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# Analysis of the relationship between ecosystem services: biomass production and biodiversity in herbaceous communities of seminatural grasslands and urban green spaces

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# ABSTRACT

The strategic planning of Green Infrastructure (GI) is pivotal for the achievement of the goals set by sustainable development policies on urban and rural areas. Since GI are built to simultaneously provide a wide range of ecosystem services (ESs), it is crucial to understand the relationships between ESs and the implication of external factors (e.g., landscape configuration) to maximise the supply of all the ESs. However, substantial knowledge gaps persist in the literature, and useful insights on GI planning are still missing. In this study, we investigated the relationship between two ESs: biomass production and biodiversity of herbaceous communities of seminatural grasslands and urban green spaces in Cartigliano (VI). The analysis aims at i) defining the relationship between the two ESs and ii) identifying the main spatial configuration attributes involved in this relationship. First, the correlation analysis showed a trade-off between biomass production and biodiversity for herbaceous communities. Second, linear regression analysis revealed that the patch configuration attributes (namely the area, the perimeter and the contrast with artificial areas) affected the trade-off. Therefore, our study highlighted that both intrinsic and extrinsic features of seminatural and urban herbaceous patches need to be accounted in GI planning, to maximise the simultaneous supply of ESs.

# CHAPTER 1. INTRODUCTION

The concept of ecosystem services (ESs) has become pivotal in the last decades as highlighted by the Millennium Ecosystem Assessment (MEA; Fisher et al., 2009). The MEA defined ESs as “the benefits that people obtain from ecosystems” (MEA, 2005). Serving the socio-economic system, ESs indicate that people are integral part of ecosystems leading to a dynamic interaction between humans and ecosystems. Humans, through their actions, drive, both directly and indirectly, changes in ecosystem structure and function that in turn affect human well-being (MEA, 2005).

In the last 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period in human history (MEA, 2005), as a result of land use planning to enhance a specific set of provisioning ESs to satisfy the rapid growing demand for food, fresh water, and timber, in an economical and reliable manner (Bennett et al., 2009; MEA, 2005).

Land use changes have mainly impacted on biodiversity, i.e., the diversity of life on Earth (genetic diversity, diversity within and between species, populations, and ecosystems), reducing the number of plant species by at least 10-15% since 1970 (MEA, 2005). Being part of the natural capital (Bateman & Mace, 2020), biodiversity can be defined as a supporting ES, ensuring the existence and the functioning of ecosystems themselves, at the same time being pivotal for the provision of all the other ESs (Fisher et al., 2009).

However, ESs are not independent of each other, i.e., they interact in complex and dynamic ways (Bennett et al., 2009; Rodríguez et al., 2006), and any effort aiming at increasing a single service often induces a decrease or loss of other services, namely a trade-off between ESs (Cord et al., 2017). The MEA reported that approximately 60% of ESs examined during the assessment were planned unsustainably and were consequently degraded (MEA, 2005).

Dealing with trade-off situations requires management decisions since any land use change results in changes in the types, magnitudes and interactions of ESs (Deng et al., 2016), thereby making spatial planning crucial to preserve the natural capital, particularly in urban and rural areas, and enhance its functionality (Ferrari et al., 2019), so as to ensure both sustainable management of the ecosystems through the conservation of biodiversity and human well-being.

Due to the great changes that the landscape has undergone, European policies suggested that the restoration of its functionality can be achieved through the reintroduction and/or the improvement of a network of natural and semi-natural landscape elements, i.e., a Green Infrastructure (GI; John et al., 2019), planned and managed to provide a wide range of ESs. GI uses the Nature-Based Solution (NBS) approach to implement natural and semi-natural elements with the landscape in the best possible way and in a sustainable manner (Sanesi et al., 2017).

However, the concept of GI and NBS is still new, and many points remain to be clarified. Firstly, policy makers still have a limited comprehension of such policies (Cameron & Blanuša, 2016). Furthermore, the implementation or the improvement of natural and semi-natural elements is hindered by financial constraints, by the lack of tools to evaluate different types of green spaces, and by the limited knowledge of some processes that affect the provision of multiple ESs (Wang & Banzhaf, 2018), including understanding the correlation between landscape composition and configuration variables with the trade-offs of ESs (Karimi et al., 2021). Clarifying these aspects would allow us to satisfy the requirements for an efficient planning of GI and NBS in urban and rural landscapes (Chang et al., 2021; Deng et al., 2016; Karimi et al., 2021; Wang & Banzhaf, 2018).

Among the most studied ESs trade-offs, biomass production and biodiversity of herbaceous communities has become one of the most important ESs relationships to be accounted for in landscape planning. To date, numerous studies and meta-analysis have been carried out by scientific community on the relationship among biodiversity and biomass production, especially for grasslands (Adler et al., 2011; Cardinale et al., 2013; Fraser et al., 2015; Grace et al., 2016; Mahaut et al., 2023; Mittelbach et al., 2001; Whittaker, 2010).

Given the loss of biodiversity related to the prioritization of agriculture and urbanization, understanding the relationship between species richness and biomass production in plant community is crucial for landscape planning and the conservation of biodiversity. Landscape planning must be oriented to balance, and consequently to maximize the provision of both ESs because they are essential to provide other goods and services (Grace et al., 2016). To date, many controversial relationships between these two ESs have been found in the literature; particularly, positive (i.e., Hector et al., 1999), negative (i.e., Fessel et al. (2016); Grace et al., 2016; Justić & Jelaska, 2022) and unimodal (also called *hump-shaped* relationship; e.g., Fraser et al., 2015; Grime, 1973; Huston, 1979; Mittelbach et al., 2001; Poldini et al., 2011) correlations have been identified.

The conflicting relationships between biodiversity and biomass production may depend on numerous variables that can at both small and landscape scales (Bretzel et al., 2016; Gaujour et al., 2012; Molina et al., 2023; Poldini et al., 2011), and can simultaneously interact influencing the supply of the two ESs (Gaujour et al., 2012). Indeed, the investigated relationship can be influenced by abiotic factors that are reflected on the plant community by acting as an external factor (e.g., stress or disturbance); as such, the resulting effect depends on the direction and intensity with which these are expressed and depends on the adaptive responses of the species present (Di Biase et al., 2023).

At small spatial scale (i.e., plot scale), edaphic characteristics, such as soil moisture, soil reaction (pH), soil nutrient content (especially nitrogen) have been identified among the main abiotic factors that possibly influence the relationship between biomass production and biodiversity (Dengler et al., 2018; Di Biase et al., 2023; Schaffers, 2002; Wagner et al., 2007). All these factors may select the community plant species pool based on their adaptative strategies (Grime, 1977).

However, the relationship is also influenced by biotic factors including anthropogenic actions that complicate its mechanism (Suding et al., 2005). The types of management may heavily influence the relationship between the two ESs through soil fertilisation, in terms of intensity, frequency, and duration (Isbell et al., 2013; Suding et al., 2005), mowing practices, animal grazing (Bernhardt-Römermann et al., 2011; Bretzel et al., 2016; Collins et al., 1998), and soil trampling (Molina et al., 2023).

At large spatial scale (i.e., landscape scale), research has identified climatic conditions in terms of light, temperature, precipitation, altitude and latitude as the main factors that may influence the investigated relationship (Gillman et al., 2015; Poldini et al., 2011) acting as a filter to determine a specific pool of species within a territory (Aronson et al., 2016).

Landscape configuration variables that include the spatial characteristics of patches can also play a crucial role in the supply of these ESs (Öckinger et al., 2012) through attributes as patch surface area, (i.e., namely the species-area relationship (SAR), one of the fundamental laws of ecology; Dengler et al., 2020); the shape and distance between patches, which are often a consequence of human-driven loss and fragmentation of habitat and can favour the flourishing of generalist and non-native species (Matthews et al., 2014); and the contrast between patches and the landscape matrix (i.e., the influence of the matrix on the habitat).

However, these variables are often considered separately for the individual ESs considered (Gaujour et al., 2012), thereby limiting the comprehension of which and how environmental and anthropogenic variables may influence the relationship between biomass production and biodiversity (Li et al., 2022).

In light of the above, our study aims at understanding the influence of a comprehensive set of variables on the relationship between biodiversity and biomass production in herbaceous communities, both seminatural grasslands and urban green spaces. Particularly, our study aims at i) defining the relationship between the two ESs under investigation in herbaceous communities and ii) identifying the main variables involved in this relationship.

Studying the relationship between biodiversity and biomass production in an urban and rural landscape and focusing on the influence of edaphic parameters (reflected by Ellenberg Indicator Values) and landscape configuration variables (surface area, shape, distance between patches, patch and matrix contrast), allows to gain crucial information for GI planning. In fact, they allow to understand which variables are most involved in explaining the trade-off and how and determine configurational and management requirements to be met to constitute an effective GI that maximizes both ESs.

# CHAPTER 2. MATERIALS AND METHODS

## 2.1. Study area

Our study was conducted in the municipality of Cartigliano, in the Veneto region. The municipality of Cartigliano is part of the rural area and reflects the typical composition and configuration of the countryside of the Northeastern Italy. It belongs to the province of Vicenza (VI) and is situated in the Northeastern sector of the province (45° 42´ 26.950" N, 11° 42´ 0.436" E; Figure 3.1). The municipality is falls on the Brenta riverbanks at an altitude between 68 and 93 metres above sea level (Comune di Cartigliano, 2014).

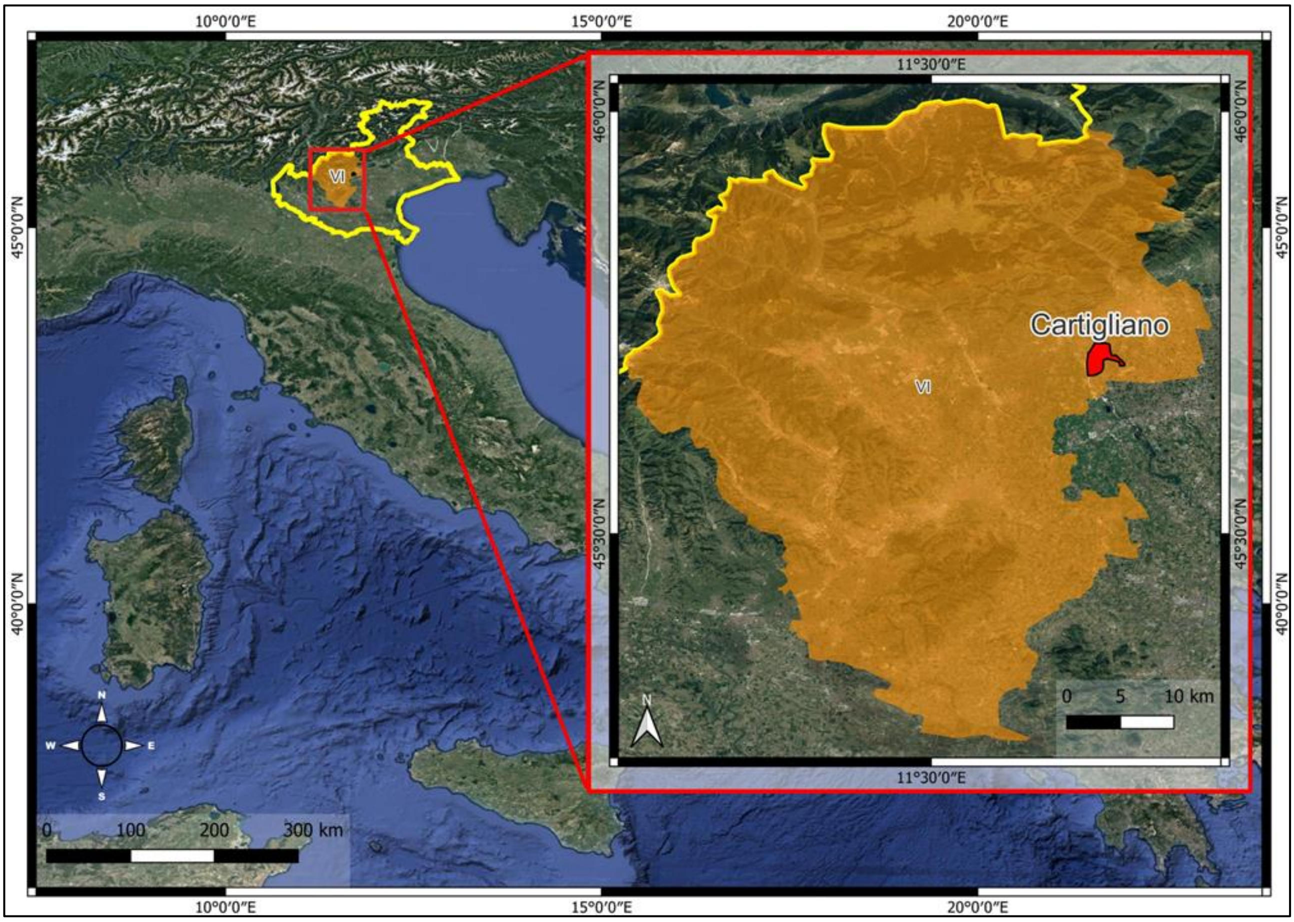


*Figure 3.1: Location of the study area.*

Cartigliano borders with Bassano del Grappa to the North, Rosà to the East, Tezze sul Brenta and Pozzoleone to the South and Nove to the West (Figure 3.2; Comune di Cartigliano, 2014). The municipal area is about 7.38 $km^2$, while the resident population on 01.10.2023 was of 3662 inhabitants (ISTAT, 2023).

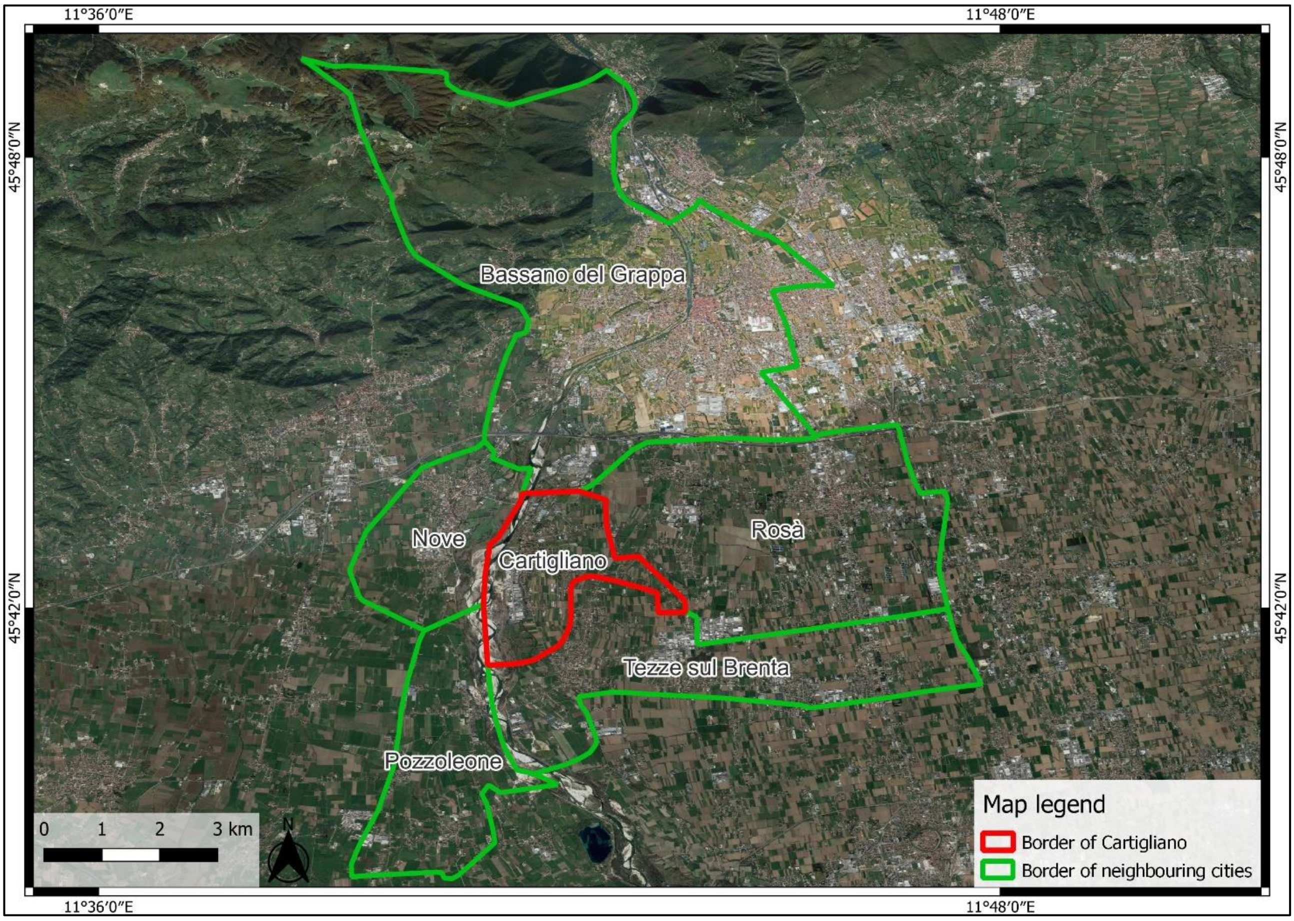


*Figure 3.2: Border of Cartigliano and neighbouring cities (Comune di Cartigliano, 2014).*

In a geomorphological perspective, the territory of Cartigliano lies on the conoid of the Brenta River, which has covered the rocky substrate with a sedimentary layer, forming a slightly inclined plane of about 0.5% to the south. In detail, the sedimentary layer is mainly composed of gravels and sandy gravels mostly calcareous or calcareous-dolomitic, and only rarely are volcanic (i.e., granites, porphyries) and metamorphic (i.e., quartz phyllites; Comune di Cartigliano, 2014).

In terms of climatic characteristics, the area reflects the continental features of the Venetian Plain, with cold, low rainfall winters and warm but not torrid summers (Comune di Cartigliano, 2014). Based on ARPAV database (https://www.arpa.veneto.it/dati-ambientali/open-data/file-e-allegati/trend_variabili_meteorologiche.zip, accessed on 11th January 2024) which provides measurements of air temperature and rainfall depth from 1994 to 2022 (climatological station located nearby municipality of Rosà), the cold season ranges from late November to early March, in which January is the coldest month with an average air temperature of 3.8 °C; while the warm season ranges from early June to early September, July being the hottest month with an average air temperature of 24.4 °C (Figure 3.3). Rainfall has an average yearly rainfall of 1206.9 mm, with two maxima in late spring and autumn (Comune di Cartigliano, 2014). In particular, the rainiest months are May and November, with a monthly average value of 131 mm and 143.3 mm respectively (Figure 3.3).

