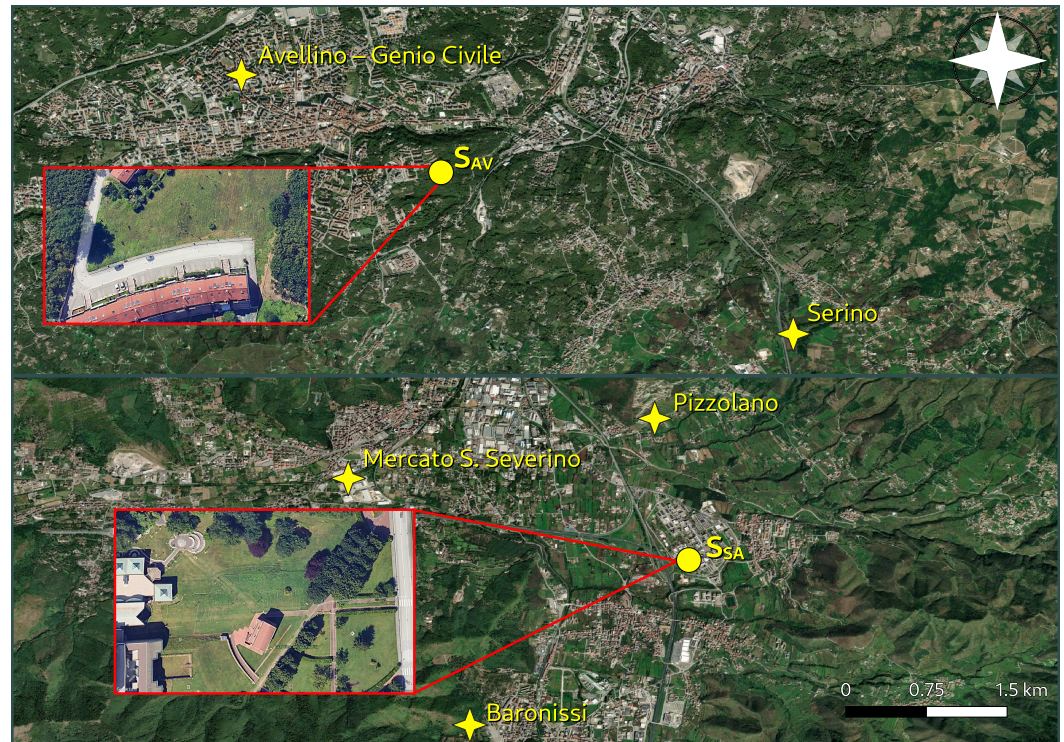


Figure 1. Aerial views of the study areas (S_{AV} , S_{SA}). Meteorological stations from which climate data were retrieved are indicated with yellow stars. Background images from ESRI Satellite imagery and inlays from Google Earth Pro.

S_{AV} is an unkempt peri-urban green space (around $160 \times 114 \text{ m}^2$) of artificial derivation. Prior to the construction of the first buildings around 2010 and the creation of the urban green space, the area was predominantly covered by orchards. After land-use conversion, efforts to enhance the fruition of the area with tree cover of *Quercus ilex* L. and *Tilia cordata* Mill. proved unsuccessful due to the lack of irrigation and fertilization. In fact, water availability for the vegetation in the area still depends exclusively on rainfall. Mowing is practiced twice a year during spring and summer, to avoid excessive vegetation growth. Trampling is negligible in the area and limited to the occasional passage of people, mainly during mowing.

S_{SA} is also an urban green space (around $130 \times 48 \text{ m}^2$) of artificial origin with recreational use. Before the construction of the first buildings, the area hosted agricultural fields and orchards. According to satellite imagery, land-use conversion to the actual destination occurred between 1984 and 1998, with the construction of a warehouse, sidewalks, and managed gardens. Further details regarding the area are reported in Baldi et al. [19]. Vegetation in the area is irrigated for 30 min daily and mowing is carried out every two weeks. Urea (40 g/m^2) is also applied as a fertilizer twice a year. Regular trampling occurs due to daily pedestrian use and recreational activities, except during holidays and weekends.

2.2. Phytosociological Surveys

Seasonally, 15 phytosociological surveys ($50 \times 50 \text{ cm}^2$) were carried out per study area, with their positions randomly selected, resulting in a total of 120 samplings over the course of one year. Each sampling campaign was completed within one week per area in order to avoid appreciable vegetation changes during the analyses. Herbaceous plants in each relevée were identified at the species level and their relative abundance was measured in terms of (i) coverage, (ii) number of plants and (iii) dry biomass [37]. In the field, species were preliminary identified through expert judgment and their coverage was estimated using the Braun–Blanquet method [38]. Individual plants of each species were then collected in paper bags, with the number of individuals recorded, and stored at 75°C for the dry biomass measurements. In the laboratory, species identification was revised using a M165C stereomicroscope (Leica Microsystems, Wetzlar, Germany) and the dichotomous keys of Pignatti et al. [39], while dry biomass was measured using a XT-220A analytical balance (Precisa, Dietikon, Switzerland). Species functional traits were also retrieved, i.e., family, Raunkiær life forms and chorology [39], as well as the Ellenberg indices [40].

2.3. Data Analysis

Data on species composition (thereafter referred to as P/A-presence-absence) and abundances were used to derive information on vegetation structural biodiversity, and were combined with the functional traits to investigate community functional biodiversity. Specifically, coverage data were transformed through the equation $x' = x^y$, where x is the coverage and y was chosen to be equal to 0.25 according to Wildi [38]. Chorotypes from Pignatti et al. [39] were grouped according to Di Biase et al. [41] to simplify their interpretation. The combined structural and functional data were used to derive functional metrics, allowing for a comprehensive evaluation of the multiple facets of functional diversity, i.e., dissimilarity, divergence, evenness, richness and Rao's quadratic entropy [42].

Seasonal changes in community structural and functional biodiversity were evaluated by means of non-metric multidimensional scaling (NMDS) based on 2 axes and either the Bray–Curtis dissimilarity metrics (for structural diversity) or the Euclidean distances (for functional diversity). Convex hulls and standard error ellipses (for $\alpha = 0.05$) enclosing observations belonging to each season were superimposed onto the NMDS spaces to evaluate potential differentiations among seasons. Species projections onto the NMDS spaces were computed using weighted average scores to evaluate the contribution of each variable in the differentiation of seasonal groups. The relative turnover of different families, chorotypes, and life forms across the seasons were further tested using χ^2 tests and estimated by the seasonal coefficient of variation, calculated as $CV = \sigma / \bar{x}$, where $\bar{x}$ indicates the mean of the total abundance of each functional trait in the different seasons and σ the respective standard deviation. In order to test the hypothesis of management-induced damping of seasonal shifts, the seasonal differentiation among communities was estimated using both the analysis of multivariate homogeneity of group dispersions (PERMDISP) and permutational multivariate analysis of variance (PERMANOVA). Specifically, the average distance of individual relevées to the group centroid was computed in Bray–Curtis spaces (for structural diversity) and Euclidean spaces (for functional diversity) for each area and season, with respect to the different variable types (species abundances vs z-score transformed functional metrics). The differences in dispersion between S_{AV} and S_{SA} were then estimated by permutational tests. In PERMANOVA, the overall differentiation of relevées in relation to area and season was sequentially estimated using the same distance spaces used in PERMDISP.

To test the hypotheses of management-induced biotic homogenization, the differences in the incidence of combined alien and cosmopolitan species in S_{AV} and S_{SA} were evaluated using a generalized linear model with a binomial family, including area and season as fixed factors. The same approach was also adopted to test the hypothesis of management promoting the incidence of species resistant to mechanical stresses such as trampling and mowing, by focusing on the combined incidence of Asteraceae and Poaceae.

For each season, all major rank abundance distribution (RAD) models of dominance–diversity relationships (niche pre-emption, log-normal, McArthur’s broken stick, Zipf, and Zipf–Mandelbrot [43]) were fitted to the abundance data, expressed as the number of individuals per species, in order to select the model that best represents the observed dominance–diversity patterns. Model selection was carried out using the Akaike’s information criterion (AIC). Furthermore, the differences in the proportions of functional groups between S_{AV} and S_{SA} were assessed.

All the analyses were carried out within the R 4.4.1 programming environment [44] with the functions of the “climaemet” [45], “fundiversity” [46], “ggplot2” [47], “ggpubr” [48], “ggtext” [49], “gridExtra” [50], “tidyr” [51] and “vegan” [52] packages.

3. Results

S_{AV} and S_{SA} show similar trends in temperature and rainfall, with characteristic dry conditions during summer but slightly higher total rainfall in the latter (Figure 2). Overall species richness is comparable between the areas, with 47 species (Table 1) in S_{AV} and 49 species (Table 2) in S_{SA} . Areas are also characterized by comparable species richness in winter (S_{AV} : 13 ± 2 and S_{SA} : 10 ± 4), autumn (S_{AV} : 6 ± 3 and S_{SA} : 6 ± 2) and summer (S_{AV} : 7 ± 2 and S_{SA} : 5 ± 1) but not in spring, when 41% fewer species are observed in S_{SA} than in S_{AV} (10 ± 4 and 17 ± 2 , respectively).

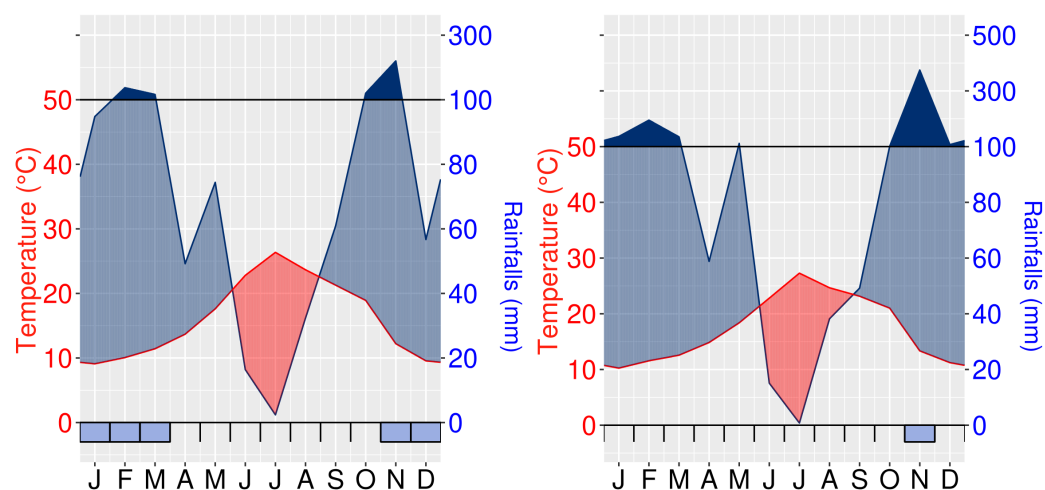


Figure 2. Walter–Lieth climatic diagrams for S_{AV} (left panel) and S_{SA} (right panel) areas. Mean temperatures are indicated in red and total precipitation in blue. Light blue boxes on the x axes indicate probable frost periods evaluated according to Pizarro et al. [45]. Temperature and precipitation data of September–December refer to 2023, whereas those of the other months refer to 2024. Data from <https://centrofunzionale.regione.campania.it/>, accessed on the 31 August 2024.

Table 1. Species identified in S_{AV} listed in Roman numerals, with indication of their families, chorology, biological forms, Ellenberg indices (L: light, T: temperature, C: continentality, U: moisture, R: soil reactivity, N: nutrients, S: salinity) and the seasons in which they were found (Aut: autumn, Spr: spring, Sum: summer, Win: winter). Abbreviations of life forms according to Ellenberg and Mueller-Dombois [53].