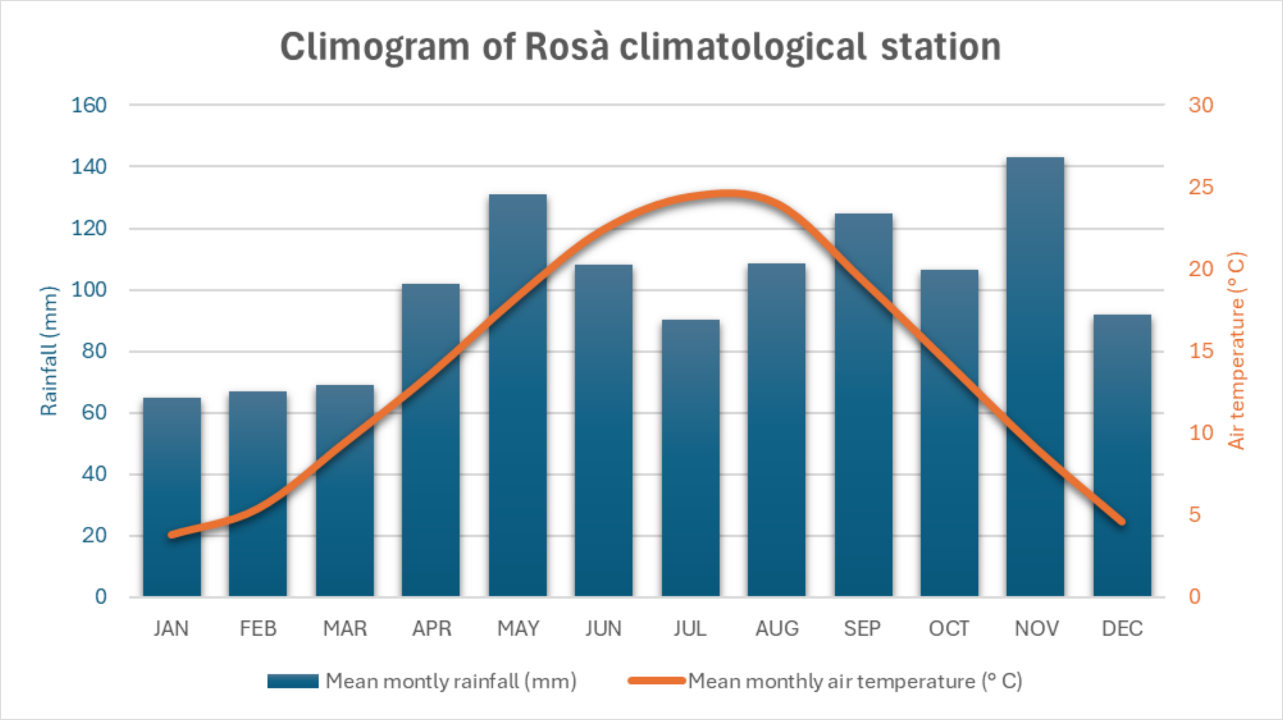


*Figure 3.3: Climogram obtained from the ARPAV Rosà climatological station measurements. The columns show the variation of the mean monthly rainfall (mm), the line shows the variation of the mean monthly air temperature (°C) (https://www.arpa.veneto.it/dati-ambientali/open-data/file-e-allegati/trend_variabili_meteorologiche.zip , accessed on 11th January 2024).*

Being located near an important river, intense anthropisation has interested the territory of Cartigliano, namely the growth of numerous activities of artisans, industries, and agriculture, since ancient times (Prislei, 2023). However, over the last century, agricultural areas have progressively decreased due to the continuous change of land use for the construction of new urban settlements, while agriculture has been more focused on intensive monoculture, partly converting seminatural grasslands present at the beginning of the 20th century and deputy to livestock nourishment (Comune di Cartigliano, 2014). To date, most of the territory of Cartigliano is characterized by the presence of agricultural areas (48%), followed by natural (24%), residential (22%), and industrial areas (6%; Figure 3.4; Cercato, 2023).

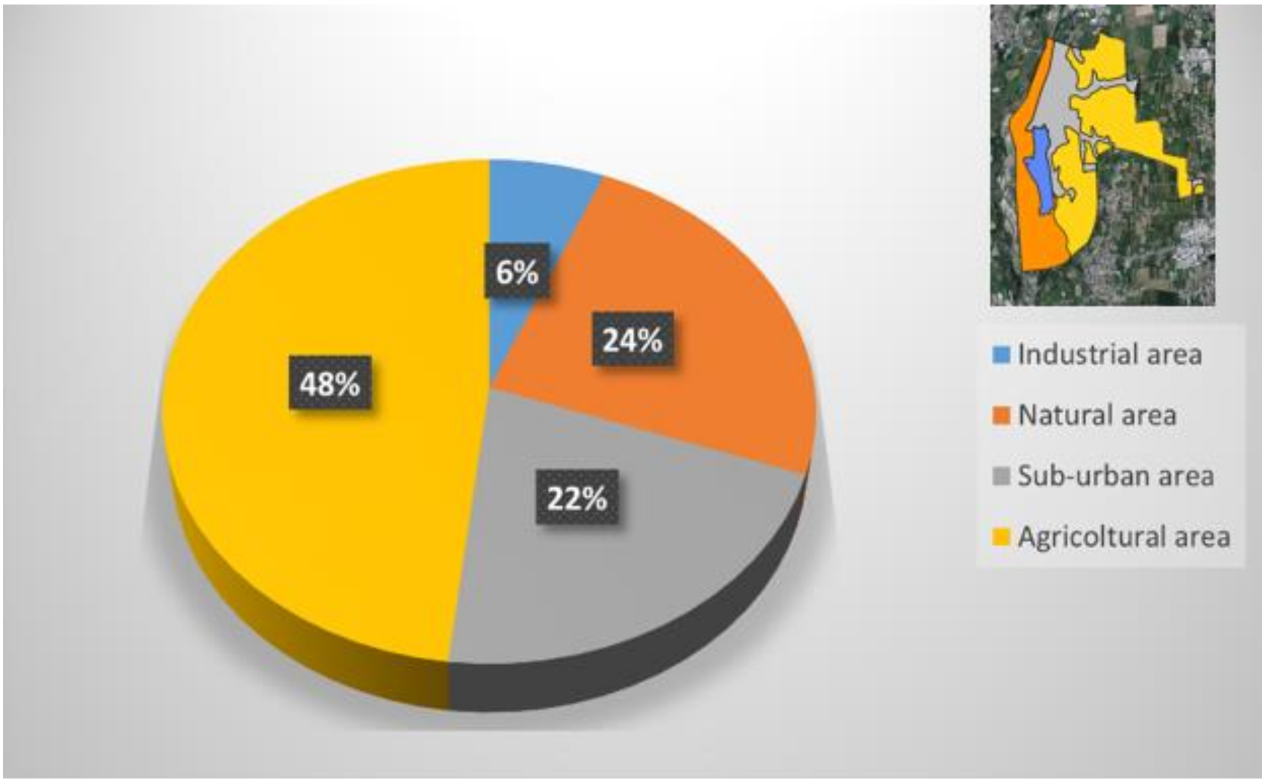


*Figure 3.4: Land use and land cover repartition of Cartigliano municipality surface (Cercato, 2023).*

As a result, the agricultural landscape of Cartigliano is now mainly characterised by seminatural grasslands and cultivated fields of arable land separated by drainage canals and hedgerows. Particularly, fields of seminatural grasslands are quite equally distributed across the municipal territory, with an area in the southern part of Cartigliano that exhibited a high concentration of seminatural grasslands and hedgerows (namely the “Parco Basse del Brenta”; Figure 3.5), a relic from the past of the enclosed fields typical of the Veneto Region. Conversely, there is a gradual shift to arable crops moving towards the northern part of the municipality (largely grain maize - always linked to animal feed; Comune di Cartigliano, 2014).

Natural areas (24%) within the municipality of Cartigliano are concentrated in the Site of Community Importance (SCI) and Special Protection Area (SPA) of the Italian Natura 2000 (N2K) Network, namely the SCI/SPA “Grave e zone umide del Fiume Brenta” (IT3260018; Figure 3.5; Comune di Cartigliano, 2014). More information on N2K habitats is provided in Annex 1.

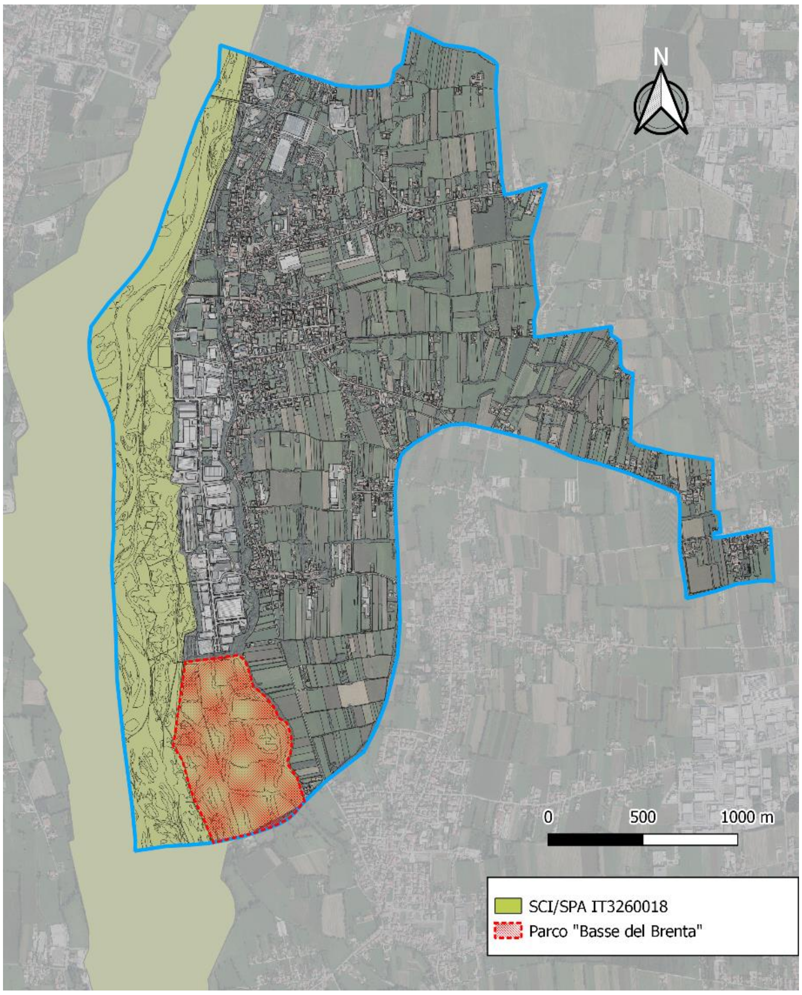


*Figure 3.5: Delimitation of SCI/SPA " Grave e zone umide del Fiume Brenta" (IT3260018) and "Parco Basse del Brenta". (https://www.provincia.vicenza.it/ente/la-struttura-della-provincia/servizi/valutazione-impatto-ambientale/valutazione-dincidenza-ambientale/grave-e-zone-umide-della-brenta ).*

In the area located near the Brenta River and no more affected by river flooding, the soil is mainly composed of gravel and cobbles and is therefore not so fertile. This type of soil has allowed the development of vast areas of dry grasslands, which are only suitable for grazing. Moving away from the river environment, soils are more developed and more suitable for agriculture. These soils are mainly sandy soils, as typical of the high plain formed following the last ice age in the North of the Vicenza province (https://gaia.arpa.veneto.it/maps/778/view ; Figure A10.1, Annex 2). This feature led to a moderately high permeability of the soils (https://gaia.arpa.veneto.it/maps/294 ; Figure A10.2, Annex 2), that lead to a decrease of surface water, but also to an increase in percolating rainwater. Thus, water availability can be a limiting factor for agriculture and led to the construction of an intricate system of artificial canals for irrigation that criss-crossed the entire municipal territory (Comune di Cartigliano, 2014).

## 2.2. Data collection

The study focused on herbaceous communities including both seminatural grasslands and urban green spaces such as public parks, roundabouts or traffic islands. The selection of the patches to be surveyed was based on an existing categorical map of Cartigliano (1m resolution), built on the III level of EUNIS classification system (Figure  3.6; [https://eunis.eea.europa.eu/habitats.jsp](https://eunis.eea.europa.eu/habitats.jsp)).

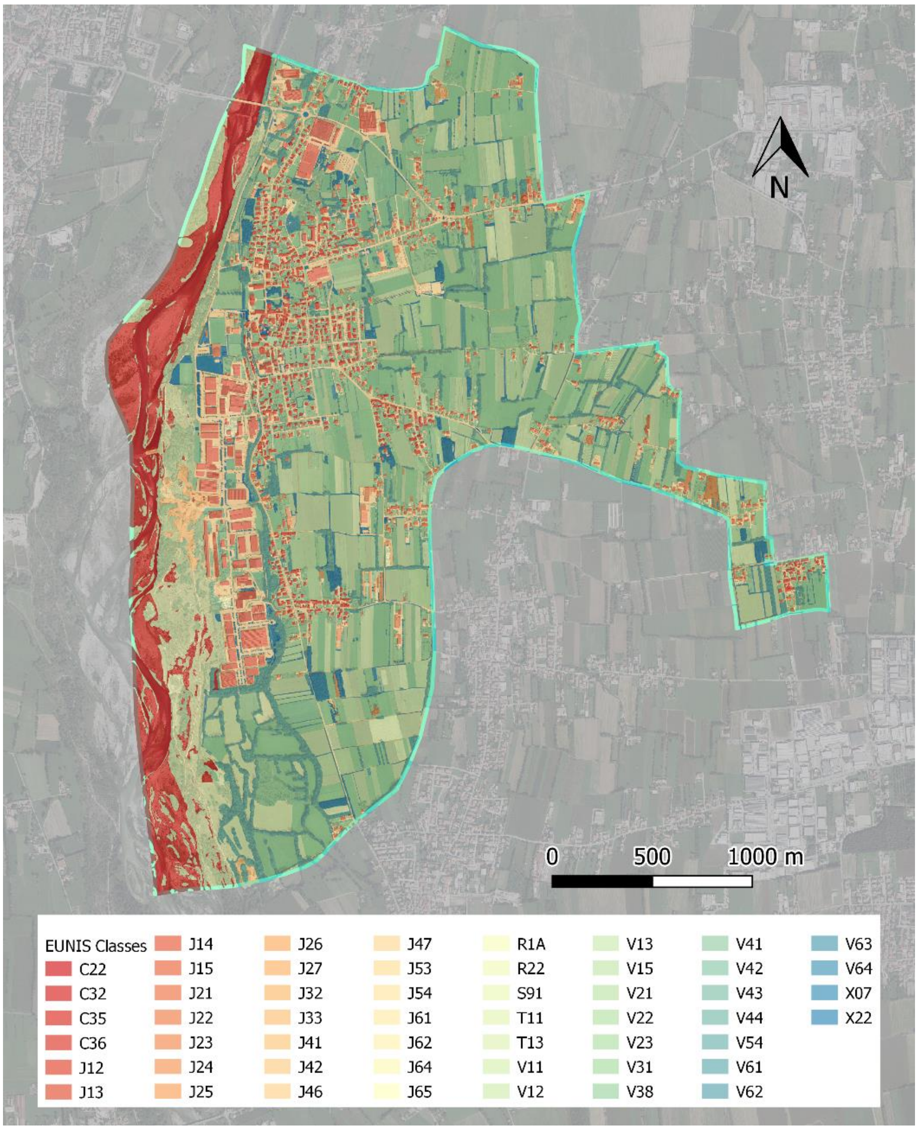


*Figure  3.6: EUNIS categorical map of the study area (modified from Cercato, 2023; names of EUNIS classes of the legend are reported in Table A11.1, Annex 3).*

By using the random stratified polygon selection on the categorical map, we identified a total of 60 patches considering two landscape classes, namely seminatural grasslands and urban green areas (30 of seminatural grasslands and 30 of urban green areas; Figure  3.7) across the municipality territory. Patches were selected so as to ensure the variability in configuration attributes (i.e., area, perimeter and contrast between habitat and matrix) needed to our analysis. The selection of the patches was conducted through GIS software (QGis 3.22).