	Species	Family	Form	Chorotype	L	T	C	U	R	N	S	Season
I	<i>Anchusella cretica</i> (Mill.) Bigazzi, E. Nardi & Selvi	Boraginaceae	T scap	Stenomediterranean	7	8	6	3	5	6	0	Spr
II	<i>Arabidopsis thaliana</i> (L.) Heynh.	Brassicaceae	T scap	Paleotemperate	6		5	4	5	4	0	Spr, Win
III	<i>Artemisia vulgaris</i> L.	Asteraceae	H scap	Boreal	9	7	8	4		5	0	Spr
IV	<i>Avena barbata</i> Pott ex Link	Poaceae	T scap	Eurymediterranean	8	8	5	3	7	2	0	Spr, Sum, Win
V	<i>Briza media</i> L.	Poaceae	H caesp	Euro-Asiatic	6		4			2	0	Sum
VI	<i>Calepina irregularis</i> (Asso) Thell.	Brassicaceae	T scap	Eurymediterranean	8	8	4	3	5	3	0	Spr
VII	<i>Capsella bursa-pastoris</i> (L.) Medik.	Brassicaceae	H bienne	Cosmopolitan	7		5	5	5	4	0	Spr, Win
VIII	<i>Cardamine hirsuta</i> L.	Brassicaceae	T scap	Cosmopolitan	7	8	5	3	5	4	0	Win
IX	<i>Carex distachya</i> Desf.	Cyperaceae	H caesp	Stenomediterranean	6	6	4	2	4	5	0	Win
X	<i>Cerastium glomeratum</i> Thuill.	Caryophyllaceae	T scap	Eurymediterranean	7		5	5	5	5	0	Spr, Win
XI	<i>Cota tinctoria</i> (L.) J. Gay	Asteraceae	H bienne	European	8	6	5	2	6	4	0	Aut, Win
XII	<i>Crepis neglecta</i> L.	Asteraceae	T scap	Euro-Montane	7	6	3	4	6	3	0	Sum
XIII	<i>Crepis sancta</i> L.	Asteraceae	T scap	Eurymediterranean	11	9	6	2		2	0	Aut, Spr, Win
XIV	<i>Cynodon dactylon</i> L.	Poaceae	G rhiz	Cosmopolitan	8	8	5	4		4	0	Aut, Spr, Sum, Win
XV	<i>Daucus carota</i> L. subsp. <i>carota</i>	Apiaceae	H bienne	Paleotemperate	8	6	5	4	5	4	0	Aut, Spr, Sum, Win
XVI	<i>Digitaria sanguinalis</i> (L.) Scop.	Poaceae	T scap	Cosmopolitan	7	7	5	3	6	4	0	Aut
XVII	<i>Equisetum telmateja</i> Ehrh.	Equisetaceae	G rhiz	Boreal	5	7	4	8	8	5	0	Sum
XVIII	<i>Erigeron sumatrensis</i> Retz.	Asteraceae	T scap	Alien	8	8	5	3		7	0	Spr, Sum
XIX	<i>Erodium cicutarium</i> (L.) L'Hér	Geraniaceae	T scap	Cosmopolitan	8	7	5	3	5	3	0	Spr
XX	<i>Hypericum perforatum</i> L.	Hypericaceae	H scap	Paleotemperate	7	8	6				0	Aut, Spr, Sum, Win
XXI	<i>Hypochaeris radicata</i> L.	Asteraceae	H ros	European	9	8	4	2		1	0	Spr
XXII	<i>Lamium purpureum</i> L.	Lamiaceae	T scap	Euro-Asiatic	7	7	5	4	5	5	0	Spr, Win
XXIII	<i>Lolium perenne</i> L.	Poaceae	H caesp	Boreal	8	5	4	5		7	0	Sum
XXIV	<i>Medicago arabica</i> (L.) Huds.	Fabaceae	T scap	Eurymediterranean	9	9	5	2		2	0	Aut, Spr, Sum, Win
XXV	<i>Medicago lupulina</i> L.	Fabaceae	T scap	Paleotemperate	7	5		4	8	7	0	Spr, Sum
XXVI	<i>Minuartia hybrida</i> (Vill.) Shischk	Caryophyllaceae	T scap	Paleotemperate	7	7	5	3	6	2	0	Spr
XXVII	<i>Myosotis ramosissima</i> Rochel subsp. <i>ramosissima</i>	Boraginaceae	T scap	European	9	8	5	2	4	3	0	Spr
XXVIII	<i>Ornithogalum umbellatum</i> L.	Asparagaceae	G bulb	Eurymediterranean	5	6	5	5	7	5	0	Spr, Win
XXIX	<i>Ornithopus compressus</i> L.	Fabaceae	T scap	Eurymediterranean	11	9	5	2	2	1	0	Aut, Spr, Sum, Win
XXX	<i>Papaver rhoeas</i> L.	Papaveraceae	T scap	Euro-Montane	6	6	5	5	7		0	Spr
XXXI	<i>Petrorhagia prolifera</i> (L.) P.W. Ball & Heywood	Caryophyllaceae	T scap	Eurymediterranean	8	5	5	2		2	0	Sum
XXXII	<i>Picris hieracioides</i> L.	Asteraceae	H scap	Euro-Asiatic	8		5	4	8	4	0	Sum
XXXIII	<i>Plantago lanceolata</i> L.	Plantaginaceae	H ros	Euro-Asiatic	6	7	5				0	Aut, Spr, Sum, Win
XXXIV	<i>Poa annua</i> L.	Poaceae	T caesp	Cosmopolitan	7		5	6		8	0	Spr, Win
XXXV	<i>Raphanus raphanistrum</i> L.	Brassicaceae	T scap	Eurymediterranean	11	5	5		4	5	0	Aut, Sum
XXXVI	<i>Senecio vulgaris</i> L.	Asteraceae	T scap	Eurymediterranean	7			5		8	0	Spr
XXXVII	<i>Setaria pumila</i> (Poir.) Roem & Schult.	Poaceae	T scap	Cosmopolitan	7	7	5	4	5	6	0	Aut, Sum
XXXVIII	<i>Sherardia arvensis</i> L.	Rubiaceae	T scap	Eurymediterranean	8	6	5	5	8	5	0	Aut, Spr, Sum, Win
XXXIX	<i>Silene gallica</i> L.	Caryophyllaceae	T scap	Eurymediterranean	8	9	5	3	2	1	0	Spr
XL	<i>Sorghum halepense</i> (L.) Pers.	Poaceae	G rhiz	Cosmopolitan	8	8		7	8	8	0	Aut, Sum
XLI	<i>Trifolium arvense</i>	Fabaceae	T scap	Paleotemperate	8	5	5	2	2	1	0	Spr
XLII	<i>Trifolium campestre</i> Schreb.	Fabaceae	T scap	Paleotemperate	8	5	5	4		3	0	Spr, Sum
XLIII	<i>Trifolium pratense</i> L.	Fabaceae	Ch pulv	Euro-Asiatic	7		4				0	Aut, Spr, Sum, Win
XLIV	<i>Trifolium repens</i> L.	Fabaceae	Ch rept	Paleotemperate	8					7	0	Aut, Spr, Sum, Win
XLV	<i>Valerianella carinata</i> Loisel.	Valerianaceae	T scap	Eurymediterranean	7	8	5	4	8		0	Spr, Win
XLVI	<i>Veronica arvensis</i> L.	Plantaginaceae	T scap	Paleotemperate	5	5	5	5	6		0	Aut, Spr, Win
XLVII	<i>Vicia sativa</i> L.	Fabaceae	T scap	Eurymediterranean	5	5	6				0	Aut, Spr, Sum, Win

Table 2. Species identified in S_{SA} listed in Roman numerals, with indication of their families, chorology, biological forms, Ellenberg indices (L: light, T: temperature, C: continentality, U: moisture, R: soil reactivity, N: nutrients, S: salinity) and the seasons in which they were found (Aut: autumn, Spr: spring, Sum: summer, Win: winter). Abbreviations of life forms according to Ellenberg and Mueller-Dombois [53].