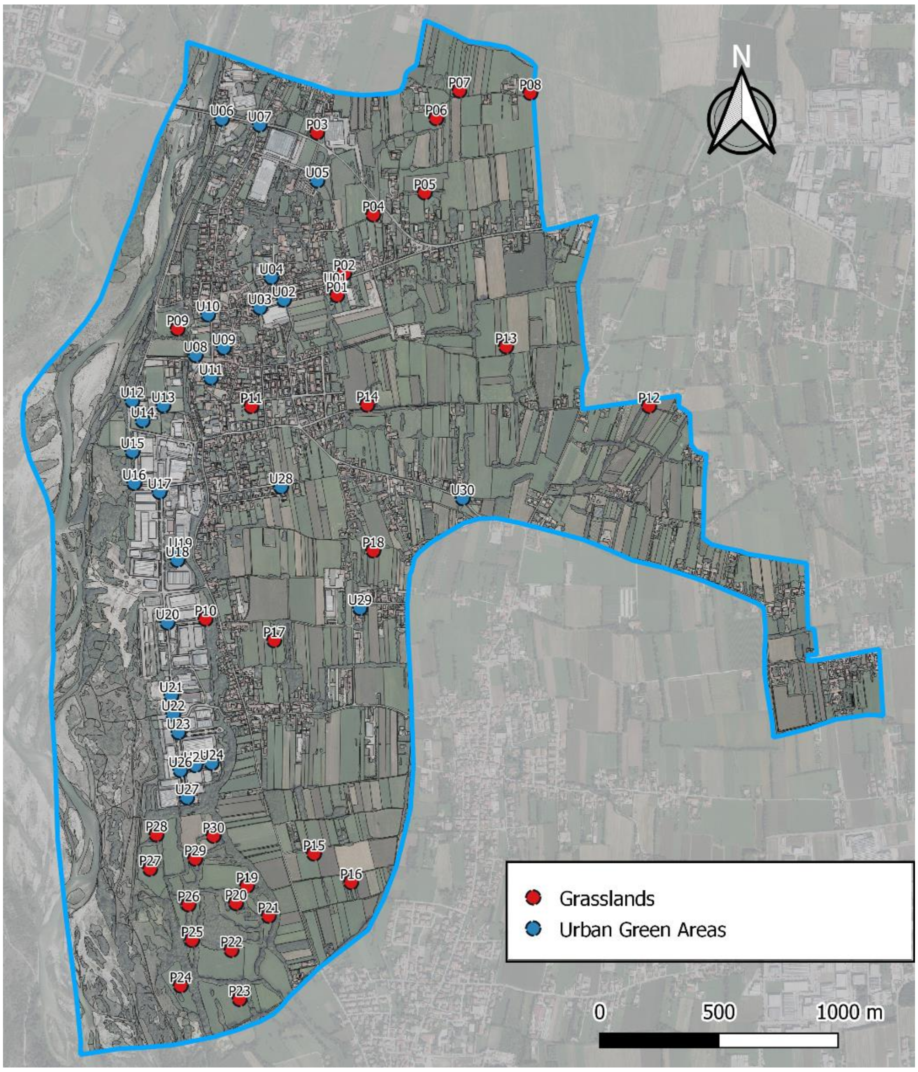


*Figure 3.7: Location of the selected patches.*

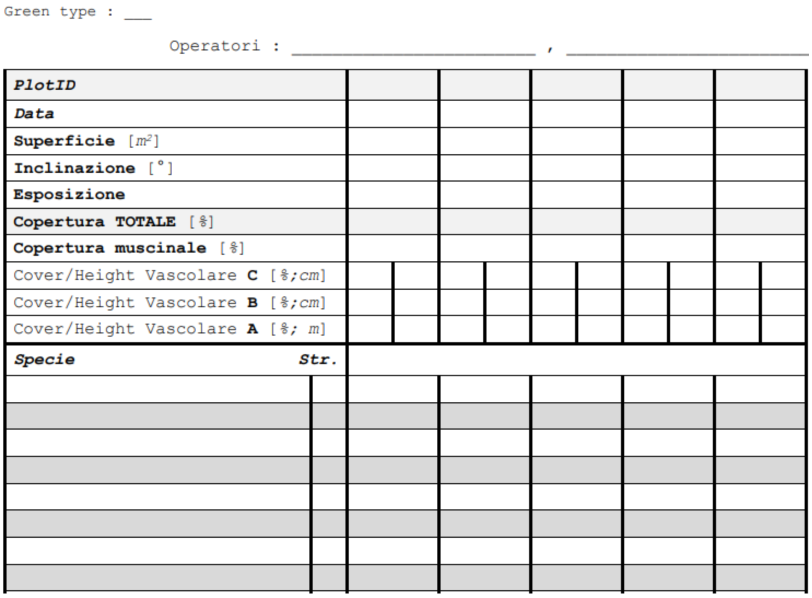
To select the 30 patches of seminatural grasslands we considered those patches of herbaceous communities managed for hay production for livestock. Particularly, we randomly selected patches in the categorical map belonging to the EUNIS classes R22 (*Low and medium altitude hay meadow*) and V39 (*Mesic perennial anthropogenic herbaceous vegetation*).

To select patches of the urban green areas we considered herbaceous communities of public green spaces, constructed and managed in order to improve the aesthetic beauty of residential or industrial areas. Specifically, we randomly selected patches considering the EUNIS classes X22 (*Small city centre non-domestic gardens*) and X23 (*Large non-domestic gardens*) in which no trees or shrubs were present.

### 2.2.1. Vegetation survey

Vegetation survey was done in the first two weeks of May, namely during the maximum detectability of herbaceous species (i.e., when most plant species are at peak of flowering and some plants already have their fruits). In turn, this made it easier to correctly identify the species. In each selected patch, we surveyed vegetation in 4x4 m sampling plots located near the centre of the patch and selecting plots representative of the whole patch. Additionally, plots mowed prior to our surveys (since the previous winter season) were not considered as suitable for our analyses and were not included in our study.

Then, in each suitable plot, we recorded all the vascular plants and their percentage cover as the projected area of all individuals of a species with respect to the total area of the plot (Silan et al., 2017) using a standard survey sheet (Figure 3.8). According to the scale used to record species percentage cover, a 1% cover was given to species that globally occupied a square of 40x40 cm (0.16 $m^2$) within the given plot of 4x4 m (16 $m^2$). Furthermore, in each plot we collected data about community structure (e.g., total cover percent, average plant height).



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| **Esposizione** | | | | | | |
| **Copertura TOTALE** [%] | | | | | | |
| **Copertura muscinale** [%] | | | | | | |
| Cover/Height Vascolare **C** [%;*cm*] | | | | | | |
| Cover/Height Vascolare **B** [%;*cm*] | | | | | | |
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*Figure 3.8: Example of survey sheet.*

While most of the species were recognized directly on field, we collected and stored samplings (i.e., entire plant individuals) of those species that we were unable to clearly identify during the survey. Then, through dichotomous keys (e.g., Pignatti, 1982; Pignatti et al., 2017) we identified species in laboratory and correctly updated our records. Species nomenclature follows Bartolucci et al. (2018).

For the determination of biomass production, we collected above-ground biomass in the same surveyed plots. The biomass was sampled between the end of May and June, namely during the annual peak of biomass (Dengler et al., 2021; Justić & Jelaska, 2022). Within each 4x4 m plot, we identified a sub-plot of size 50x50 cm representative of the whole sampled community (i.e., sub-plot with a similar composition and abundance in plant species with the respect to the whole 4x4 m plot). In each sub-plot we cut the above-ground biomass at a height of 1 cm from the ground without picking the litter (Dengler et al., 2021; Pan et al., 2022; Figure 3.9).

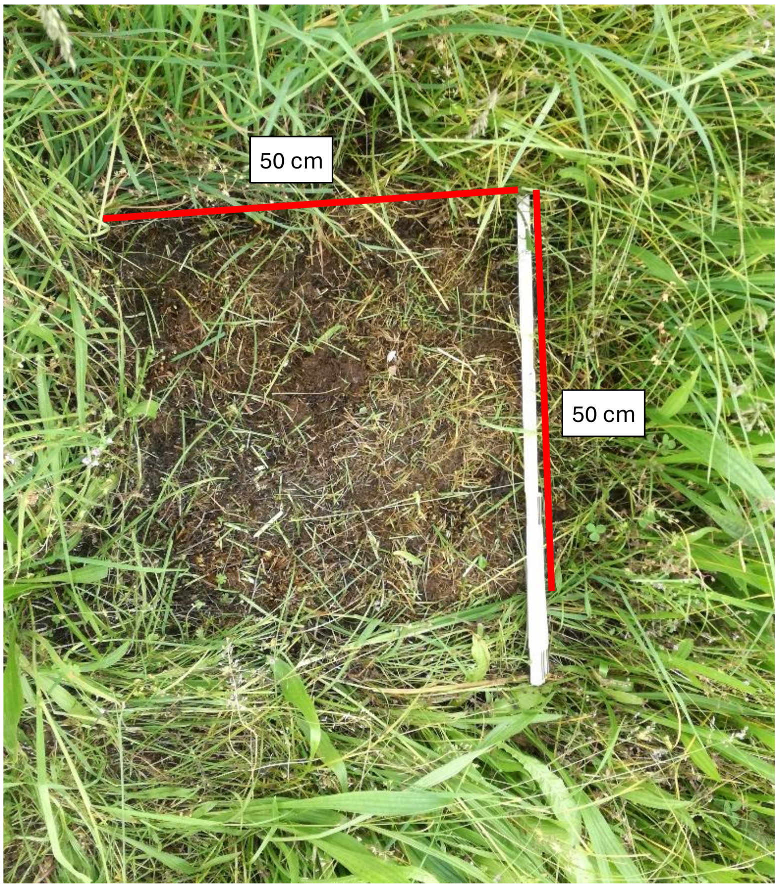

*Figure 3.9: Example of a biomass sampling plot.*

Following Justić & Jelaska (2022), collected samples were placed in paper bags for the transport to the laboratory and the subsequent stock. The paper bags allowed water vapour to escape from the samples avoiding respiration processes that could compromise the amount of carbon, and therefore the sampled biomass.

To quantify the dry biomass, each sample was put in aluminium pans and dried in a dryer oven (Memmert Oven UN110) at a constant temperature of 65°C (Dengler et al., 2021). Then, after a preliminary drying cycle of 12 hours, we weighed each sample every 3 hours until we reached a constant sample weight for two consecutive times (i.e., in a range of ± 1 g). We recorded data of the weight of each sample by using a technical balance (RADWAG-PS 2100.R2; accuracy ± 0.01 g). Finally, we standardised the measures of biomass production in $g/m^2$.

## 2.3. Data analysis

### 2.3.1. Analysis of plant community composition and structure

In order to investigate the relationship between the two ESs, we first selected the attributes of biodiversity to be considered in the trade-off analysis. With attributes of biodiversity, we mean the quantification of the diversity of species within plots based on plant traits, as well as on their ecological and adaptative strategies. In particular, since it is well known that more productive species (i.e. perennial, graminoid, and invasive alien species; Jackson, 2005; Kosolapov et al., 2021) are used to promote hay production and often cause a decrease of species richness and diversity (Sanaei & Ali, 2019), we investigated biodiversity accounting for those plant traits and ecological strategies able to reveal useful information on ecosystem management and conservation.

Thus, we calculated the summarising attributes of biodiversity by considering number and abundance of species both overall and separately by subdividing them based on i) life cycle, ii) growth form, and iii) spatial distribution. Specifically, we computed for each plot:

- the total number of species (S_plot) and the total cover, as the sum of the abundances of all species in each plot (C_plot);
- the number and relative abundance of annual (i.e., terophyte species according to Pignatti, 2005; S_ann; C_ann) and perennial (i.e., non-terophyte species; S_per; C_per) species;
- the number and relative abundance of graminoid (i.e., species belonging to Poaceae and Cyperaceae; S_gram; C_gram) and non-graminoid (S_ngram; C_ngram) species;
- the number and relative abundance of native (S_nat; C_nat) and alien (i.e., alien species according to Galasso et al., 2018; S_ali; C_ali) species.

To account for environmental features, we computed edaphic attributes based on Ellenberg Indicator Values (EIVs; Dengler et al., 2018). EIVs are the most used scoring system for expressing ecological preferences of plants and are widely used for bioindication, since they can be used to extract insights about the environment, particularly for edaphic conditions, from the species composition of a specific community (Di Biase et al., 2023). The edaphic variables were computed by accounting for the species relative abundance and included:

- the Ellenberg Indicator Value for (soil) moisture (M);
- the Ellenberg Indicator Value for (soil) nutrient content (especially nitrogen; N);
- the Ellenberg Indicator Value for (soil) reaction (R).

In addition, we retrieved more information about descriptors of the herbaceous communities to further investigate its composition and structure. Therefore, we computed taxonomic and ecological descriptive information for each species, in particular:

- **Spatial distribution/chorotype**: chorotypes are groupings of species with overlapping geographical distribution (e.g. Mediterranean, Atlantic; Jakob et al., 2022). Chorotype of each species were retrieved from Pignatti (2005), while updated information on species spatial distribution was also used to distinguish between native and alien species (i.e., archaeophyte and neophyte species) were based on the checklist of alien species in Italy (Galasso et al., 2018);
- **Life form**: we applied Raunkier (1934) life forms, namely chamaephyte (CH), geophyte (G), hemicryptophyte (H), phanerophyte (P) and nano-phanerophyte (NP), and therophyte (T) to each species by considering Pignatti (2005).
- **Ecological strategies**: following Pierce et al. (2017) we computed the adaptative strategies of each species according to Grime (1977). Particularly, we determined the component of CSR (i.e., Competitive, Stress tolerant and Ruderal species strategy) of each species through ecological traits (Leaf Area (LA, mm2), Leaf Dry Matter Content (LDMC, %), and Specific Leaf Area (SLA, mm2/mg)) downloaded from Try database (https://www.try-db.org/TryWeb/dp.php ; Kattge et al., 2020).

Then, the collected information on single species were used to compute summarising variables of each plot and, in turns, of each group distinguished by cluster analysis. Particularly, for each group we computed:

- the mean number of species belonging to each chorotype (i.e., chorological spectrum) among plots;

- the mean number of species belonging to each life form (i.e., life-form spectrum) among plots;
- after determining the values of the three components (C; S; R) for each species, we represented species in ternary plots that allows to distinguish Competitive (C), Stress tolerant (S) and Ruderal (R) species, and all intermediate strategies (e.g., competitive-stress-tolerant (CS), competitive-ruderal (CR), ruderal-stress-tolerant (RS)). The ternary Grime plots were computed by accounting for the species presence within the groups and using the information on Species' adaptative strategies (ternary package in R).

### 2.3.2. Canonical Correspondence Analisys

By accounting for the biodiversity and edaphic attributes, we performed a Canonical Correspondence Analysis (CCA) to determine which biodiversity attribute was most correlated to the environmental conditions (i.e., the edaphic features revealed by EIVs). In this way, the selected biodiversity attributes enabled to consider the environmental features reflected by plant communities and to help the interpretation of results. Indeed, CCA is a multivariate statistical technique useful to unravel relationships between biodiversity attributes and environmental variables (Ter Braak & Verdonschot, 1995). Particularly, CCA seeks to represent complex ecological data in lower-dimensional space while preserving the original relationships.

Since the analysis identifies axes that maximize the correlation between biodiversity attributes and environmental gradients, we selected those biodiversity attributes with the highest score on the first (and most significant considering a 9999 permutations technique) axis (Ter Braak, 1986).

Additionally, considering the sampled plot, we performed a cluster analysis through R (version 4.3.2) to be included in the CCA. Particularly, this statistical method allowed to examine the similarities and dissimilarities in species composition and abundance and enabled the classification of plant communities based on shared features of the plant communities in the considered plots under study. Following Del Vecchio et al. (2018), the cluster analysis was performed by using the Bray-Curtis similarity index (Bray & Curtis, 1957) and the Ward method algorithm (Ward, 1963). Groups were then added to the CCA performed in Past 4.02 and helped the interpretation of its output.

Following Fantinato et al. (2019), to highlight differences between the groups distinguished by the cluster analysis, we performed an Indicator Species Analysis (ISA; Dufrêne & Legendre, 1997) to the plots of each group using the *multipatt* function in R (package *indicspecies*; De Cáceres & Legendre, 2009; De Cáceres et al., 2010) and choosing *r* as the statistical value to identify species fidelity. Accounting for a significance level (α=0.1), only species exhibited a statistical parameter with *p-value*<0.1 were considered associated to a specific group. Indicator species are the recurring species that exhibited similar abundances across the different plots of a group and enabled us to distinguish the characteristics of plant communities among groups.

### 2.3.3. Analysis of patches configuration attributes

To understand the effects of spatial configuration of patches on the trade-off between the two ESs, for each selected patches we figured out three spatial metrics considered as crucial attributes influencing ecological processes that support the supply of ESs (Uuemaa et al., 2013). Specifically, we considered i) AREA (area in ha), ii) PERIMETER (perimeter in m) and iii) ECON (contrast between patch and matrix quantified as percentage of perimeter shared with artificial areas). ECON was computed according to the Contrast Index equation (McGarigal, 2015):

$$ECON = \frac{\sum_{k=1}^{m}(p_{ijk} * d_{ik})}{p_{ij}} * 100$$

Where:

- pijk : length (m) of edge of patch ij adjacent to patch type (class) k;
- dik : dissimilarity (edge contrast weight) between patch types i and k;
- pij : length (m) of perimeter of patch ij.

Particularly, we consider all the artificial patches (i.e., all land-use types included in the class J in the EUNIS I level; Tab. A3.1, Annex 3) with $d_{ik}$ = 1 (maximum dissimilarity) and all the non-artificial patches with $d_{ik}$ = 0 (zero dissimilarity) to compute the percentage of perimeter of the investigated patches shared with artificial areas. All the configuration attributes were computed through Fragstats 4.2 (McGarigal, 2015).

### 2.3.4. Trade-off analysis

The analysis of the trade-off between biodiversity and biomass production was conducted considering all the sampled herbaceous communities to account for the necessary variability in terms of patch configuration attributes. Specifically, the occurrence of trade-off was defined by the presence of a significant negative correlation (significance level α=0.05) between biomass production and the biodiversity attribute selected from the CCA. The trade-off analysis was conducted in R (using *cor* function) through a non-parametric test (Spearman's rank correlation). Moreover, we conducted an additional correlation analysis to verify if the trade-off occurred also when considering the relative abundance of the species accounted as descriptive of biodiversity.

After testifying the presence of a significant negative relationship (i.e., if the trade-off occurred), we performed a principal component analysis (PCA) on the two variables involved in the trade-off following Fantinato et al. (2023). Specifically, we extracted the first principal component (PC1) from the output of the PCA to summarise information about the relationship between the two ESs (i.e., biomass production and the selected species richness variable). In this way, we used the PC1 as descriptive of the revealed trade-off and considered this variable as the response variable to be included in the linear regression models (Table 3.1). Spatial configuration variables of patches were considered as predictors to be included in the regression models. Particularly, we considered AREA, PERIMETER and ECON (Table 3.1).

*Table 3.1: Set of variables used in the linear regression model.*

| Response variable | Predictors variables |
|---|---|
| *PC1* | *AREA* |
| | *PERIMETER* |
| | *ECON* |

Before performing the regression analysis, we checked for collinearity among predictors in order to avoid wrong results and misleading outputs. Particularly, we computed the Variance Inflation Factors (VIF) and remove variables with the highest VIF's values till all the predictors' VIF fell below the desired cut-off value (i.e., 3; O'Brien, 2007).

Then, to find the best model (i.e., the set of predictors which best explained the PC1 variability, and consequently the trade-off), we performed several regression models. In these models, we accounted for all possible combination of predictors by considering the whole set and all possible subsets of selected predictors.

To reveal the best regression model (i.e., the model with the smallest value of AIC; Akaike, 1974), we computed the Akaike Information Criterion (AIC) (Schumacher & Roscher, 2009; Kahmen et al., 2005). All regression models and respective AIC were performed in R by creating a function able to consider all predictors combinations and select the best (sub)set by looking at the regression model with the smallest AIC. Additionally, we checked for the meeting of assumptions on linear regression, particularly on the normality of residuals, to avoid unbiased estimates (Schmidt & Finan, 2018).

# CHAPTER 3. RESULTS

As 12 out of the 60 selected patches were mowed prior to our sampling (since the previous winter season), a total of 48 plots were deemed as suitable for the assessment of the two ESs investigated, namely 30 plots of seminatural grasslands and 18 plots of urban green areas.

In the 48 herbaceous patches surveyed, we found a total of 144 plant species (Table A12.1, Annex 4). The average number of species per plot was 25.81±7.25, while the average total cover per plot was 119.22±21.49% and the mean height of the herbaceous communities was of 36.04±18.62 cm. While most plots were characterised by only herbaceous species, three plots exhibited one seedling per plot of woody individual (less than 0.5% in relative abundance per plot). Moreover, moss cover has never exceeded the 20% of the total plot area. Finally, all plots lay on a horizontal plain (i.e., the measured inclination has always been 0°).

In the procedure of sample drying, the average time to reach a constant weight of dry biomass was about 24 h in the oven. After standardising the biomass obtained from the drying process to g/m$^2$, we found a mean dry biomass production of 408.20±139.01 g/m$^2$.

## 3.1. Plant community composition and structure

The summarising attributes of species diversity highlighted different values among groups according to the grouping factors (Figure 4.1). Based on the life cycle, surveyed plots had a mean number of perennial species (15.81±5.03) only slightly higher than that of the annual species (10.0±5.2), but on average, perennial species were more abundant than annual species (93.91±34.69% and 25.30±24.69%, respectively) and dominated the community (Figure 4.2). Under a growth form perspective, there was a mean prevalence of non-graminoids species (19.06±6.02) on graminoids (6.77±2.23), although their mean abundance was comparable (61.48±25.84% and 57.74±28.84 % respectively). Finally, grouping on spatial distribution revealed that the community is dominated by native species both as species number (24.9±6.9) and abundance (114.79±23.61%), while alien species were on average very few (0.94±0.86) and with negligible abundance (4.42±7.31%).

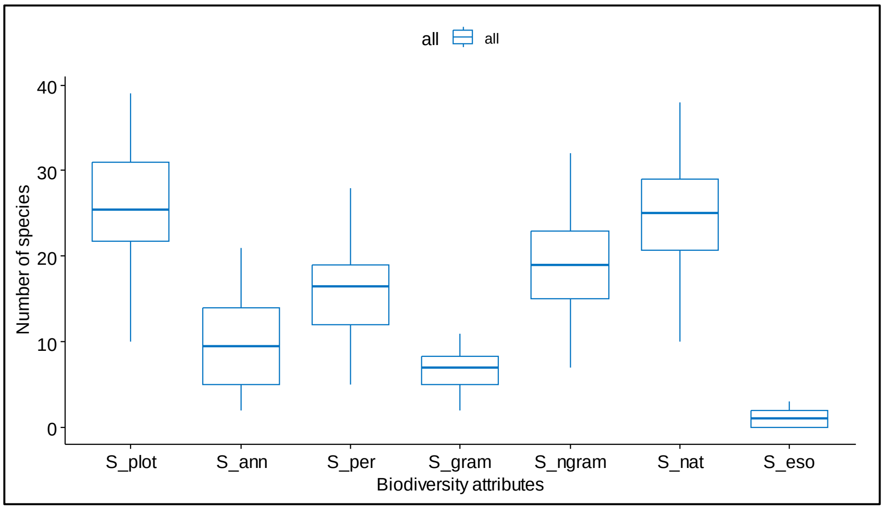

*Figure 4.1: Boxplot of the number of species of biodiversity attributes.*

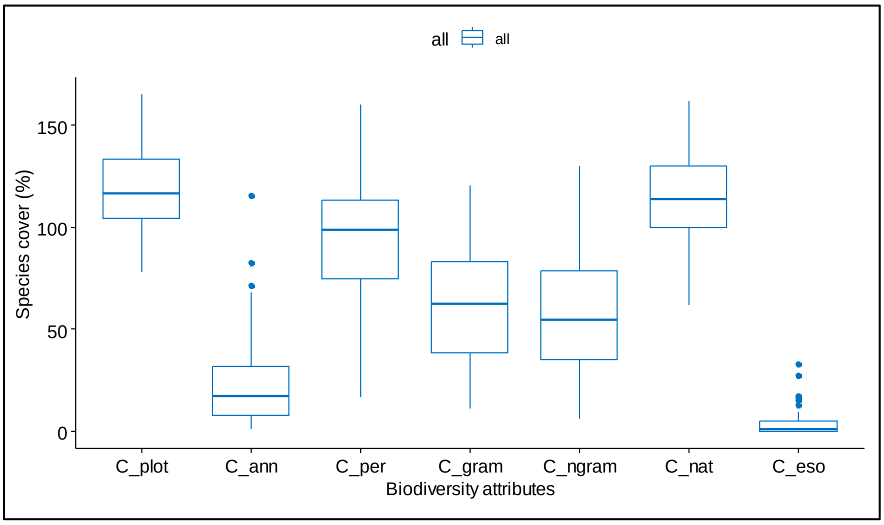

*Figure 4.2: Boxplot of the relative abundance of species of biodiversity attributes.*

Attributes of environmental (edaphic) conditions based on communities' composition and abundance revealed a mean EIVs of 4.21±0.47 for the moisture (M; i.e., indicating mesic conditions), of 5.30±0.68 for the nutrient (N; moderately fertile soils) and 6.12±0.38 for the soil reaction (R; sub-alkaline; Figure 4.3).

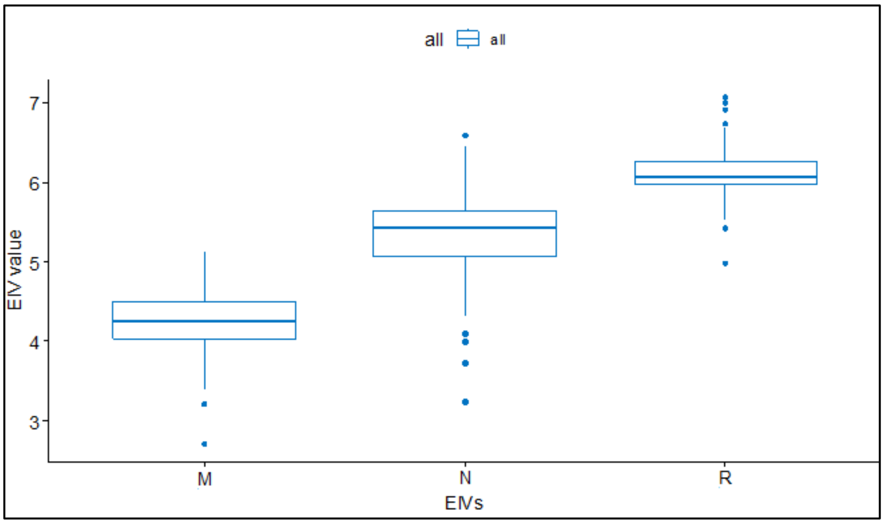

*Figure 4.3: Boxplot of the attributes of environmental (edaphic) conditions.*

The additional information about descriptors of herbaceous community (spatial distribution/chorotype, life forms, and ecological strategies) provided more detailed information on community composition and structure of the groups identified by the cluster analysis.

Looking at spatial distribution, we found that chorotype spectra were quite similar among groups, with a prevalence of Mediterranean and Paleotemperate species, while Atlantic and Endemic revealed to be almost absent according to the location of the study area (Table A13.1, Annex 5). However, group 4 slightly differed from the other groups for a smaller number of Boreal species, while Cosmopolite, Mediterranean and alien species appeared in higher frequency. Specifically, within the plots of the group 1, in terms of the chorological spectrum we found that Boreal and Palaeotemperate species were the most frequent (Figure A13.1; Table A13.1, Annex 5). About group 2, in addition to Boreal and Paleotemperate species, also Eurasian species were the most frequent species of this group (Figure A13.2; Table A13.1, Annex 5). On the other hand, regarding group 3, the most frequent species showed an equally distribution among Boreal species, followed by Cosmopolitan, Eurasian, Mediterranean and Paleotemperate species (Figure A13.3; Table A13.1, Annex 5). In contrast, group 4 showed the highest frequencies of Cosmopolitan, Mediterranean, and Paleotemperate species compared to all other groups (Figure A13.4; Table A13.1, Annex 5). Regarding adventitious (alien) species, an intermediate frequency was shown for all groups; although among all groups, group 4, was the one with the highest frequency. Atlantic and Endemic species were no longer present in any group. While regarding Orophytic species, they were rarely present in all groups.

Investigating life-form spectra, species belonged to the different life forms typical of herbaceous communities. Indeed, we found a predominance of Hemicryptophyte (H) and Terophyte (T) species, followed by smaller number of Chamaephytes (CH) and Geophytes (G; Table A13.2, Annex 5). Almost absent revealed to be Nano-Phanerophytes (NP) and Phanerophytes (P). However, T species (i.e., annual species) showed to be predominant in the group 4, conversely to what happened in the other groups in which prevailed H species. By looking at the life-form spectrum of the group 1, group 2 and group 3, we observed a most frequent of H species (respectively: mean >11 species; mean >14 species; mean >13 species), followed by T (i.e., annual) species (Figure A13.5; Figure A13.6; Figure A13.7, Annex 5). Group 4, in contrast to all other groups, is dominated by T (i.e., annual) species (mean >15 species), followed by H species (Figure A13.8, Annex 5). As for CH and G species were hardly present in all groups. While NP+P species were rarely observed in all groups.

Looking at the ecological strategies, communities' composition and abundance highlighted a quite equal distribution among strategies, with Stress tolerant and Ruderal species slightly greater with respect to Competitive ones (Table A13.3, Annex 5). However, this difference emerged to be more pronounced while considering the group 4, in which an increase in Stress tolerant species presence and abundance prevailed on Competitive. The checklist of species with their associated CSR values is attached in Annex 6 (Table A14.1). Particularly, the ternary Grime plot of group 1 revealed that the species in this group showed predominantly ruderal (R; e.g., *Veronica arvensis* L., *Veronica persica* Poir.), competitive-ruderal (CR) and intermediate (CSR) strategies (e.g., *Trifolium pratense* L., *Dactylis glomerata* L., Figure A13.9, Annex 5). Specifically, most frequent species exhibited an intermediate strategy, while only few species showed mean cover higher than 10%. The species that emerged as most relevant based on species frequency (i.e., one-third of the most frequent species; ≥66%) in the group are *Poa pratensis* L., *Taraxacum officinale* L., *Trifolium pratense*, *Dactylis glomerata*, *Trifolium repens* L., *Geranium molle* L., *Plantago lanceolata* L., *Veronica arvensis*, *Veronica persica*, while 10 species present high values of R (i.e., higher than 80%). The ternary Grime plot of group 2 showed a predominance of intermediate (CSR) strategy species (e.g., *Trifolium pratense*, *Dactylis glomerata*), followed by ruderal (R; e.g., Veronica arvensis), competitive-ruderal (CR) species (Figure A13.10, Annex 5). Specifically, both the frequency and the mean cover of intermediate strategy species were found to be higher than the group 1, while the number of high ruderal species (i.e., with R component >80%) was lower (6 species). The species that appear most frequent within the plots of group 2 (i.e., one-third of the most frequent species; ≥66%) are: *Poa pratensis*, *Trifolium pratense*, *Carex spicata* Huds., *Arrhenatherum elatius* (L.) P.Beauv. ex J.Presl & C.Presl, *Dactylis glomerata*, *Geranium molle*, *Plantago lanceolata*, *Achillea roseoalba* Ehrend., *Veronica arvensis*. The ternary Grime plot of the group 3 reflected that of the group 2 with a predominance of intermediate (CSR) strategy species (e.g., *Sorghum halepense* (L.) Pers., *Trifolium pratense*), followed by ruderal (R), competitive-ruderal (CR) species (Figure A13.11, Annex 5). Conversely, the group 3 showed the presence of more stress-tolerant species. Considering the species present in more than 4 plots (i.e., one-third of the most frequent species; ≥66%), the species that emerged as common among the plots in the group are *Sorghum halepense*, *Taraxacum officinale*, *Trifolium pratense*, *Erigeron annuus* (L.) Desf., *Geranium molle*, and *Plantago lanceolata*. The ternary Grime plot of group 4 appeared different from the other groups. Although intermediate strategy (CSR) species were present, they were less frequent and abundant. Conversely, ruderal species (R) showed to be more frequent (e.g., *Veronica arvensis*, *Cerastium glutinosum* Fr.), while stress-tolerant (S) and ruderal-stress-tolerant (SR) species were more frequent and meanly abundant (e.g., *Vulpia myuros* (L.) C.C. Gmel., *Cynodon dactylon* (L.) Pers.; Figure A13.12, Annex 5). Moreover, the species that appear most frequently (i.e., one-third of the most frequent species; ≥66%) within the plots of group 4 are *Vulpia myuros*, *Arenaria serpyllifolia* L., *Cynodon dactylon*, *Aphanes arvensis* L., *Erigeron annuus*, *Veronica arvensis*, *Cerastium glutinosum*.

## 3.2. Canonical Correspondence Analisys

The Canonical Correspondence Analysis allowed to investigate the collinearity among the chosen biodiversity attributes and revealed the most significant that reflects the environmental (edaphic) conditions.

Considering the three EIVs as environmental variables, the CCA computed three axes. Particularly, the significance test revealed that axes 1 and 2 were significantly involved ($p<0.05$) in the explanation of the correlations among biodiversity attributes and edaphic features (Table 4.1).

*Table 4.1: Significant test of CCA.*

| **Axis** | **Eigenvalue** | **p** |
|---|---|---|
| **1** | 0.0043612 | 0.0114 |
| **2** | 0.00052089 | 0.0337 |
| **3** | 2.8731E-09 | 0.6015 |

Moreover, the significant axes were found to be the most involved in the explanation of the correlations among the two set of variables tested, with almost 100% of variability explained (Table 4.2). Specifically, axis 1 was involved for 89.33%, while axis 2 for 10.67%.

*Table 4.2: Variability explained of the axes of CCA.*

| Axis | Eigenvalue | % |
|---|---|---|
| **1** | 0.0043612 | 89.33 |
| **2** | 0.00052089 | 10.67 |
| **3** | 2.8731E-09 | 5.885E-03 |

Looking at the scores, namely the correlation between each biodiversity variables and environmental variables for each axis, we found that life cycle was the most important in the first axis (i.e., in the axis that most summarised the correlations with environmental conditions; Table 4.3). Particularly the number of annual species (S_ann) emerged to be the most correlated to the environmental conditions among the biodiversity attributes. Thus, we selected this attribute to investigate the relationship with biomass production.

*Table 4.3: CCA variable scores.*

| | Axis 1 | Axis 2 | Axis 3 |
|---|---|---|---|
| **S_plot** | -0.00134 | -0.00101 | -0.01215 |
| **S_ann** | 2.43235* | 0.560388 | 0.286924 |
| **S_per** | -1.54044 | -0.35604 | -0.20129 |
| **S_gram** | -0.81213 | 3.19607 | 0.634011 |
| **S_ngram** | 0.290282 | -1.13385 | -0.20874 |
| **S_nat** | 0.029233 | 0.081785 | -0.36634 |
| **S_eso** | -0.7393 | -2.14413 | 10.0628 |

**Variable most correlated to the environmental conditions*

While considering the correlation of S_ann with the environmental (edaphic) attributes and focusing on the first axis, we found that the EIV moisture (M) was the most important. Indeed, a negative correlation emerged (Figure 4.4), meaning that at high values of annual species corresponded low values of EIV moisture (i.e., xeric conditions). Relatively smaller relevance was played by EIV nutrient

(N), also negatively correlated to the number of annual species, while the soil reaction (R) emerged to be the least involved.

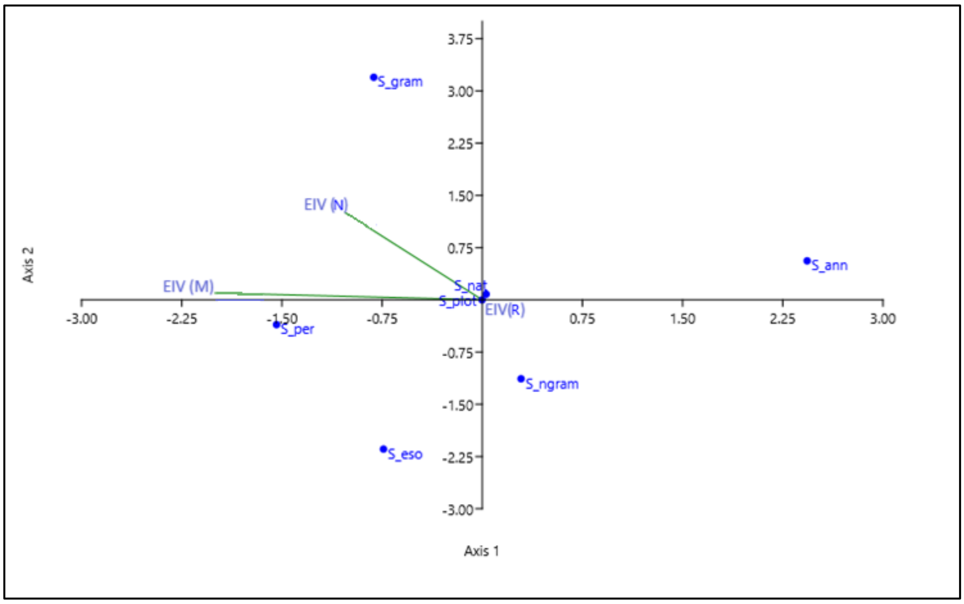

*Figure 4.4: bi-plot diagram of the CCA. This diagram shows axes 1 and 2 of the biodiversity and the environmental variables.*

The cluster analysis identified 4 different groups (Figure 4.5). Particularly, Group 1 included eighteen plots, group 2 fourteen plots, group 3 six plots and group 4 ten plots (Table A15.1, Annex 7). Within the groups revealed by the cluster analysis, we observed that seminatural grassland and urban green plots were mixed (because of the high similarity), except for group 2 in which the analysis grouped only plots of seminatural grasslands.