	Species	Family	Form	Chorotype	L	T	C	U	R	N	S	Season
I	<i>Artemisia vulgaris</i> L.	Asteraceae	H scap	Boreal	9	7	8	4		5	0	Aut, Spr, Sum, Win
II	<i>Avena barbata</i> Pott ex Link	Poaceae	T scap	Eurymediterranean	8	8	5	3	7	2	0	Spr
III	<i>Bromus hordeaceus</i> L.	Poaceae	T scap	Cosmopolitan	7	6	5				0	Spr
IV	<i>Cardamine hirsuta</i> L.	Brassicaceae	T scap	Cosmopolitan	7	8	5	3	5	4	0	Spr, Win
V	<i>Carex distachya</i> Desf.	Cyperaceae	H caesp	Stenomediterranean	6	6	4	2	4	5	0	Win
VI	<i>Catapodium rigidum</i> (L.) C.E. Hubb.	Poaceae	T scap	Eurymediterranean	8	8	5	2	5	4	0	Spr
VII	<i>Cerastium glomeratum</i> Thuill.	Caryophyllaceae	T scap	Eurymediterranean	7		5	5	5	5	0	Spr, Win
VIII	<i>Convolvulus arvensis</i> L.	Convolvulaceae	G rhiz	Paleotemperate	7	7	5	4	5	5	0	Aut, Spr, Sum
IX	<i>Crepis bursifolia</i> L.	Asteraceae	H scap	Endemic	9	6	4	3	8	2	0	Win
X	<i>Crepis neglecta</i> L.	Asteraceae	T scap	European	7	6	3	4	6	3	0	Win
XI	<i>Cynodon dactylon</i> L.	Poaceae	G rhiz	Cosmopolitan	8	8	5	4		4	0	Aut, Spr, Sum, Win
XII	<i>Cyperus rotundus</i> L.	Cyperaceae	G rhiz	Cosmopolitan	8	10	5	6	8	5	0	Aut
XIII	<i>Dactylis glomerata</i> L.	Poaceae	H caesp	Paleotemperate	7	6	5	4	5	6	0	Spr, Sum, Win
XIV	<i>Dichondra micrantha</i> Urb.	Convolvulaceae	G rhiz	Alien	5	8	5	6	3	2	0	Aut, Spr, Sum, Win
XV	<i>Digitaria sanguinalis</i> (L.) Scop.	Poaceae	T scap	Cosmopolitan	7	7	5	3	6	4	0	Aut
XVI	<i>Erigeron canadensis</i> L.	Asteraceae	T scap	Alien	8	8	5	3		7	0	Aut
XVII	<i>Festuca ciliata</i> Gouan	Poaceae	T caesp	Eurymediterranean	8	9	5	2	4	2	0	Spr
XVIII	<i>Geranium rotundifolium</i> L.	Geraniaceae	T scap	Paleotemperate	7	8	5	3	6	3	0	Aut, Spr, Win
XIX	<i>Hypochaeris radicata</i> L.	Asteraceae	H ros	European	9	8	4	2		1	0	Aut, Spr, Sum, Win
XX	<i>Lamium purpureum</i> L.	Lamiaceae	T scap	Euro-Asiatic	7	7	5	4	5	5	0	Spr, Win
XXI	<i>Malva sylvestris</i> L.	Malvaceae	H scap	Euro-Asiatic	8	6	4	4		8	0	Aut, Spr, Sum, Win
XXII	<i>Medicago arabica</i> (L.) Huds.	Fabaceae	T scap	Eurymediterranean	9	9	5	2		2	0	Aut, Spr, Win
XXIII	<i>Medicago lupulina</i> L.	Fabaceae	T scap	Paleotemperate	7	5		4	8	7	0	Aut, Spr, Sum
XXIV	<i>Medicago sativa</i> L.	Fabaceae	H scap	Euro-Asiatic	8	5	7	3	9	3	0	Sum
XXV	<i>Medicago tenoreana</i> Ser.	Fabaceae	T scap	European	11	9	6	2		2	0	Win
XXVI	<i>Ornithogalum umbellatum</i> L.	Asparagaceae	G bulb	Eurymediterranean	5	6	5	5	7	5	0	Win
XXVII	<i>Oxalis corniculata</i> L.	Oxalidaceae	Ch rept	Eurymediterranean	7	7	0	4		6	0	Aut, Spr, Sum, Win
XXVIII	<i>Paspalum dilatatum</i> Poir.	Poaceae	H caesp	Alien		8		10	8	8	0	Aut, Sum, Win
XXIX	<i>Plantago lanceolata</i> L.	Plantaginaceae	H ros	Euro-Asiatic	6	7	5				0	Spr, Sum, Win
XXX	<i>Poa annua</i> L.	Poaceae	T caesp	Cosmopolitan	7		5	6		8	0	Spr, Win
XXXI	<i>Polygonum aviculare</i> L.	Polygonaceae	T rept	Cosmopolitan	7	7	5	3	6	1	0	Spr, Sum
XXXII	<i>Portulaca oleracea</i> L.	Portulacaceae	T scap	Cosmopolitan	7	8	5	4	7	7	0	Aut
XXXIII	<i>Potentilla reptans</i> L.	Rosaceae	H ros	Paleotemperate	6	6	5	6	7	5	0	Aut, Spr, Sum, Win
XXXIV	<i>Prunella vulgaris</i> L.	Lamiaceae	H scap	Boreal	7	6	4	6	4		0	Spr
XXXV	<i>Ranunculus arvensis</i> L.	Ranunculaceae	T scap	Paleotemperate	6	6	5	4	8		0	Spr
XXXVI	<i>Raphanus raphanistrum</i> L.	Brassicaceae	T scap	Eurymediterranean	11	5	5		4	5	0	Spr
XXXVII	<i>Rumex crispus</i> L.	Polygonaceae	H scap	Cosmopolitan	7	5	5	6		5	0	Spr, Win
XXXVIII	<i>Senecio vulgaris</i> L.	Asteraceae	T scap	Eurymediterranean	7			5		8	0	Win
XXXIX	<i>Sherardia arvensis</i> L.	Rubiaceae	T scap	Eurymediterranean	8	6	5	5	8	5	0	Aut, Spr, Win
XL	<i>Silene dioica</i> (L.) Clairv.	Caryophyllaceae	H scap	Paleotemperate	7	5	5	6	7	8	0	Spr, Sum, Win
XLI	<i>Sonchus oleraceus</i> L.	Asteraceae	T scap	Euro-Asiatic	7	5						Aut, Spr, Sum, Win
XLII	<i>Sorghum halepense</i> (L.) Pers.	Poaceae	G rhiz	Cosmopolitan	8	8		7	8	8	0	Aut, Spr, Sum
XLIII	<i>Stellaria media</i> (L.) Vill.	Caryophyllaceae	T rept	Cosmopolitan	6			4	7	8	0	Spr, Sum, Win
XLIV	<i>Symphyotrichum squamatum</i> (Spreng.) G.L. Nesom	Asteraceae	T scap	Alien	8	8	5	4	7	7	0	Aut
XLV	<i>Trifolium campestre</i> Schreb.	Fabaceae	T scap	Paleotemperate	8	5	5	4		3	0	Spr
XLVI	<i>Trifolium repens</i> L.	Fabaceae	Ch rept	Paleotemperate	8					7	0	Aut, Spr, Sum, Win
XLVII	<i>Trifolium resupinatum</i> L.	Fabaceae	T rept	Paleotemperate	8	8	5	5		5	0	Spr
XLVIII	<i>Veronica persica</i> Poir.	Plantaginaceae	T scap	Alien	8	7	5	5	5	6	0	Aut, Win, Spr
XLIX	<i>Vicia sativa</i> L.	Fabaceae	T scap	Euro-Asiatic	5	5	6				0	Spr, Win

Species in S_{AV} mostly belong to the families Fabaceae ($28 \pm 8\%$), Plantaginaceae ($17 \pm 7\%$) and Poaceae ($13 \pm 3\%$) (Figure 3), whereas in S_{SA} (Figure 3) they are mostly represented by Poaceae ($26 \pm 8\%$, e.g., *C. dactylon* and *D. glomerata*) and, to a lesser extent, by Asteraceae ($10 \pm 4\%$), Convolvulaceae ($10 \pm 3\%$), Fabaceae ($15 \pm 3\%$) and Rosaceae ($10 \pm 3\%$). Overall, the combined number of species belonging to Poaceae and Asteraceae is 33% higher in S_{SA} than in S_{AV} ($p < 0.001$). Both areas show significant seasonal changes in family composition (both $p < 0.001$) and comparable association strengths between families and seasons (Cramér's V effect sizes equal to 0.304 and 0.312 in S_{AV} and S_{SA} , respectively), but substantially less family turnover ($\chi^2 = 188$ in S_{AV} vs. $\chi^2 = 135$ in S_{SA}) in the managed area than in the unmanaged one. The variations in S_{AV} are mostly associated with 4 families (Caryophyllaceae, Hypericaceae, Rubiaceae, and Brassicaceae) undergoing near complete seasonal turnover ($1.01 \leq CV \leq 0.96$), whereas the others, including the dominant ones (Fabaceae, Poaceae), show low to moderate seasonality ($0.47 \leq CV \leq 0.28$). In contrast, S_{SA} show compressed seasonality dynamics ($0.89 \leq CV \leq 0.25$) and a more equitable distribution of CV values, with seasonal variations mainly involving several families represented by few species (Plantaginaceae, Geraniaceae, Malvaceae, Oxalidaceae, Caryophyllaceae, Asteraceae, and Ciperaceae).