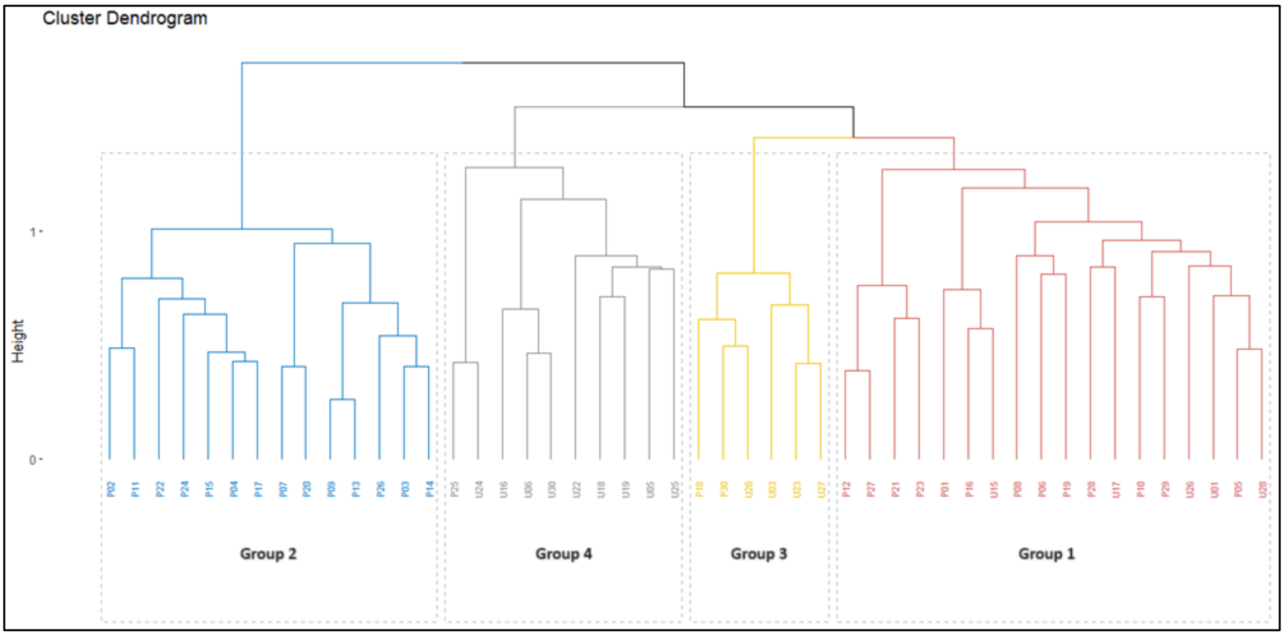

*Figure 4.5: Groupings of plots resulting from cluster analysis.*

While including groups in the CCA output, a partial overlapping was detected among groups (Figure 4.6). However, group 4 resulted to be the most influent in the number of annual species (S_ann). Indeed, group 4 showed the highest mean in terms of annual species (15.3±4.37), followed by group 3 (12.17±6.11), 1 (8.44±4.69) and 2 (7.29±2.49) with lower mean of annual species (Figure 4.7).

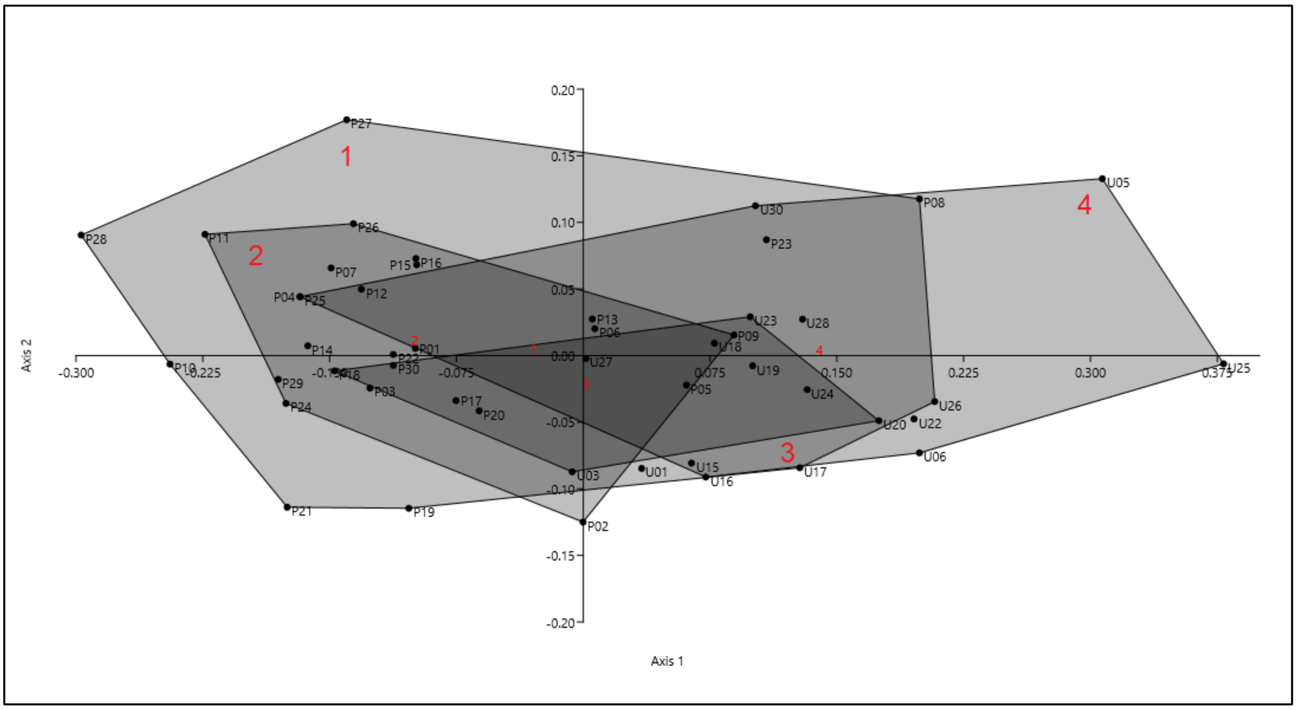

*Figure 4.6: bi-plot diagram of the CCA including the 4 groups identified by cluster analysis.*

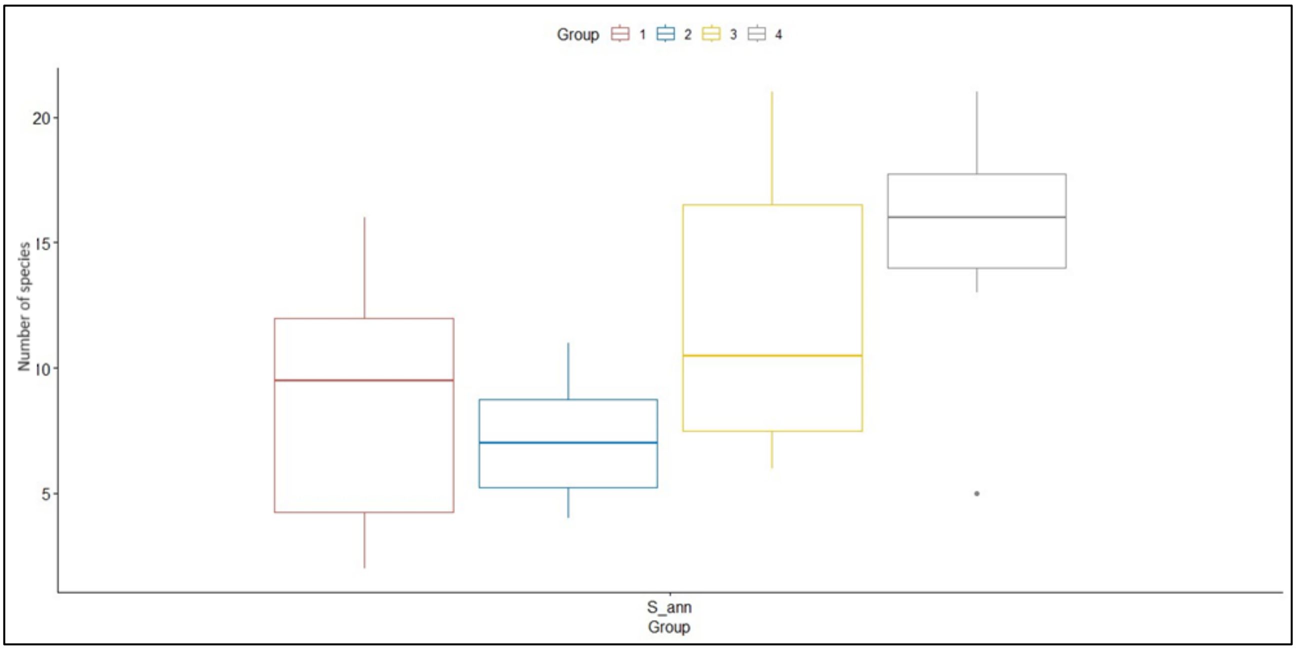

*Figure 4.7: Boxplot of the number of annual species among groups.*

Group 4 was characterised by xeric conditions (i.e., lower values of EIV moisture (M)). Indeed, the group 4 exhibited the lowest value of EIV moisture (3.58±0.43) on average, while group 3 (4.32±0.34), 2 (4.34±0.23), and 1 (4.43±0.37) showed similar mean values (Figure 4.8).

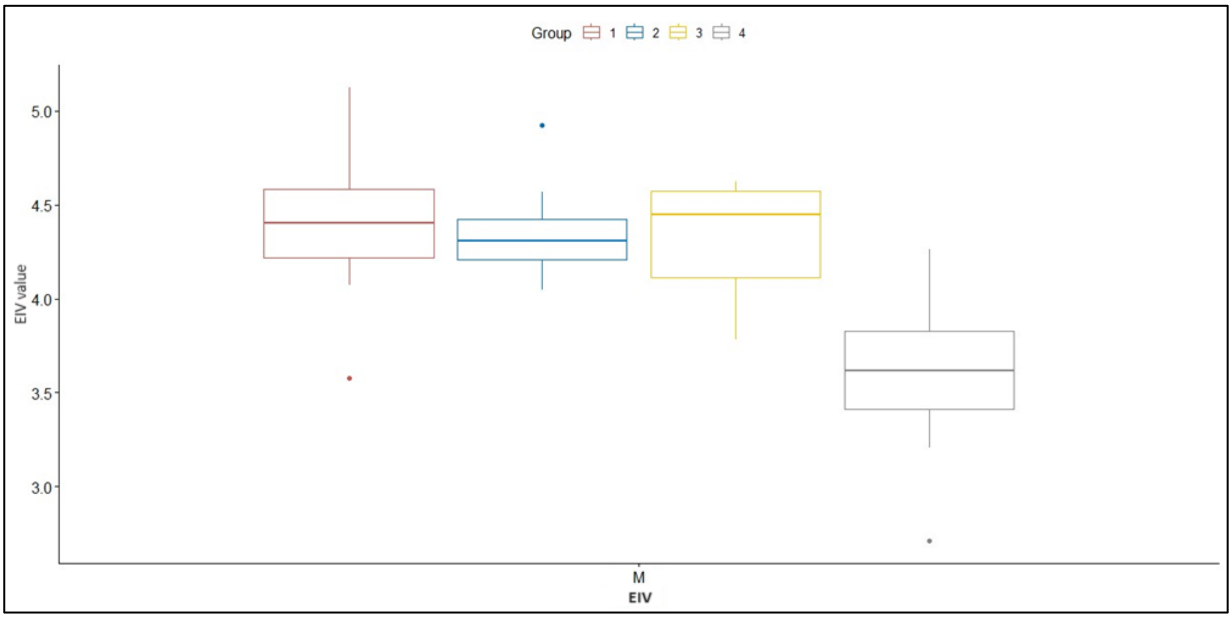

*Figure 4.8: Boxplot of EIV moisture (M) among groups.*

The same pattern emerged when considering the mean biomass production among groups. Specifically, the group 4 showed to be the lowest in biomass production (266.63±77.72 g/m$^2$) on average, followed by group 3 (366.19±56.33 g/m$^2$) with intermediate values, and group 1 (444.00±152.15 g/m$^2$), and group 2 (481.29±102.11 g/m$^2$) with the highest mean biomass productions (Figure 4.9).

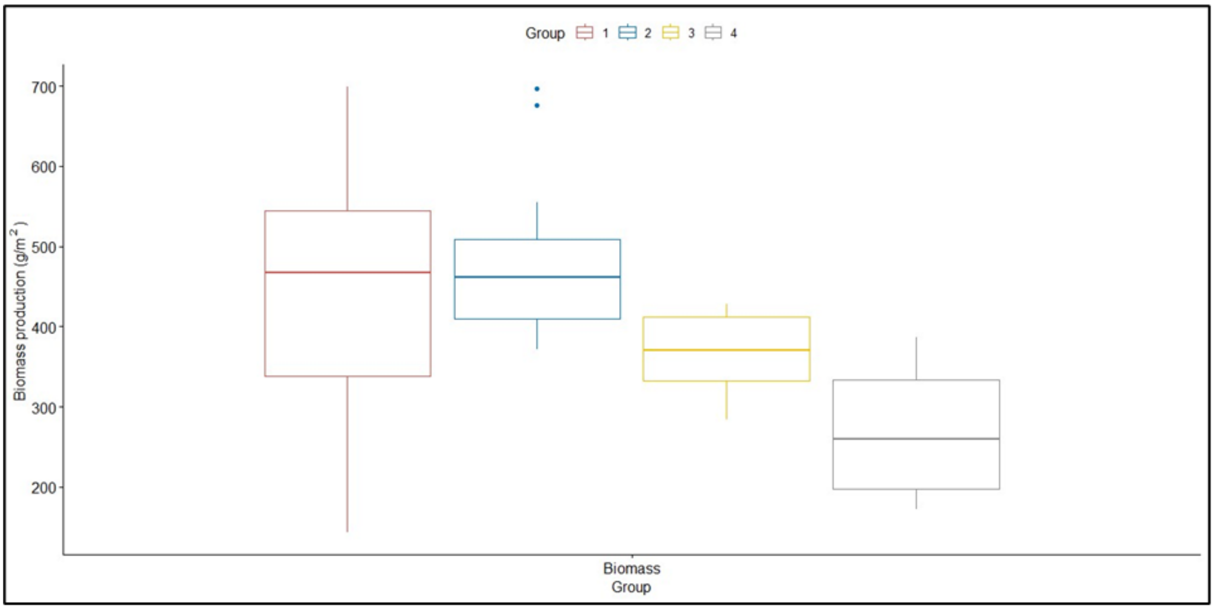

*Figure 4.9: Boxplot of biomass production among groups.*

Further details on biodiversity and EIVs attributes values for the groups distinguished by the cluster analysis are available in Annex 8 (Table A16.1).

Regarding to the Indicator Species Analysis (ISA) of group 1 three species, mostly synanthrophic, were revealed, namely: *Taraxacum officinale*, *Dactylis glomerata*, *Festuca rubra* L. (Table A17.1, Annex 9). The ISA of group 2, unlike group 1, showed a higher number of common species within plots. Specifically, the analysis revealed nine common species, mainly hay meadow species (Table A17.2, Annex 9). Differently from group 1, most of the listed species are diagnostic species of the *Arrhenatherion elatioris* alliance, as well as frequent and abundant species of this alliance like *Poa pratensis*, *Achillea roseoalba* and *Centaurea nigrescens* Willd. As for group 3, the ISA identified nine common species (Table A17.3, Annex 9). Although the presence of diagnostic species of the *Arrhenatherion elatioris* alliance, such as *Festuca pratensis* Huds., and *Plantago lanceolata*, the analysis revealed the important presence of synanthropic species, namely: *Erigeron annuus*, *Sonchus asper* (L.) Hill, *Sorghum halepense*, *Bromus madritensis* L., *Cardamine hirsuta* L. Finally, fifteen species were highlighted from the ISA for group 4 (Table A17.4, Annex 9). Contrasting to previous groups, the analysis revealed species of dry meadows (e.g., *Arenaria serpyllifolia*, *Trifolium campestre* Schreb., *Medicago minima* L.) and synanthropic generalists (e.g., *Cynodon dactylon*, *Sporobolus indicus* (L.) R.Br.). Although some species were shared with group 3 (i.e., *Sorghum halepense*, *Bromus madritensis*, *Cardamine hirsuta*), group 4 distinguished for the presence of xerophyte and therophyte species typical of along roadsides and in disturbed areas.

## 3.3. Patches configuration attributes

Concerning attributes of landscape configuration, the selected herbaceous patches revealed a mean area of 0,57±0,81 ha, a mean perimeter of 444.43±427.87 m, and a mean percentage of perimeter shared with artificial areas of 40.62±39.15 %. The random polygon selection of patches showed a high variability in terms of configuration attributes, guaranteeing the necessary variability for the following analysis.

## 3.4. Trade-off analysis

In the surveyed herbaceous patches, the number of annual species and their relative abundance among plots, as well as the biomass production previously quantified, revealed the presence of a high variability ideal for the analysis (Table 4.4).

*Table 4.4: Average and standard deviation of variables used for correlation analysis.*

| **Biomass production** | | **Number of species by group** | | **Relative cover by group (%)** | |
|---|---|---|---|---|---|
| **Biomass** | 408,2± 139,01 | **S_ann** | 10±5,2 | **C_ann** | 25,3±24,69 |

The Spearman's rank correlation test showed that biomass production was significantly negatively correlated (i.e., trade-off occurred) with the number of annual species (S_ann; Table 4.5; Figure 4.10). Additionally, the same happened while considering the relative cover of annual species (C_ann; Table 4.5), confirming that trade-off occurred both considering the number of annual species and relative abundance.

*Table 4.5: Output of correlation analysis between biomass production and S_ann and C_ann.*

| **Correlation** | **Statistic** | **P-value** |
|---|---|---|
| **S_ann** | -0,733 | 3,134E-09*** |
| **C_ann** | -0.339 | 0.018** |

****** p-value <0.001; ** p-value<0.01; * p-value < 0.05***

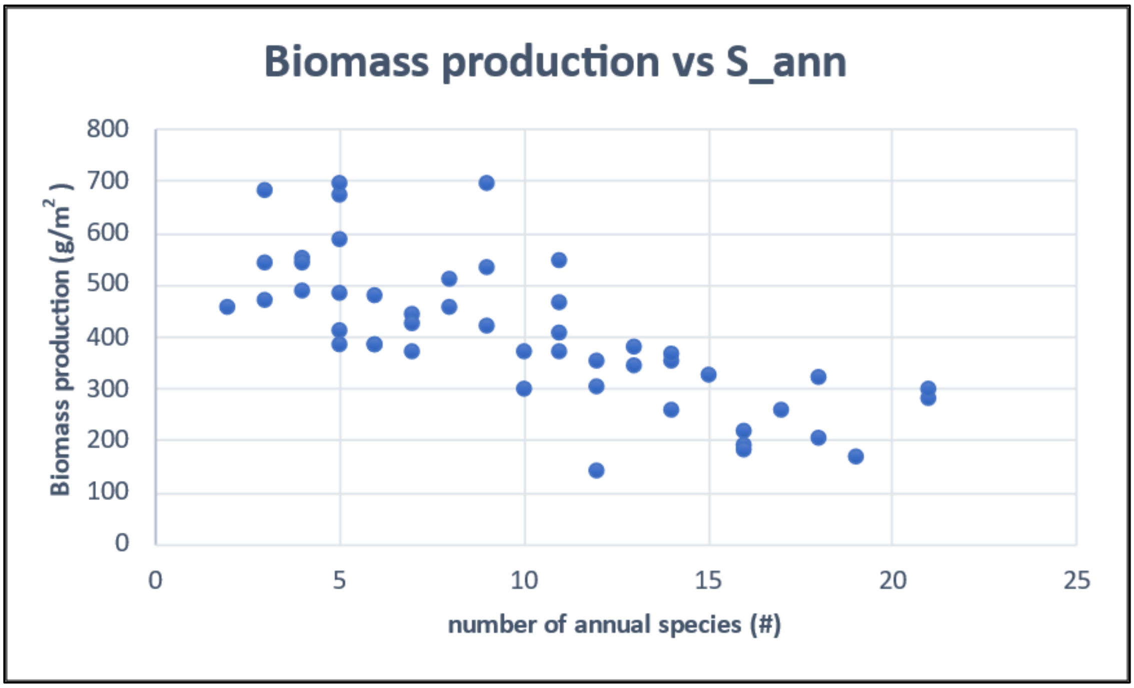

*Figure 4.10: Cartesian diagram of the relationship between biomass production and S_ann.*

We performed the PCA among the two variables involved in the trade-off and extracted the PC1 to summarise the trade-off information. In particular, PC1 revealed to be positively related to biomass production, meaning that the higher the biomass production, the higher the PC1 values (Figure 4.11).

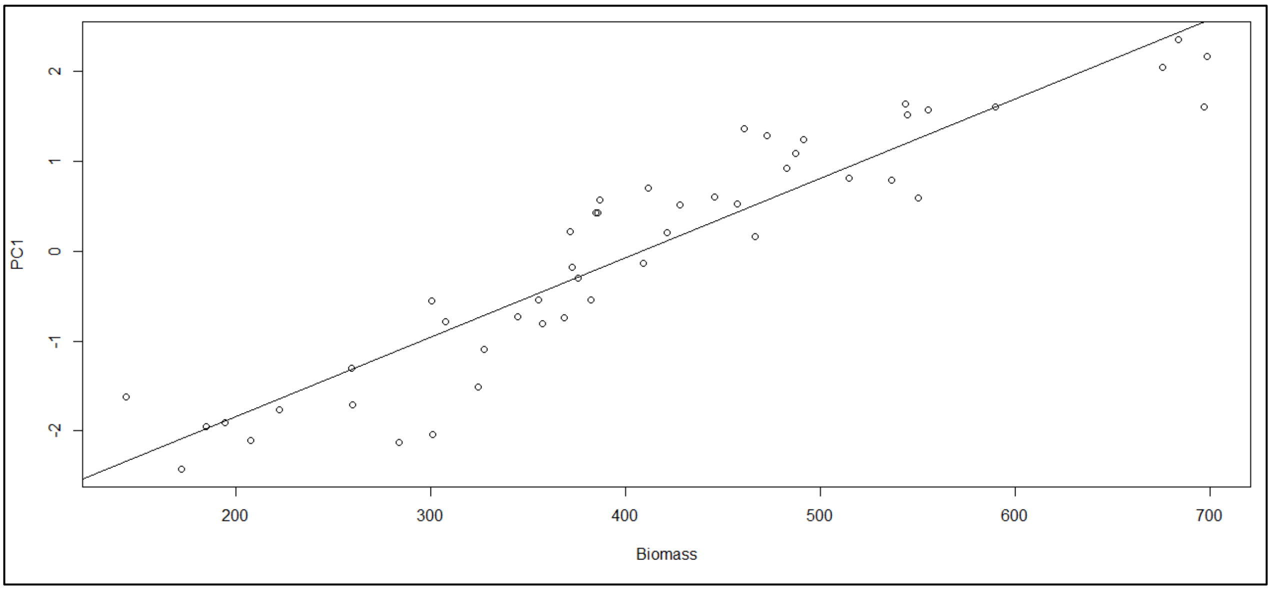

*Figure 4.11: Relationship between PC1 and Biomass production.*

Conversely, PC1 revealed to be negatively related with richness of annual species (S_ann). Thus, the higher the number of annual species (S_ann), the lower the PC1 values (Figure 4.12).

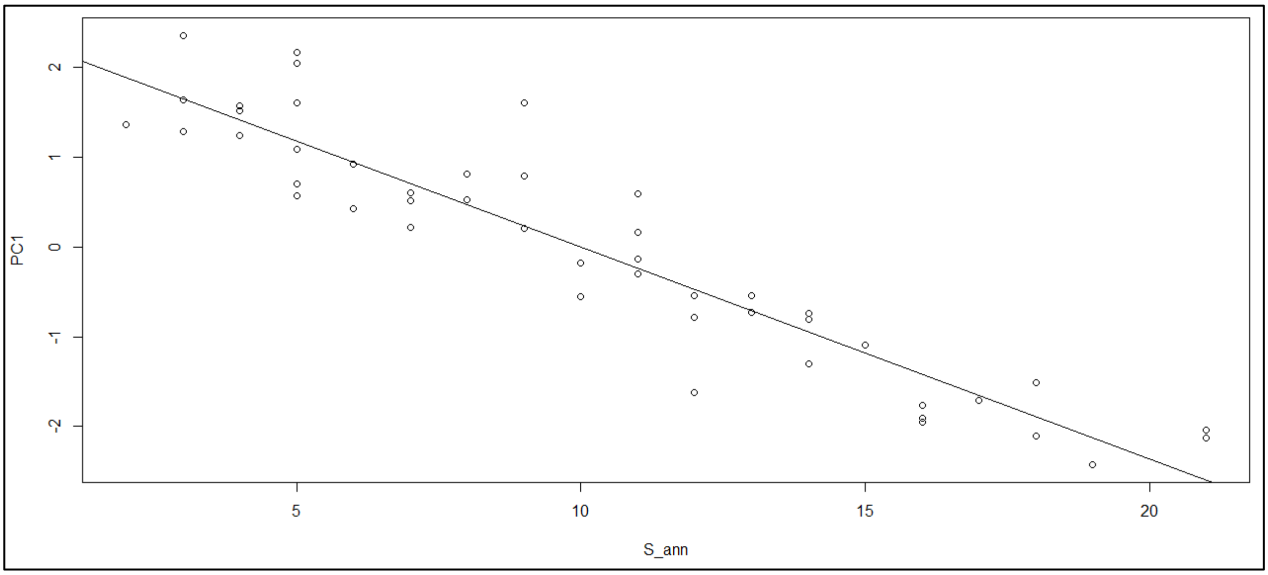

*Figure 4.12: Relationship between PC1 and richness of annual species.*

In turn, high values of PC1 corresponded to i) high biomass production and ii) low number of annual species.

The first check of collinearity among predictors showed that the predictors AREA and PERIMETER were collinear (i.e., VIF's value > 3; Table 4.6). As a result, the perimeter was removed because of the highest VIF's value. Being positively correlated to the area, perimeter positive correlation meaned that information obtained on the predictor patch area can be applied also to perimeter.

*Table 4.6: Collinearity of predictors selected for the best selection model (First run of VIF calculation).*

| **Predictors** | AREA | PERIMETER | ECON |
|---|---|---|---|
| **VIF's value** | 5.098616 | 7.096224 | 2.051781 |

The second check of collinearity revealed for all predictors a VIF values less than 3 (Table 4.7). In turn, AREA and ECON predictors were considered in the linear regression analyses.

*Table 4.7: Collinearity of predictors selected for the best selection model (Second run of VIF calculation).*

| **Predictors** | AREA | ECON |
|---|---|---|
| **VIF's value** | 1.353536 | 1.353536 |

A total of three models were performed accounting for all the combination of predictors (Table A18.1, Annex 10). The best linear model (i.e. the model with the lowest AIC) showed an AIC value of 131.4 and comprised both the predictors, namely AREA and ECON, as the best involved in the explanation of the PC1 variability. Specifically, this relationship revealed to be significant (*p-value* = 1.659e-08), as well as all the predictors were significantly related to PC1 (Table 4.8), while normality assumptions on residuals distributions emerged to be fulfilled (Figure A18.1, Annex 10).

*Table 4.8: Predictors revealed from the best selection model involved in the trade-off between biomass production and S_ann.*

| **Predictors** | **Estimate** | **Std. Error** | **t value** | **p-value** |
|---|---|---|---|---|
| AREA | 0.506169 | 0.189121 | 2.676 | 0.0103 ***** |
| ECON | -0.017873 | 0.003917 | -4.563 | 3.88e-05 ******* |

****** p-value <0.001; ** p-value<0.01; * p-value < 0.05***

As highlighted by the estimate parameters (Table 4.8), the best model revealed that predictor AREA were significantly positively related to PC1, while ECON was significantly negatively related to PC1.

Specifically, we observed that high values of PC1 (i.e., high values of biomass production and low values of number of annual species) corresponded to high values of AREA (Figure 4.13). As for the ECON predictor, which was negatively related to PC1, we found that high values of PC1 (i.e., high values of biomass production and low values of number of annual species) corresponded to low values of ECON, namely to lower percentage of perimeter shared with artificial areas (Figure 4.13).

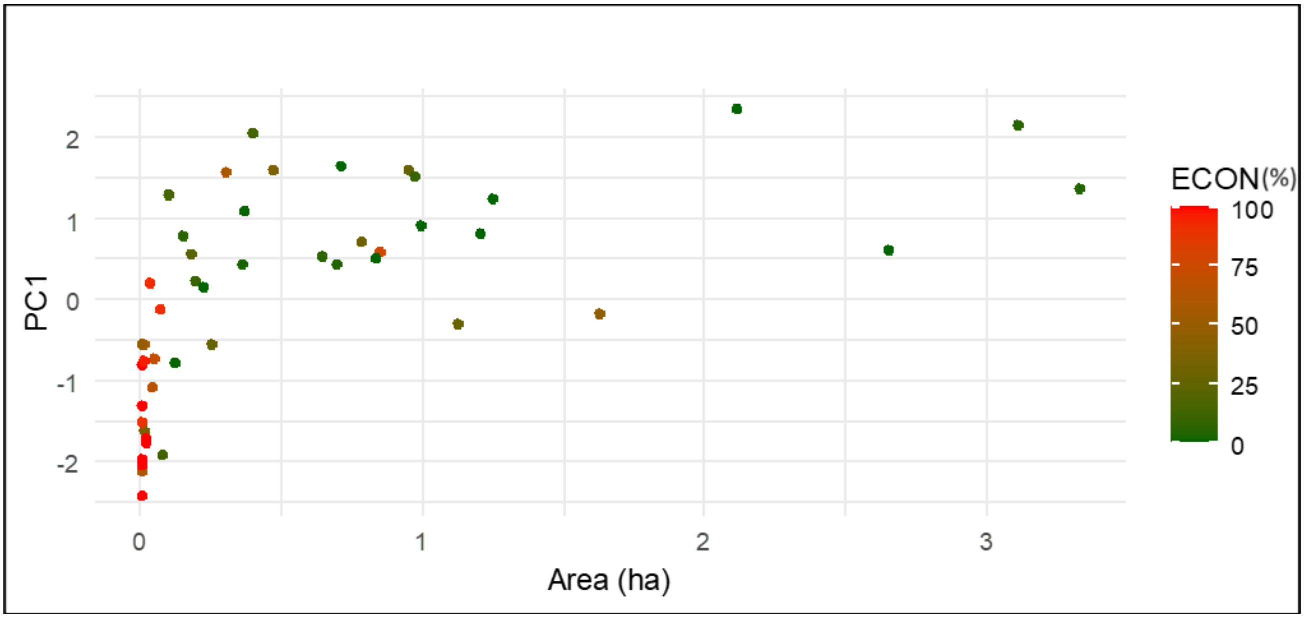

*Figure 4.13: Relationship between AREA+ECON and PC1.*

# CHAPTER 4. DISCUSSION

Our study showed the utility of considering edaphic and landscape configuration variables in describing the relationship between ESs (particularly of biomass production and biodiversity) and the role of herbaceous patches in their supply.

The grouping factors of biodiversity resulted pivotal in selecting those attributes able to account for plant traits and strategies, and environmental condition, thus enhancing the interpretation of the results. The CCA showed that the life cycle of species (i.e., the distinction of annual and perennial species) assumed the most important role compared to growth form and spatial distribution (i.e., native and alien species). Particularly, the analysis revealed that the life cycle of species is correlated to the environmental soil conditions, confirming both the adaptative strategies of species to the environment and the selective pressure of the environment on the plant communities (Grime, 2006).

These aspects agreed with Poppenwimer et al. (2023), who showed that the optimal life cycle of a species is determined by the ratio of the survival of seedlings (or seeds) and the survival of adult individuals. The reproduction of perennial plants requires multiple growing seasons (i.e., k-strategy), unlike annual plants, which require only one growing season (i.e., r-strategy; MacArthur & Wilson, 2001; Poppenwimer et al., 2023). The authors asserted that any external conditions (i.e., stress or disturbance) that decrease the ability of plants to survive between growing seasons will consequently reduce the reproductive fitness of perennial species. However, annual species could survive harsh external conditions as seeds rather than as adults (due to their r-strategy), and consequently their reproductive fitness may not be impacted. Therefore, any environmental condition that changes the adult survival rate in favour of seeds (e.g., decreasing of soil moisture) would lead to an increase of the annual plants in the herbaceous communities (and of biodiversity within them consequently).

Indeed, the CCA showed that the most relevant edaphic features related to plant life cycle was soil moisture. Specifically, when soil moisture decreased, the number of annual species increased, and biomass production decreased. These results agreed with Moeslund et al. (2013) who not only reconfirmed that the pool of species in a region can change with soil moisture (Burke et al., 1998; Ejrnæs & Bruun, 2000; Poppenwimer et al., 2023), but also stated that soil moisture was the most important factor because it affected a whole range of other environmental variables crucial for plant growth (such as nutrients availability and soil reaction). Therefore, in agreement with Poppenwimer et al. (2023), we observed that annual species increase at lower soil moisture; whereas perennial species overcome when soil moisture increased (reflecting more favourable conditions for plant survival between growing seasons and the occurrence of competition with annual species).

Considering the number (and the relative abundance) of annual species, the correlation analysis showed a negative and significant relationship (i.e., a trade-off) with biomass production. As mentioned, biomass production decreased as annual species increased, attesting a different resource allocation based on life cycle (Poldini et al., 2011). Moreover, our results agreed with the negative correlation identified by Grace et al. (2016), Justić & Jelaska (2022) and Fessel et al. (2016). According to these studies, the trade-off is described by the niche partitioning that occurs because of intermediate disturbance (of environmental conditions) in which most productive (perennial) species are limited in their growth, and less productive (annual) species can easily exploit remnant (soil) resources.

This motivation also agreed with the processes described for the top and decreasing part of the hump-shaped curve of the relationship between biodiversity and biomass production described by Fraser et al. (2015). Indeed, these two regions of the function corresponded to the position of the curve in which our data fell according to the values of species richness and biomass production found. Specifically, while perennial competitive species prevail (and enhance the biomass production) as environmental conditions become favourable and stable, annual species persist in communities when stress and disturbance of moderate intensity occur, leading to an increase in biodiversity and a decrease in biomass production (according to the intermediate disturbance hypothesis).

Poldini et al. (2011) stated that the biomass production-biodiversity relationship could be linked to the principle of energetic parsimony interconnected with Grime’s strategies (Grime, 1977). This principle states that the lack of nutritional and water resources leads to the predominance of species that invest more in flower production (mainly annual species) by implementing an entomogamic strategy, a less energy-consuming strategy for plants (coupled with lower biomass productions) that becomes important for the supply of other ESs, such as pollination or aesthetic beauty.

Thus, our results confirmed the role of environmental conditions in influencing the herbaceous communities’ structure and processes.

Our analysis revealed that the trade-off (i.e. both the biomass production and the number of annual species, namely the relation of two ESs) was also linked to the spatial characteristics of the patch in which these communities were located. Particularly, we found that all the considered configuration attributes were involved in the trade-off highlighting the influence of spatial configuration on both biotic and abiotic features of ecosystems and their processes (i.e., the supply of ESs).

Concerning the relationship between the patch area and the trade-off, our results showed that the larger the patches the lower the number of annual species and the higher the biomass production. Moreover, the same pattern is deemed for the perimeter attribute because of the positive relationship to the area. We suggest that this relationship relies on the environmental stability of patches, which depends on patch size and can be expressed as the variability of hosted plant communities over time. Specifically, highly variable community reflects patch instability, while lower variability refers to high stable patch (Dunstan & Johnson, 2006). As described by She et al. (2023), plant community stability is influenced by different factors, such as interspecific competition, environmental pressure and human disturbance. Furthermore, Dunstan & Johnson (2006) stated that larger patches are generally more stable demonstrating more suitable environmental conditions (i.e. less disturbance) for plant growth. She et al. (2023) asserted that there is a 'stability succession' in which plant species change in relation to patch stability. Consequently, there will be annual plants in patches with low stability, and perennials in patches with high stability. This succession has been explained by She et al. (2023) through the correlation between the stability of a patch and the vegetation cover, height and biomass production. An increase in vegetation cover leads to a decrease in thermal radiation on the soil surface, which consequently reduces the evapotranspiration of surface water and increases the survival rate of seedlings. Thus, changes in the species composition of communities occur, improving plant community stability (She et al., 2023). Therefore, larger and more stable patches will contain a predominance of perennial plant species that produce more biomass; while smaller patches will be less stable because of the higher disturbance and will contain annual plant species that are better adapted to a less stable environment. In turns, less biomass will be produced as annual species will rather allocate resources on reproduction (i.e., seeds) to overcome unfavourable conditions (e.g., dry periods).

In this context, edge effect affects the stability and the environmental condition of a patch, especially when considering small ones. The edge effect relies on the ecological response of plant communities due to changes in environmental conditions on the edge as influenced by the matrix (Ries et al., 2004). Thus, small patches proportionally experience higher changes because of the higher ratio between edge and area, and the higher the matrix dissimilarity (e.g., natural patches vs artificial matrix), the higher the change (Ewers et al., 2007).