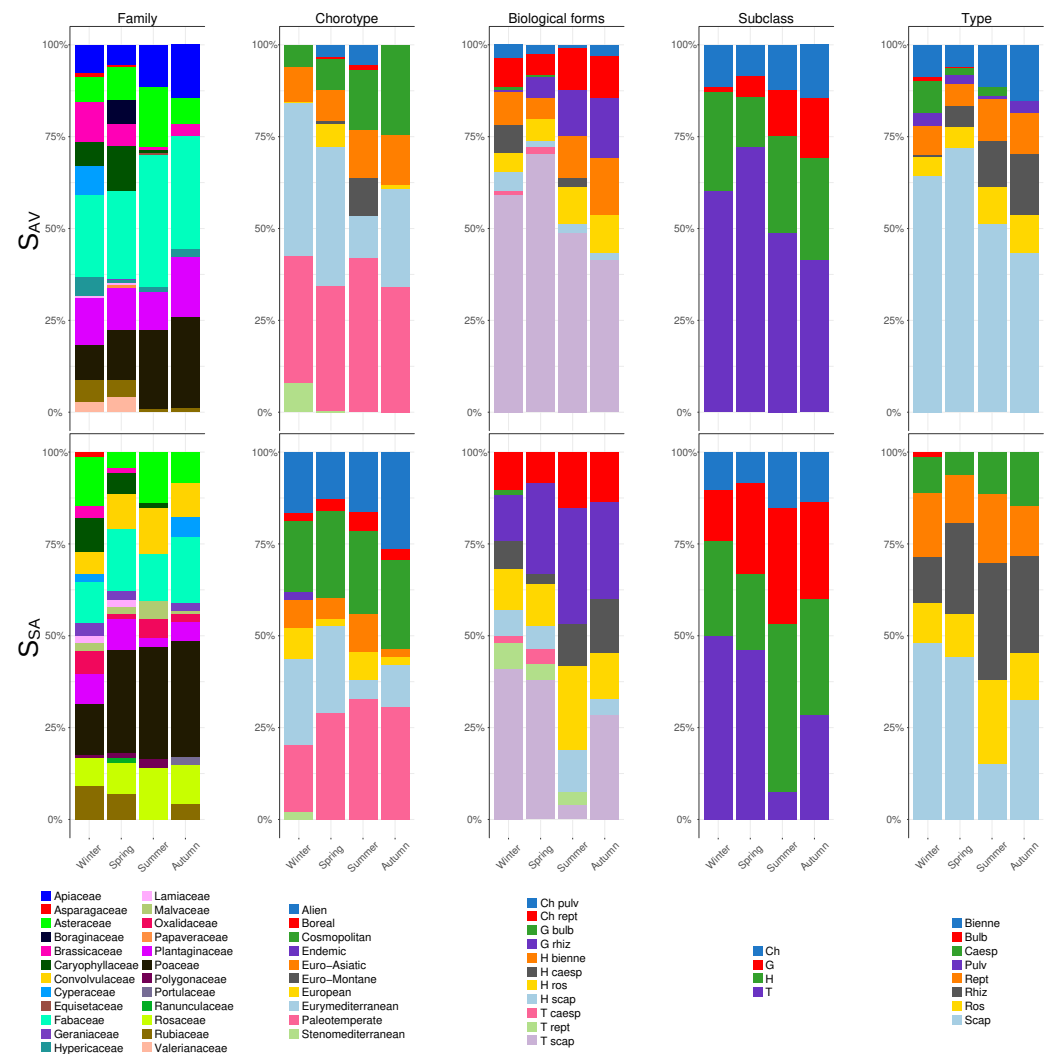


Figure 3. Functional trait abundances in the different seasons in S_{AV} (first row) and S_{SA} (second row), represented through stacked bar plots. Specifically, the family, chorology, Raunkiær life form (abbreviated according to Ellenberg [53]) general class, subclass and type are reported.

In terms of chorological spectra, S_{AV} and S_{SA} differ in the dominance of specific chorotypes and their seasonal dynamics. In particular, S_{AV} is mainly characterized by paleotemperate and eurymediterranean chorotypes all over the year ($36 \pm 4\%$ and $29 \pm 13\%$ respectively; Figure 3), whereas S_{SA} communities are dominated by paleotemperate, cosmopolitan and alien chorotypes ($28 \pm 7\%$, $23 \pm 2\%$ and $18 \pm 6\%$ respectively; Figure 3), with eurymediterranean species accounting for only $16 \pm 9\%$ of the taxa. Remarkably, the increase in the combined abundance of alien and cosmopolitan species in S_{SA} compared to S_{AV} amounts to 260% ($p < 0.001$). In terms of seasonal dynamics, the chorological variations are similar to those observed for families, with significant changes in both areas (both $p < 0.001$) and comparable, modest association strengths between chorotypes and seasons (Cramér's V effect sizes equal to 0.299 and 0.237 in S_{AV} and S_{SA} , respectively). In terms of chorology, however, the reduction in chorotype turnover in S_{SA} relative to S_{AV} amounts to 57% ($\chi^2 = 187$ in S_{AV} vs. $\chi^2 = 77.7$ in S_{SA}) compared with the 28% observed for families. Chorotype seasonal variations in S_{AV} result mainly from european, stenomediterranean and euro-montane species undergoing complete seasonal turnover ($1.44 \leq CV \leq 1.04$), as well as from boreal and eurymediterranean species ($CV = 0.85$ and $CV = 0.70$), whereas paleotemperate, cosmopolitan, euro-asiatic and alien chorotypes show low to modest seasonal variations ($0.37 \leq CV \leq 0.09$). Conversely, coefficient of variation values in S_{SA} show both restricted dynamic range ($0.88 \leq CV \leq 0.29$) and a more equitable distribution, with seasonal variations of alien species reaching $5.5\times$ higher values in S_{SA} than in S_{AV} ($CV = 0.52$ vs. $CV = 0.09$).

In terms of Raunkiær life forms, S_{AV} and S_{SA} are dominated by therophytes, particularly scapose species, and by geophytes/hemicryptophytes (Figure 3), respectively. Although seasonal variations are significant in both areas (both $p < 0.001$), life forms exhibit reduced seasonal turnover in respect to families and chorology, with values 13% lower in S_{SA} than in S_{AV} ($\chi^2 = 99.4$ vs. $\chi^2 = 86.3$ in S_{SA}). Cramér's V effect sizes also indicate low and comparable association strengths between life forms and seasons (0.299 and 0.237 in S_{AV} and S_{SA} , respectively). Seasonal coefficients of variation show similar dynamic ranges in S_{AV} and S_{SA} ($0.76 \leq CV \leq 0.06$ and $0.73 \leq CV \leq 0.04$, respectively) and comparable distributions of values.

The overall variations in community structural and functional diversity across the seasons in S_{AV} and S_{SA} are summarized in Table 3, as well as in Figures 4 and 5.

Table 3. PERMANOVA F-ratios (seasonal signal strength) and PERMDISP average distances to median (within-season variability) for structural and functional diversity across four abundance measures. q values represent percentage changes in the managed area (S_{SA}) relative to the unmanaged area (S_{AV}). All q values are significant at $\alpha = 0.001$. Asterisks indicate significant seasonal effects according to PERMANOVA (for $\alpha = 0.05$).