Indeed, a negative relationship was also found between the trade-off and the contrast at patches' edge with the surroundings. Particularly, we found that the number of annual species increased, and biomass production decreased, at increasing contrast, namely at increasing percentage of perimeter of the herbaceous patches shared with artificial areas. Conversely, when an herbaceous patch was bordered by other natural and semi-natural patches it showed fewer annual species, and higher biomass production. Matthews et al. (2014) showed that biodiversity and biomass production have been threatened by human-induced environmental changes, especially where humans have altered the landscape due to habitat loss and fragmentation. Consequently, the contrast between habitats of herbaceous communities and the surrounding artificial matrix can play a crucial role in the provision of these ESs.

Janišová et al. (2014) stated that, generally, the increase of percentage of natural and semi-natural habitats in the surrounding of patches increases their diversity, while diversity decreases with a greater proportion of non-natural habitats in the surroundings. The authors argue that the number of species in natural and semi-natural patches is lower when completely surrounded by highly contrasting patches (i.e., artificial areas). In this situation, the probability of extinction of local populations within grassland patches will be increased due to fragmentation and because of the selective pressure induced by adverse environmental conditions posed by artificial (and humans frequented) areas. However, Janišová et al. (2014) also found that there are some species predominant in the surrounding artificial habitats, such as ruderal and stress tolerant species, and may spread into the grassland patches increasing their biodiversity. Specifically, highly contrasted patches may experience the so-called 'spatial mass effect' (Shmida & Ellner, 1984). Thus, our results agreed with Janišová et al. (2014) as an increase in the contrast between the investigated patches and the artificial areas produced an increase in ruderal and stress tolerant species (i.e., annual species) able to compete with perennials for the resources.

Thus, calling back the edge effect related to the size of the herbaceous patches, small patches experiencing higher contrast with artificial areas may undergo significant changes in edaphic conditions, and in the plant community structure consequently. Indeed, small patches mainly surrounded by artificial matrix experience adverse environmental conditions, such as limited soil moisture during summer season because of a temperature further increase due to warmer surface of the surroundings (Cercato, 2023). These adverse conditions limit the growth of perennial species, lead to greater spread of annual species adapted to high disturbed environments, increasing the biodiversity and simultaneously negatively affecting the biomass production. Then, as previously described, a trade-off occurs between ESs (She et al., 2023).

In conclusion, our study proved that spatial configuration attributes are involved in the supply of ESs because related to the environmental conditions and plant communities' structure and processes within patches. Moreover, our study proved that the (indirect) effects of patch configuration on the supply is not the same among ESs and trade-off occur. Thus, a balance needs to be reached to maximise the total amount of ESs supplied by herbaceous patches. Accounting for the effect of configuration attributes on ESs supply, crucial insights on the strategic planning of Green Infrastructure can be gained. Our results showed that extreme values in patch size and matrix contrast can promote one ecosystem service to the detriment of other ones. Therefore, as a rule of thumb, intermediate values need to be preferred in the planning of herbaceous patches within urban and rural areas to constitute an effective GI.

As a result, herbaceous patches of intermediate size and partly adjacent to each other should be preferred in planning human dominated areas; this type of spatial configuration can be traced back to the typical one of ecological corridors. Thus, other ecosystem processes can be promoted, as well as the supply of multiple ESs. Under this point of view, further investigations should be considered to support our findings.

## REFERENCES

Adler, P. B., Seabloom, E. W., Borer, E. T., Hillebrand, H., Hautier, Y., Hector, A., ... & Yang, L. H. (2011). *Productivity is a poor predictor of plant species richness*. Science, 333(6050), 1750-1753.

Akaike, H. (1974). *A new look at the statistical model identification*. IEEE Transactions on Automatic Control, 19(6), 716-723.

Aronson, M. F., Nilon, C. H., Lepczyk, C. A., Parker, T. S., Warren, P. S., Cilliers, S. S., ... & Zipperer, W. (2016). *Hierarchical filters determine community assembly of urban species pools*. Ecology, 97(11), 2952-2963.

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A. N. M. G., Ardenghi, N. M. G., ... & Conti, F. (2018). *An updated checklist of the vascular flora native to Italy*. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 152(2), 179-303.

Bateman, I. J., & Mace, G. M. (2020). *The natural capital framework for sustainably efficient and equitable decision making*. Nature Sustainability, 3(10), 776-783.

Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). *Understanding relationships among multiple ecosystem services*. Ecology Letters, 12(12), 1394-1404.

Bernhardt-Römermann, M., Römermann, C., Sperlich, S., & Schmidt, W. (2011). *Explaining grassland biomass–the contribution of climate, species and functional diversity depends on fertilization and mowing frequency*. Journal of Applied Ecology, 48(5), 1088-1097.

Bray, J. R., & Curtis, J. T. (1957). *An ordination of the upland forest communities of southern Wisconsin*. Ecological Monographs, 27(4), 326-349.

Bretzel, F., Vannucchi, F., Romano, D., Malorgio, F., Benvenuti, S., & Pezzarossa, B. (2016). *Wildflowers: From conserving biodiversity to urban greening—A review*. Urban forestry & Urban Greening, 20, 428-436.

Burke, I. C., Lauenroth, W. K., Vinton, M. A., Hook, P. B., Kelly, R. H., Epstein, H. E., ... & Gill, R. A. (1998). *Plant-soil Interactions in Temperate Grasslands*. Biogeochemistry, 42, 121-143.

Cameron, R. W., & Blanuša, T. (2016). *Green infrastructure and ecosystem services–is the devil in the detail?*. Annals of Botany, 118(3), 377-391.

Cardinale, B. J., Gross, K., Fritschie, K., Flombaum, P., Fox, J. W., Rixen, C., ... & Wilsey, B. J. (2013). *Biodiversity simultaneously enhances the production and stability of community biomass, but the effects are independent*. Ecology, 94(8), 1697-1707.

Cercato, A. (2023). *Cross scale evaluation of cooling effect ecosystem service supplied by vegetation: understanding the relationship with landscape and patch attributes for Green Infrastructure strategic planning*. Ca' Foscari University of Venice, Venice, Italy.

Chang, H. S., Lin, Z. H., & Hsu, Y. Y. (2021). *Planning for green infrastructure and mapping synergies and trade-offs: A case study in the Yanshuei River Basin, Taiwan*. Urban Forestry & Urban Greening, 65, 127325.

Collins, S. L., Knapp, A. K., Briggs, J. M., Blair, J. M., & Steinauer, E. M. (1998). *Modulation of diversity by grazing and mowing in native tallgrass prairie*. Science, 280(5364), 745-747.

Comune di Cartigliano (2014). *Piano di Assetto del Territorio – Rapporto Ambientale*. Vicenza, Italy. https://www.comune.cartigliano.vi.it/home/amministrazione/documenti/Documento-9.html (accessed on 23th November 2023).

Cord, A. F., Bartkowski, B., Beckmann, M., Dittrich, A., Hermans-Neumann, K., Kaim, A., ... & Volk, M. (2017). *Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead*. Ecosystem Services, 28, 264-272.

De Cáceres, M., & Legendre, P. (2009). *Associations between species and groups of sites: indices and statistical inference*. Ecology, 90(12), 3566-3574.

De Cáceres, M., Legendre, P., & Moretti, M. (2010). *Improving indicator species analysis by combining groups of sites*. Oikos, 119(10), 1674-1684.

Del Vecchio, S., Fantinato, E., Janssen, J. A. M., Bioret, F., Acosta, A., Prisco, I., ... & Buffa, G. (2018). *Biogeographic variability of coastal perennial grasslands at the European scale*. Applied Vegetation Science, 21(2), 312-321.

Deng, X., Li, Z., & Gibson, J. (2016). *A review on trade-off analysis of ecosystem services for sustainable land-use management*. Journal of Geographical Sciences, 26, 953-968.

Dengler, J., Biurrun, I., & Dembicz, I. (2021). *Standardised EDGG methodology for sampling grassland diversity: second amendment*. Palaearctic Grasslands, (49), 22-26.

Dengler, J., Matthews, T. J., Steinbauer, M. J., Wolfrum, S., Boch, S., Chiarucci, A., ... & Biurrun, I. (2020). *Species–area relationships in continuous vegetation: Evidence from Palaearctic grasslands*. Journal of Biogeography, 47(1), 72-86.

Dengler, J., Wagner, V., Dembicz, I., García-Mijangos, I., Naqinezhad, A., Boch, S., ... & Talebi, A. (2018). *GrassPlot–a database of multi-scale plant diversity in Palaearctic grasslands*. Phytocoenologia, 48(3), 331-347.

Di Biase, L., Tsafack, N., Pace, L., & Fattorini, S. (2023). *Ellenberg Indicator Values Disclose Complex Environmental Filtering Processes in Plant Communities along an Elevational Gradient*. Biology, 12(2), 161.

Dufrêne, M., & Legendre, P. (1997). *Species assemblages and indicator species: the need for a flexible asymmetrical approach*. Ecological Monographs, 67(3), 345-366.

Dunstan, P. K., & Johnson, C. R. (2006). *Linking richness, community variability, and invasion resistance with patch size*. Ecology, 87(11), 2842-2850.

Ejrnæs, R., & Bruun, H. H. (2000). *Gradient analysis of dry grassland vegetation in Denmark*. Journal of Vegetation Science, 11(4), 573-584.

Ewers, R. M., Thorpe, S., & Didham, R. K. (2007). *Synergistic interactions between edge and area effects in a heavily fragmented landscape*. Ecology, 88(1), 96-106.

Fantinato, E., Del Vecchio, S., & Buffa, G. (2019). *The co-occurrence of different grassland communities increases the stability of pollination networks*. Flora, 255, 11-17.

Fantinato, E., Fiorentin, R., Della Bella, A., & Buffa, G. (2023). *Growth-survival trade-offs and the restoration of non-forested open ecosystems*. Global Ecology and Conservation, 41, e02383.

Ferrari, B., Quatrini, V., Barbati, A., Corona, P., Masini, E., & Russo, D. (2019). *Conservation and enhancement of the green infrastructure as a nature-based solution for Rome's sustainable development*. Urban Ecosystems, 22, 865-878.

Fessel, C., Meier, I. C., & Leuschner, C. (2016). *Relationship between species diversity, biomass and light transmittance in temperate semi-natural grasslands: is productivity enhanced by complementary light capture?*. Journal of Vegetation Science, 27(1), 144-155.

Fisher, B., Turner, R. K., & Morling, P. (2009). *Defining and classifying ecosystem services for decision making*. Ecological Economics, 68(3), 643-653.

Fraser, L. H., Pither, J., Jentsch, A., Sternberg, M., Zobel, M., Askarizadeh, D., ... & Zupo, T. (2015). *Worldwide evidence of a unimodal relationship between productivity and plant species richness*. Science, 349(6245), 302-305.

Galasso, G., Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., ... & Bartolucci, F. (2018). *An updated checklist of the vascular flora alien to Italy*. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 152(3), 556-592.

Gaujour, E., Amiaud, B., Mignolet, C., & Plantureux, S. (2012). *Factors and processes affecting plant biodiversity in permanent grasslands. A review*. Agronomy for Sustainable Development, 32(1), 133-160.

Gillman, L. N., Wright, S. D., Cusens, J., McBride, P. D., Malhi, Y., & Whittaker, R. J. (2015). *Latitude, productivity and species richness*. Global Ecology and Biogeography, 24(1), 107-117.

Grace, J. B., Anderson, T. M., Seabloom, E. W., Borer, E. T., Adler, P. B., Harpole, W. S., ... & Smith, M. D. (2016). *Integrative modelling reveals mechanisms linking productivity and plant species richness*. Nature, 529(7586), 390-393.

Grime, J. P. (1973). *Competitive exclusion in herbaceous vegetation*. Nature, 242(5396), 344-347.

Grime, J. P. (1977). *Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory*. The American Naturalist, 111(982), 1169-1194.

Grime, J. P. (2006). *Trait convergence and trait divergence in herbaceous plant communities: mechanisms and consequences*. Journal of Vegetation Science, 17(2), 255-260.

Hector, A., Schmid, B., Beierkuhnlein, C., Caldeira, M. C., Diemer, M., Dimitrakopoulos, P. G., ... & Lawton, J. H. (1999). *Plant diversity and productivity experiments in European grasslands*. Science, 286(5442), 1123-1127.

Huston, M. A. (1979). *A General Hypothesis OF Species Diversity*. The American Naturalist, 113, 81-101.

Isbell, F., Reich, P. B., Tilman, D., Hobbie, S. E., Polasky, S., & Binder, S. (2013). *Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity*. Proceedings of the National Academy of Sciences, 110(29), 11911-11916.

ISTAT. (2023). *Bilancio demografico anno 2023 del Comune di Cartigliano*. https://demo.istat.it/app/?i=D7B (accessed on 11th January 2024).

Jackson, J. (2005). *Is there a relationship between herbaceous species richness and buffel grass (Cenchrus ciliaris)?*. Austral Ecology, 30(5), 505-517.

Jakob, A., Breg Valjavec, M., & Čarni, A. (2022). *Turnover of plant species on an ecological gradient in karst dolines is reflected in plant traits: chorotypes, life forms, plant architecture and strategies*. Diversity, 14(8), 597.

Janišová, M., Michalcová, D., Bacaro, G., & Ghisla, A. (2014). *Landscape effects on diversity of semi-natural grasslands*. Agriculture, Ecosystems & Environment, 182, 47-58.

John, H., Neubert, M., Marrs, C., Alberico, S., Bovo, G., Ciadamidaro, S., ... & Grasso, S. (2019). *Green infrastructure handbook–conceptual & theoretical background, terms and definitions*. Interreg Central Europe Project MaGICLandscapes–Managing Green Infrastructure in Central European Landscapes.

Justić, M., & Jelaska, S. D. (2022). *The relationship between biodiversity and the biomass of grasslands in the Zagreb area (NW Croatia)*. Acta Botanica Croatica, 81(2), 221-232.

Kahmen, A., Perner, J., Audorff, V., Weisser, W., & Buchmann, N. (2005). *Effects of plant diversity, community composition and environmental parameters on productivity in montane European grasslands*. Oecologia, 142, 606-615.

Karimi, J. D., Corstanje, R., & Harris, J. A. (2021). *Understanding the importance of landscape configuration on ecosystem service bundles at a high resolution in urban landscapes in the UK*. Landscape Ecology, 36, 2007-2024.

Kattge, J., Bönisch, G., Díaz, S., Lavorel, S., Prentice, I. C., Leadley, P., ... & Cuntz, M. (2020). *TRY plant trait database–enhanced coverage and open access*. Global Change Biology, 26(1), 119-188. https://try-db.org/TryWeb/Home.php (accessed on 15th November 2023).

Kosolapov, V. M., Kostenko, S. I., Tyurin, Y. S., Shamsutdinova, E. Z., & Piskovskii, Y. M. (2021). *Perennial forage grasses-the basis for greening agricultural production*. IOP Conference Series: Earth and Environmental Science, 663(1), 012022.

Li, W., Gan, X., Jiang, Y., Cao, F., Lü, X. T., Ceulemans, T., & Zhao, C. (2022). *Nitrogen effects on grassland biomass production and biodiversity are stronger than those of phosphorus*. Environmental Pollution, 309, 119720.

MacArthur, R. H., & Wilson, E. O. (2001). *The theory of island biogeography*. Princeton University Press, Princeton, United States.

Mahaut, L., Choler, P., Denelle, P., Garnier, E., Thuiller, W., Kattge, J., ... & Violle, C. (2023). *Trade-offs and synergies between ecosystem productivity and stability in temperate grasslands*. Global Ecology and Biogeography, 32(4), 561-572.

Matthews, T. J., Cottee-Jones, H. E., & Whittaker, R. J. (2014). *Habitat fragmentation and the species–area relationship: a focus on total species richness obscures the impact of habitat loss on habitat specialists*. Diversity and Distributions, 20(10), 1136-1146.

McGarigal, K. (2015). *FRAGSTATS help*. University of Massachusetts, Massachusetts, United States.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington D.C., United States.

Mittelbach, G. G., Steiner, C. F., Scheiner, S. M., Gross, K. L., Reynolds, H. L., Waide, R. B., ... & Gough, L. (2001). *What is the observed relationship between species richness and productivity?*. Ecology, 82(9), 2381-2396.

Moeslund, J. E., Arge, L., Bøcher, P. K., Dalgaard, T., Ejrnæs, R., Odgaard, M. V., & Svenning, J. C. (2013). *Topographically controlled soil moisture drives plant diversity patterns within grasslands*. Biodiversity and Conservation, 22, 2151-2166.

Molina, J. A., Martín-Sanz, J. P., Casermeiro, M. Á., & Quintana, J. R. (2023). *Spontaneous urban vegetation as an indicator of soil functionality and ecosystem services*. Applied Vegetation Science, 26(2), e12827.

O'brien, R. M. (2007). *A caution regarding rules of thumb for variance inflation factors.* Quality & Quantity, 41, 673-690.

Öckinger, E., Lindborg, R., Sjödin, N. E., & Bommarco, R. (2012). *Landscape matrix modifies richness of plants and insects in grassland fragments*. Ecography, 35(3), 259-267.

Pan, Q., Symstad, A. J., Bai, Y., Huang, J., Wu, J., Naeem, S., ... & Han, X. (2022). *Biodiversity–productivity relationships in a natural grassland community vary under diversity loss scenarios*. Journal of Ecology, 110(1), 210-220.

Pierce, S., Negreiros, D., Cerabolini, B. E., Kattge, J., Díaz, S., Kleyer, M., ... & Tampucci, D. (2017). *A global method for calculating plant CSR ecological strategies applied across biomes world-wide*. Functional Ecology, 31(2), 444-457.

Pignatti, S. (1982). *Flora d'Italia*. Edagricole, Bologna, Italy.

Pignatti, S. (2005). *Valori di bioindicazione delle piante vascolari della flora d'Italia*. Department of Botany and Ecology of Camerino University, Macerata, Italy.

Pignatti, S., Guarino, R., & La Rosa, M. (2017). *Flora d'Italia*. Edagricole, Bologna, Italy.

Poldini, L., Sburlino, G., Buffa, G., & Vidali, M. (2011). *Correlations among biodiversity, biomass and other plant community parameters using the phytosociological approach: A case study from the south-eastern Alps*. Plant Biosystems, 145(1), 131-140.