		PERMANOVA			PERMDISP		
	Season	S_{AV}	S_{SA}	q (%)	S_{AV}	S_{SA}	q (%)
Structural	P/A	32.6 *	7.43 *	−77.2	0.0559	0.0703	25.7
	Number	16.3 *	3.87 *	−76.2	0.291	0.409	40.6
	Biomass	19.5 *	6.28 *	−67.8	0.194	0.369	90.0
	Cover	25.3 *	4.99 *	−80.3	0.106	0.128	20.9
Functional	P/A	13.3 *	2.96 *	−77.7	1.28	2.06	60.9
	Number	8.50 *	1.90	−77.6	1.28	1.88	46.9
	Biomass	8.72 *	1.27	−85.4	1.54	1.87	21.4
	Cover	8.81 *	1.94	−78.0	1.27	2.03	59.8

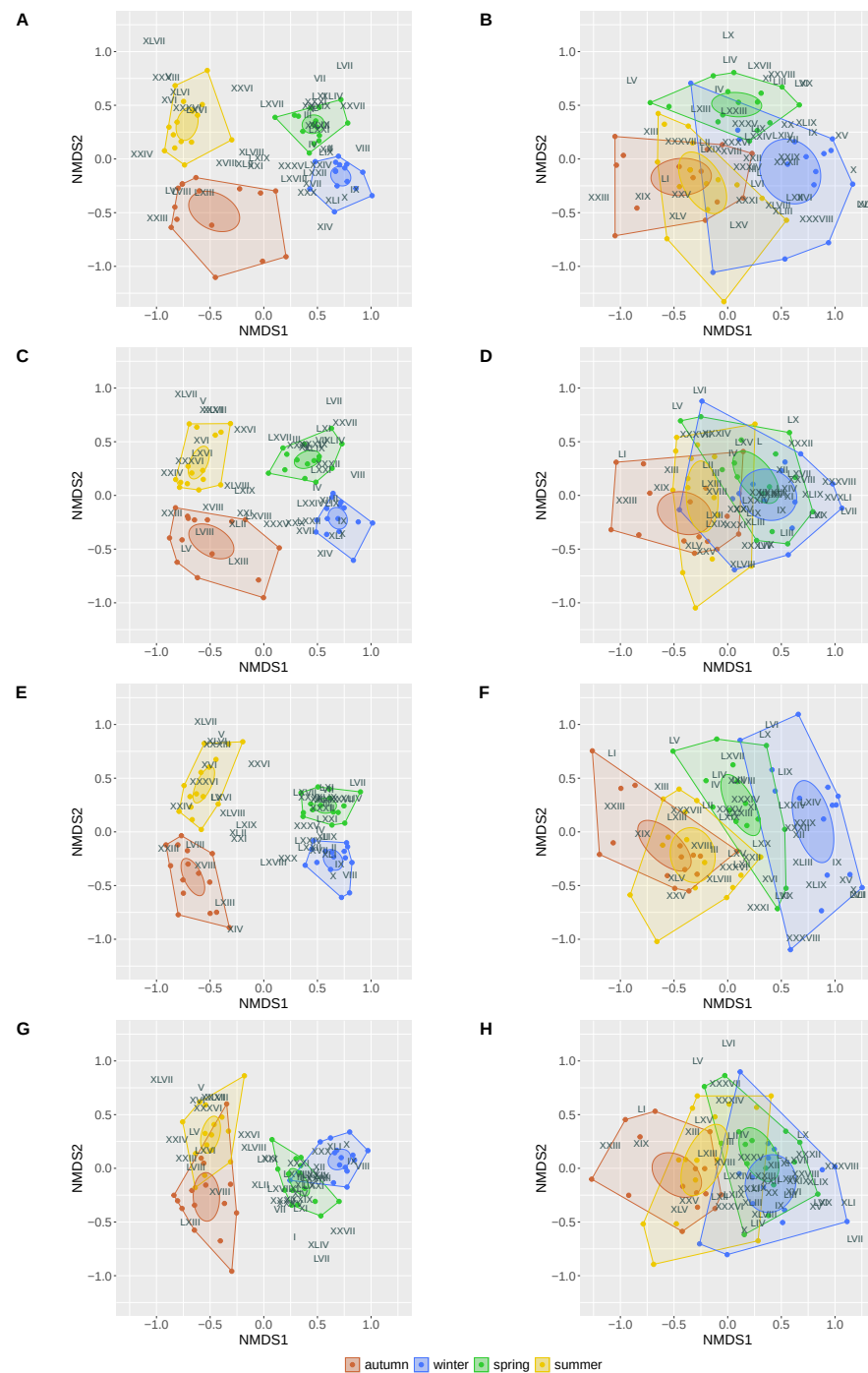


Figure 4. NMDS biplots relative to P/A (A,B), number of plants (C,D), dry mass (E,F) and cover (G,H) in S_{AV} (left) and S_{SA} (right). The convex hulls grouping the observations in the four seasons and the respective standard confidence ellipses at $\alpha = 0.05$ are also shown. Species are indicated with Roman numerals according to Tables 1 and 2. Biplots are drawn with equal scales to simplify comparisons.

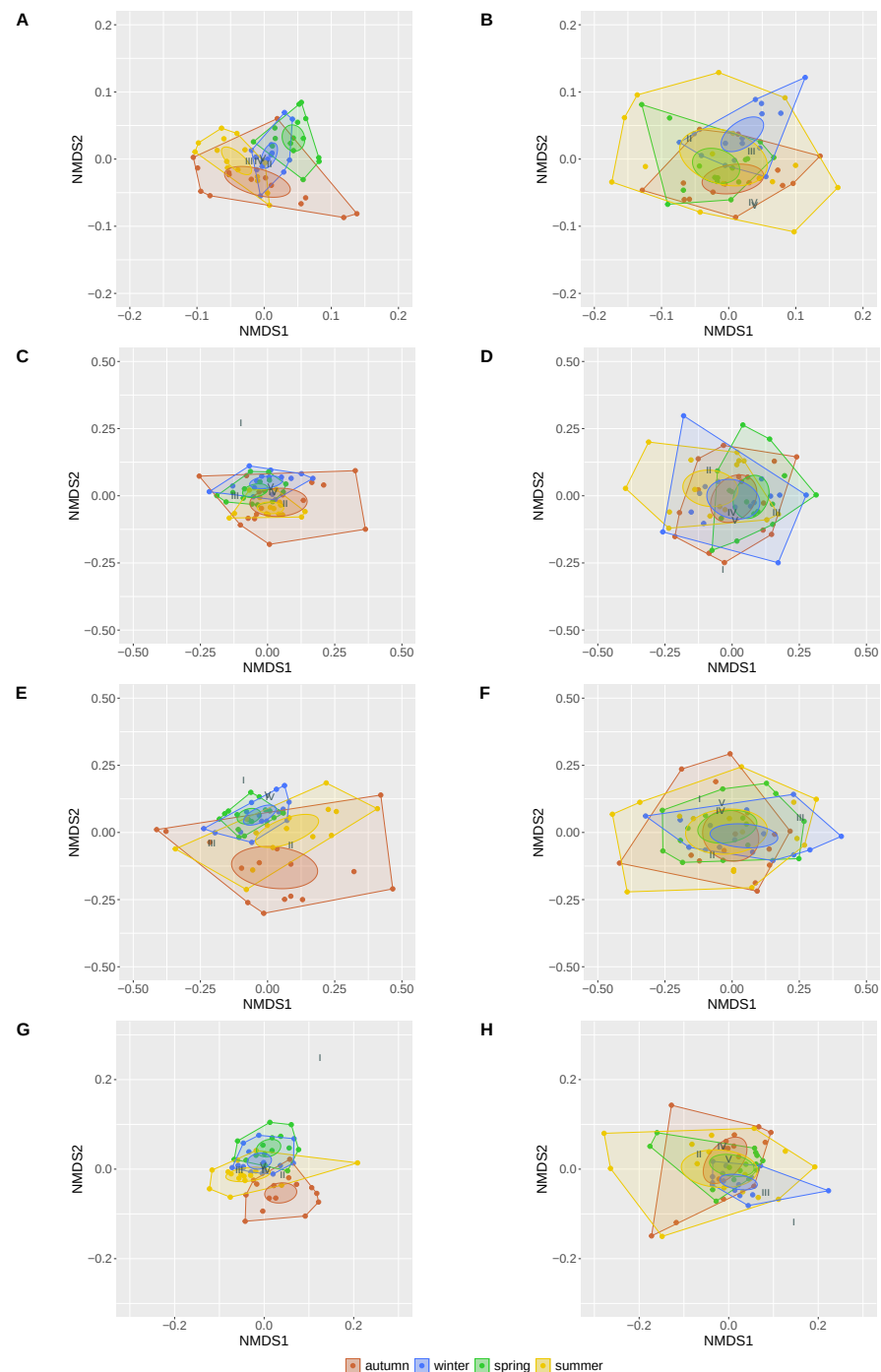


Figure 5. NMDS biplots based on functional diversity indices (richness: ric, evenness: eve, dispersion: dis, divergence: div, Rao's quadratic entropy: rao) with community weighted means calculated from P/A (**A,B**), number of plants (**C,D**), dry mass (**E,F**) and cover (**G,H**) in S_{AV} (**left**) and S_{SA} (**right**). The convex hulls grouping the observations in the four seasons and the respective standard confidence ellipses at $\alpha = 0.05$ are also shown. Species are indicated with Roman numerals according to Tables 1 and 2. Biplots are drawn with equal scales to simplify comparisons.

Community seasonal variations were consistently significant in S_{AV} when considering the P/A data and all abundance measures for both structural and functional biodiversity (always $p < 0.001$), whereas they were significant in S_{SA} only for structural biodiversity (always $p < 0.001$) and for functional diversity calculated from P/A data ($p < 0.01$). S_{SA} invariably exhibits significant damping (always $p < 0.001$) of seasonal variations in both structural and functional diversity relative to S_{AV} , with comparable effect sizes ($3.0\text{--}5.5 \times \text{re}$).

duction in PERMANOVA F-values; Table 3) among P/A, number, biomass and cover data. PERMDISP values (Table 3) further indicate that the reduction in seasonal differentiation in S_{SA} is accompanied by significant increases (always $p < 0.001$) in within-season variance with respect to S_{AV} , with management inducing different effect sizes on the P/A and abundance data in the case of structural and functional diversity (Table 3). Indeed, the sequence of effect size values for structural diversity, i.e., $P/A < \text{number} < \text{biomass}$, is reversed in the case of functional diversity. The variations in S_{AV} are mainly associated with therophytes such as *A. cretica*, *A. thaliana*, *B. media*, *P. hieracioides*, *S. halepense* and *V. carinata*, with increase in abundance according to their specific phenologies (Figure 4). Conversely, in S_{SA} , the reduced seasonal variations are mainly associated with the abundance of perennial species such as *C. dactylon*, *O. corniculata*, *P. reptans* and *T. repens*, which dominate the community throughout the year (Figure 4).

The different seasonal dynamics in species composition between S_{AV} and S_{SA} are reflected in the seasonal variations of the community dominance–diversity structure (Figure 6). Indeed, remarkable variations were observed in the dominance–diversity structure of the S_{AV} community, regardless of the abundance measure adopted, whereas S_{SA} presented similar structures across most of the seasons, albeit with varying evenness (Figure 6).

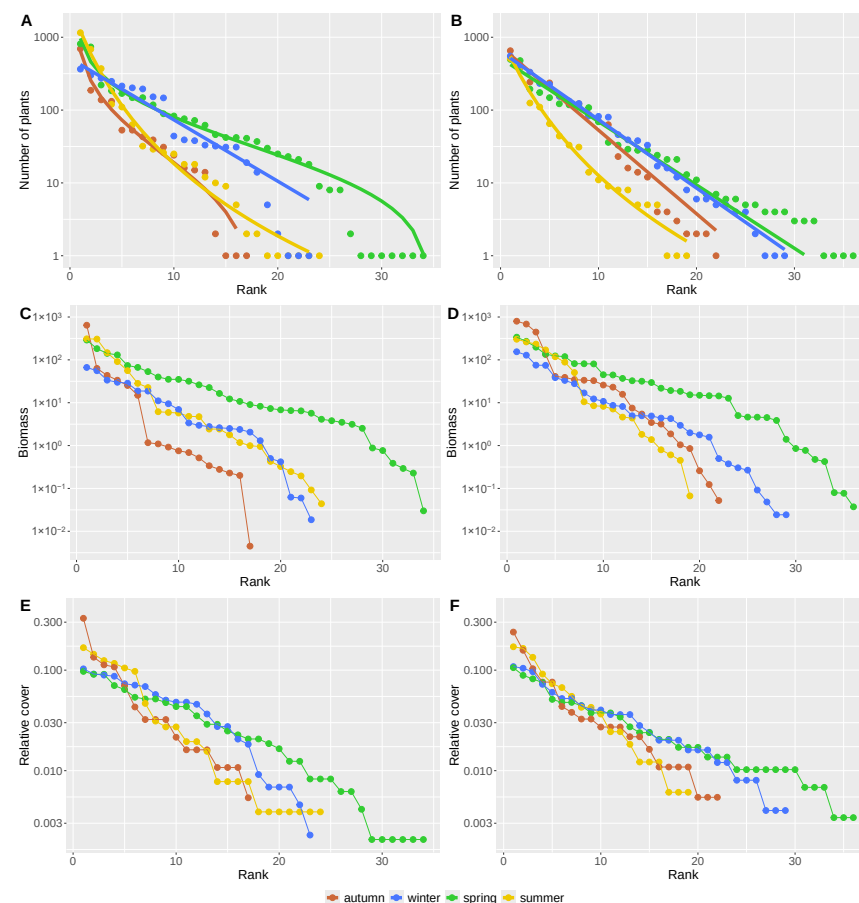


Figure 6. Seasonal rank–abundance curves based on total number of plants, total biomass and relative cover of each species from S_{AV} (A,C,E) and S_{SA} (B,D,F). The former were described through dominance–diversity models: pre-emption (S_{AV} : winter; S_{SA} : autumn, winter, spring), log-normal (S_{AV} : autumn, spring) and Zipf–Mandelbrot models (summer in both areas).

The models best describing the dominance–diversity relationships, fitted on the number of plants abundance data, vary in S_{AV} from niche pre-emption in winter, to log-normal in spring and autumn, to Zipf–Mandelbrot in summer (AIC reduction as compared to the second best model: autumn 42.6%, spring 16.1%, summer 8.7%, winter 47.6%). In S_{SA} ,

dominance–diversity relationships were consistently best described by the pre-emption and Zipf–Mandelbrot (with comparable AIC values) in all seasons, except in summer, when the Zipf–Mandelbrot model scores lower AIC values (reduction as compared to the second best model: autumn 0.2‰, spring 0.01‰, summer 49.6%, winter 0.4‰). Overall, the slope of the dominance–diversity curves in S_{AV} decreases according to the order autumn > summer > winter > spring, with variations greater than those observed in S_{SA} , where the main differentiation appears between autumn/summer and spring/winter for cover data (Figure 6).

4. Discussion

Overall, the obtained results form several lines of evidence that consistently demonstrate strong environmental filtering inducing dramatic shifts from niche-based to stochastic-based community assembly rules under management. The main ones include (i) the promotion of biotic homogenization, (ii) the induction of (inverted) contingency cascades on structural and functional diversities, (iii) the constrained seasonal dynamics in dominance–diversity relationships, (iv) the seasonal signal attenuation, and (v) the hierarchical filtering on species traits.

First, the substantial increases in alien and cosmopolitan species [54,55], as well as in species resistant to mowing and trampling [19,56], provide unequivocal evidence of management that induces biotic homogenization by promoting specific functional traits [57–59], while reducing overall functional diversity [60–62]. Environmental filtering in the study system is primarily exerted through mechanical damage to reproductive structures caused by mowing and trampling, and through the promotion of species that exploit high nutrient availability with rapid population dynamics. These processes account for the increased incidence and dominance of Poaceae and Asteraceae species in S_{SA} , most of which are also alien or cosmopolite [56]. These species can easily preempt or outcompete native populations, becoming dominant within a short time [59] as exemplified by the autumnal outbreak of *P. dilatatum*, a weed with allelopathic properties that proliferates in environments with high nitrogen availability [63]. The year-round availability of water and nutrients also promotes the dominance of species with long life cycles [24,64], especially in conjunction with mowing and trampling. Indeed, the persistence of gemmae in or at the soil level allows geophytes and hemicryptophytes to resist these pressures and be competitive in managed urban ecosystems [65]. For instance, by spreading horizontally, they can access patchily distributed resources or spaces left vacant by other plants [66,67]. Such a hypothesis is supported by the results of Kelemen et al. [68], who observed that in managed urban lawns, litter accumulation following the cessation of mowing tends to increase the dominance of grasses and reduce the presence of prostrate plants.

The differential variance inflation in P/A , number and biomass data implies a contingency cascade, in which initially stochastic differences in species establishment are amplified over time, leading to highly divergent and path-dependent outcomes in ecological dominance. This applies for both structural and functional diversity, although the inverted contingency cascades indicate that management generates two parallel yet complementary assembly processes, where stochastic establishment coexists with deterministic functional outcomes. At the structural level, the local species pool remains relatively stable, but population sizes become more contingent on local factors and species randomly achieve ecological dominance (the seemingly contradictory cover results can be explained by the strong variance-stabilizing transformation— $30\times$ variance compression—making the 21% increase a conservative estimate of management's true effect on spatial occupancy patterns). At the functional level, different functionally equivalent species randomly establish across plots, yet pervasive environmental filtering ensures that only a narrow subset

of trait combinations can achieve ecological dominance—a mechanism coherent with a “functional redundancy saturation” hypothesis. This process may be further amplified by abundance-decoupling and priority effects, where initial colonists preempt resources within a constrained functional space [19,69,70], a hypothesis supported by the observed dominance–diversity patterns across seasons in S_{AV} and S_{SA} .

Indeed, the consistent niche pre-emption dominance–diversity patterns across most seasons in S_{SA} indicate that a few dominant species, favored by management-induced filtering but contingently selected by local factors, disproportionately control resources through strong asymmetric competition. The shift to a Zipf–Mandelbrot model during the summer drought indicates that the signal from natural environmental drivers, typically overridden by management, briefly becomes strong enough to be discernible from the anthropogenic noise. In this season, the balance between the contributions of anthropogenic filtering and drought stress tips sufficiently to allow a more complex assemblage of subordinate species. Conversely, the niche pre-emption model observed in S_{AV} in winter, when harsh climate favors few dominant species, gives way to models indicating complex biotic interactions in spring and autumn, and to intermediate stages in summer with both abiotic (drought) and biotic control [43,71,72]. Remarkably, the same seasonal variations were observed in coastal lagoons by Bellino et al. [73], who suggested that the winter pre-emption model indicates a buildup phase in algal communities culminating in spring under optimal environmental conditions, followed by a phase of exogenous control of community structure by summer temperatures, returning to an autumnal pre-emption model. As a cautionary note, since slightly more than 20 species were seasonally observed in S_{SA} , the dominance–diversity patterns can be equally well described by Zipf–Mandelbrot models [74]. However, even in this case the interpretation would remain substantially the same, differing only in the extent of environmental control *vs* endogenous niche-structuring processes [43,73–77]. The stark comparison between areas indicates that management overweighs the natural environmental and biotic controls, replacing responsive, seasonally adapted communities with others characterized by muted seasonal dynamics.

In terms of seasonal dynamics, the 4–7× compression of the seasonal signal in S_{SA} is remarkable and further demonstrates that management overrides natural environmental rhythms, creating functionally static assemblages in which the same strategies dominate year round. Furthermore, the compression of the seasonal signal unevenly affects functional traits and establishes a hierarchy of management impacts from the broadest to the finest ecological adaptations, i.e., from muted effects on life forms to the dramatic collapse of chorological specializations. Indeed, while life forms, representing broad solutions to survival, demonstrate remarkable resistance to management, the chorological affinities, which reflect fine-tuned evolutionary adaptations to specific regional climates and historical biogeographic contexts, are rendered useless by the novel and homogenized conditions of managed urban ecosystems [35,78,79]. In other words, management filters primarily against the deepest ecological specializations, favoring instead a pool of generalist species whose broad strategies remain viable across a wide range of disturbed environments [31,80].

5. Conclusions

The obtained findings demonstrate that management through mowing, irrigation, and fertilization induces regime shifts characterized by strong biotic homogenization and markedly muted seasonal dynamics. This shift establishes management as the dominant ecological force, increasing stochasticity and creating a cascade of contingency that affects species composition, demography, and resource control, while functionally constraining the traits that dominate the communities. The impact of this filtering is hierarchical, with severe consequences for specialized adaptations like chorology, while broader ecological

strategies, such as life forms, remain relatively unaffected. Collectively, this evidence points toward a comprehensive rewiring of urban plant communities and a fundamental change in community assembly rules, where local contingency and anthropogenic filters override natural abiotic and biotic drivers. From a practical perspective, although specific management thresholds inducing regime shifts remain to be quantified across different systems, reducing management intensity and frequency—and aligning management schedules with natural seasonal dynamics—would mitigate anthropogenic filtering. Such an approach is essential for preserving viable, niche-based community assemblies and the ecological functions they support in urban ecosystems.

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Abbreviations

The following abbreviations are used in this manuscript:

S _{AV}	Study area in the municipality of Avellino
S _{SA}	Study area in the municipality of Fisciano
P/A	Presence-Absence
NMDS	Non-metric multidimensional scaling
PERMDISP	Analysis of multivariate homogeneity of group dispersions
PERMANOVA	Permutational multivariate analysis of variance
RAD	Rank abundance distribution
AIC	Akaike’s information criterion

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