Poppenwimer, T., Mayrose, I., & DeMalach, N. (2023*). Revising the global biogeography of annual and perennial plants*. Nature, 624(7990), 109-114.

Prislei, C. (2023). *A tale of two greens: Sense of Place drivers and pro-environmental behaviours*. Università Ca' Foscari di Venezia. Ca' Foscari University of Venice, Venice, Italy.

Raunkiaer, C. (1934). *The life forms of plants and statistical plant geography*. Oxford University Press, London, United Kingdom.

Ries, L., Fletcher, R. J., Battin, J., & Sisk, T. D. (2004). *Ecological responses to habitat edges: Mechanisms, models, and variability explained*. Annual Reviews of Ecology, Evolution and Systematics, 35, 491–522.

Rodríguez, J. P., Beard Jr, T. D., Bennett, E. M., Cumming, G. S., Cork, S. J., Agard, J., ... & Peterson, G. D. (2006). *Trade-offs across space, time, and ecosystem services. Ecology and Society*, 11(1).

Sanaei, A., & Ali, A. (2019). *What is the role of perennial plants in semi-steppe rangelands? Direct and indirect effects of perennial on annual plant species*. Ecological Indicators, 98, 389-396.

Sanesi, G., Colangelo, G., Lafortezza, R., Calvo, E., & Davies, C. (2017). *Urban green infrastructure and urban forests: a case study of the Metropolitan Area of Milan*. Landscape Research, 42(2), 164-175.

Schaffers, A. P. (2002). *Soil, biomass, and management of semi-natural vegetation–Part II. Factors controlling species diversity*. Plant Ecology, 158, 247-268.

Schmidt, A. F., & Finan, C. (2018). *Linear regression and the normality assumption*. Journal of Clinical Epidemiology, 98, 146-151.

Schumacher, J., & Roscher, C. (2009). *Differential effects of functional traits on aboveground biomass in semi-natural grasslands*. Oikos, 118(11), 1659-1668.

She, Y., Li, X., Li, C., Yang, P., Song, Z., & Zhang, J. (2023). *Relationship between Species Diversity and Community Stability in Degraded Alpine Meadows during Bare Patch Succession*. Plants, 12(20), 3582.

Shmida, A., & Ellner, S. (1984). *Coexistence of plant species with similar niches*. Vegetatio, 58, 29-55.

Silan, G., Del Vecchio, S., Fantinato, E., & Buffa, G. (2017). *Habitat quality assessment through a multifaceted approach: the case of the habitat 2130* in Italy*. Plant Sociology, 54(2), 13-22.

Suding, K. N., Collins, S. L., Gough, L., Clark, C., Cleland, E. E., Gross, K. L., ... & Pennings, S. (2005). *Functional-and abundance-based mechanisms explain diversity loss due to N fertilization*. Proceedings of the National Academy of Sciences, 102(12), 4387-4392.

Tasinazzo, S. (2014). *La vegetazione dei Colli Berici*. Provincia di Vicenza, Vicenza, Italy.

Ter Braak, C. J. (1986). *Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis*. Ecology, 67(5), 1167-1179.

Ter Braak, C. J., & Verdonschot, P. F. (1995). *Canonical correspondence analysis and related multivariate methods in aquatic ecology*. Aquatic Sciences, 57, 255-289.

Uuemaa, E., Mander, Ü., & Marja, R. (2013). *Trends in the use of landscape spatial metrics as landscape indicators: A review*. Ecological Indicators, 28, 100-106.

Wagner, M., Kahmen, A., Schlumprecht, H., Audorff, V., Perner, J., Buchmann, N., & Weisser, W. W. (2007). *Prediction of herbage yield in grassland: How well do Ellenberg N-values perform?*. Applied Vegetation Science, 10(1), 15-24.

Wang, J., & Banzhaf, E. (2018). *Towards a better understanding of Green Infrastructure: A critical review*. Ecological Indicators, 85, 758-772.

Ward Jr, J. H. (1963). *Hierarchical grouping to optimize an objective function*. Journal of the American Statistical Association, 236-244.

Whittaker, R. J. (2010). *Meta-analyses and mega-mistakes: calling time on meta-analysis of the species richness–productivity relationship*. Ecology, 91(9), 2522-2533.

## WEB REFERENCES

https://eunis.eea.europa.eu/habitats.jsp (accessed on 19th January 2024).

https://gaia.arpa.veneto.it/maps/294 (accessed on 11th January 2024).

https://gaia.arpa.veneto.it/maps/778/view (accessed on 11th January 2024).

https://www.arpa.veneto.it/dati-ambientali/open-data/file-e-allegati/trend_variabili_meteorologiche.zip (accessed on 11th January 2024).

https://www.arpa.veneto.it/temi-ambientali/suolo/conoscenza-dei-suoli/carte-1-50.000/leg_50k.pdf/@@display-file/file (accessed on 11th January 2024).

https://www.provincia.vicenza.it/ente/la-struttura-della-provincia/servizi/valutazione-impatto-ambientale/valutazione-dincidenza-ambientale/grave-e-zone-umide-della-brenta (accessed on 12th January 2024).

# ANNEXES

## Annex 1

Within this SCI/SPA there are different types of habitats that must be conserved and protected *sensu* Habitats Directive 92/43/EEC:

- **Natural eutrophic lakes with Magnopotamion (Vollmar 1947) Den Hartog & Segal 1964 (art. 22) or Hydrocharition Rübel 1933 nom. nud. (art. 2b, 8) vegetation (Habitat Code Natura 2000: 3150)**: A very important and relatively rare habitat in the Alpine biogeographical region. It includes lakes and ponds with turbid waters particularly rich in alkaline solutes (pH generally higher than 7), with freely floating Hydrocharition communities on the surface or, with Magnopotamion associations in deep and open water (Comune di Cartigliano, 2014).
- **Alpine rivers with herbaceous riparian vegetation (Habitat Code Natura 2000: 3220):** This habitat includes pioneer communities of herbaceous or suffruticose plants that colonise the gravelly and sandy areas of Alpine streams and rivers. The communities in this habitat are exposed to considerable variations in ecological conditions, with alternating periods when they are submerged (e.g. during flood periods) and others when they must tolerate relative drought (late summer). In the upper section of Alpine streams, the guiding species is *Epilobium fleischeri* Hochst., which is exclusive to siliceous substrates, while in the lower section, where the speed of the current decreases, *Calamagrostis pseudophragmites* (Haller f.) Koeler abounds (Comune di Cartigliano, 2014).
- **Alpine rivers with *Salix elaeagnos* Scop. woody riparian vegetation (Habitat Code Natura 2000: 3240)**: Woodlands or shrublands that develop on the gravelly-sandy riverbeds of the main streams and rivers, from the mountain belt (1600-1700 m at most) to the valley in the lowlands. The leading species among the willows in this habitat is *Salix eleagnos* Scop. In contrast, when considering other shrubs, the indicator species for this habitat is *Hippophaë rhamnoides* L. The most important ecological character of these vegetation associations in the riverbed is the possibility of tolerating both periods of overflooding and drought phenomena (Comune di Cartigliano, 2014).
- **Rivers of the lowlands and mountain areas with vegetation of *Ranunculenion fluitantis (Neuhäusl 1959) Hartog & Segal 1964* and *Callitricho-Batrachion* Hartog & Segal 1964 p.p. (Habitat Code Natura 2000: 3260)**: This habitat includes watercourses, from the plains to the

mountain area, characterised by submerged or floating vegetation of *Ranunculenion fluitantis* and Callitricho-Batrachion (with low water levels in the summer period) or with aquatic mosses (Comune di Cartigliano, 2014).

- **Dry semi-natural grassland and shrub-covered facies on calcareous substrate (51.2A.2 ALL. FESTUCO AMETHYSTINAE-BROMION ERECTI BARBERO & LOISEL 1972) (orchid flowering) (Habitat Code Natura 2000: 6210)**: Habitat that includes dry or mesophile herbaceous or partly shrub-covered formations, extending from the hillsides to the mountain. The maintenance of these habitats is ensured by regular mowing (or non-excessive grazing) and the absence of fertilisation. Without this type of management, the habitat would easily be invaded by shrub and woody species. The habitat only becomes a priority if it represents an important site for orchids. To be a priority habitat it must fulfil at least one of the following three criteria (Comune di Cartigliano, 2014):
  - the site includes a rich sequence of orchid species.
  - the site includes an important population of an orchid that is rare in the national territory.
  - the site contains one or more orchid species considered rare, very rare or exceptional in the national territory.
- **Lean hay grasslands at low altitudes (*Alopecurus pratensis* L., *Sanguisorba officinalis* L.) (Habitat Code Natura 2000: 6510)**: Mowed meadows rich in species, on low to moderately fertilised soils, extending from the floodplains of the valley to the submontane area. These grasslands are characterised by beautiful flowering and are usually mowed no more than twice a year, only after the grasses have bloomed. These habitats correspond to the "56.2.1 ALL. ARRHENATHERION ELATIORIS KOCH 1926", namely to herbaceous communities, rich in species, that are mowed up to three times a year in sunny and low-altitude locations, namely within our study area (Comune di Cartigliano, 2014). Particularly, this habitat characterizes most of the seminatural grasslands in the "Parco Basse del Brenta", the part of SCI/SPA "Grave e zone umide del Fiume Brenta" that falls out of the riparian zone of the Brenta River in Cartigliano.
- **Floodplain forests of *Alnus glutinosa* (L.) Gaertn. and *Fraxinus excelsior* L. (Habitat Code Natura 2000: 91E0)**: This habitat includes different types of hygrophilous woods characterising the riparian belts of rivers in the lowlands and streams in the mountains (up to about 1500 m). These riparian formations develop on heavy soils in correspondence with alluvial deposits with a silty-sandy matrix. These soils are exposed to periodic flooding and are well drained in lean periods; furthermore, there is no summer drought, which has been found in the associations identified

in habitat 3240. In addition to the guide species of this habitat, the herbaceous layer is represented by robust species that sometimes form habitat 6430 associations and, in well-preserved patches, by a rich array of spring-flowering geophytes (Comune di Cartigliano, 2014).

# Annex 2

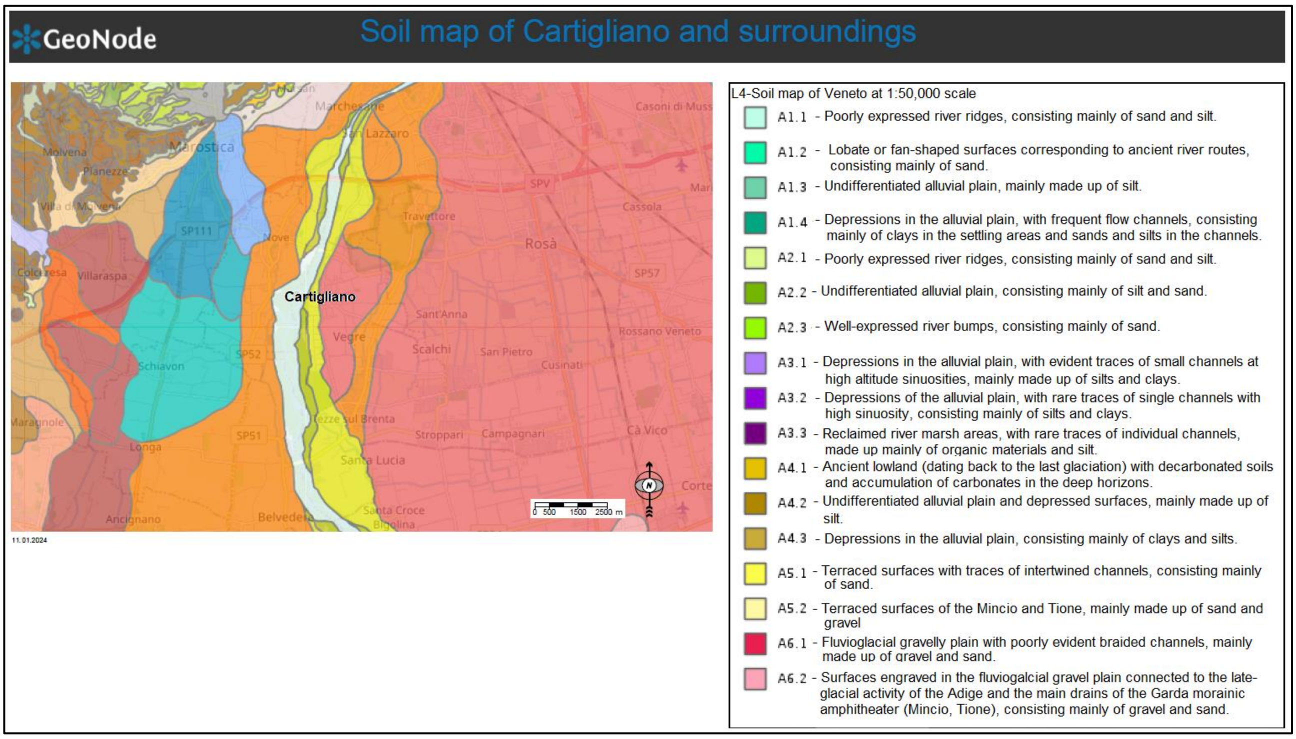

*Figure A10.1: Soil map of Cartigliano and surroundings (https://gaia.arpa.veneto.it/maps/778/view , modified; Legend of soil map:https://www.arpa.veneto.it/temi-ambientali/suolo/conoscenza-dei-suoli/carte-1-50.000/leg_50k.pdf/@@display-file/file).*

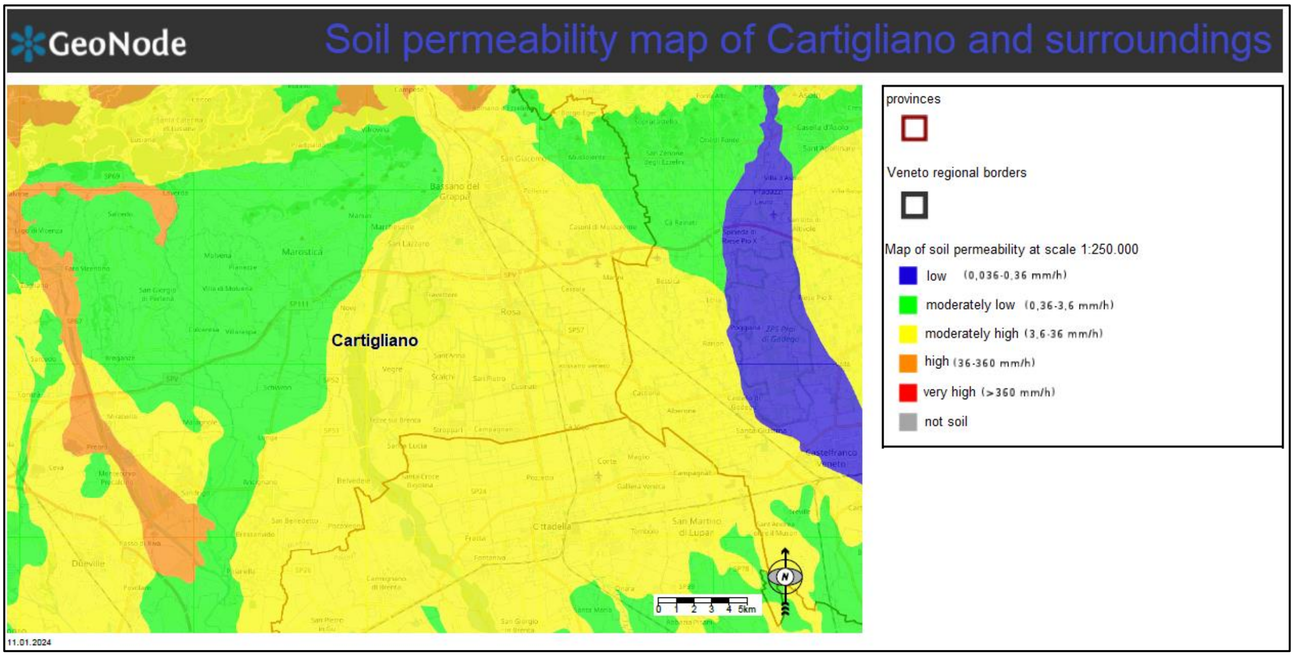

*Figure A10.2: Soil permeability map of Cartigliano and surroundings (https://gaia.arpa.veneto.it/maps/294 , modified).*

## Annex 3

*Table A11.1: EUNIS classification system of Cartigliano habitats.*

| ***Code*** |
|---|
| **C – Inland surface waters** |
| C1 - Surface standing waters |
| C12 - *Permanent mesotrophic lakes, ponds and pools (3130 - 3140)* |
| |
| C2 - Surface running waters |
| C22 - *Permanent non-tidal, fast, turbulent watercourses (3260)* |
| |
| C3 - Littoral zone of inland surface waterbodies |
| C32 - *Water-fringing reedbeds and tall helophytes other than canes* |
| C35 - *Periodically inundated shores with pioneer and ephemeral vegetation (3220 - 3270)* |
| C36 - *Unvegetated or sparsely vegetated shores with soft or mobile sediments* |
| |
| **R1 – Dry grasslands** |
| R1 – Dry grasslands |
| R1A - *Semi-dry perennial calcareous grassland (meadow steppe) (6210)* |
| |
| R2 - *Mesic grasslands* |
| R22 - *Low and medium altitude hay meadow (6510)* |
| |
| **S – Heatlands** |
| S9 - Riverine and fen scrubs |
| S91 - *Temperate riparian scrub (3240)* |
| |
| **T – Forests** |
| T1 - Deciduous broadleaved forest |
| T11 - *Temperate Salix and Populus riparian forest (91E0)* |
| T13 - *Temperate hardwood riparian forest* |
| |
| **V – Man made vegetated areas** |
| V1 - Arable land and market gardens |
| V11 - *Intensive unmixed crops* |
| V12 - *Mixed crops of market gardens and horticulture* |
| V13 - *Arable land with unmixed crops grown by low-intensity agricultural methods* |
| V15 - *Bare tilled, fallow or recently abandoned arable land* |
| |
| V2 - Cultivated areas of gardens and parks |
| V21 - *Large-scale ornamental garden areas* |
| V22 - *Small-scale ornamental and domestic garden areas* |
| V23 - *Recently abandoned garden areas* |
| |

| |
|---|
| V3 - Artificial grasslands and herb-dominated habitats |
| V31 - *Agriculturally-improved, re-seeded and heavily fertilised grassland, including sports fields and grass lawns* |
| V39 - *Mesic perennial anthropogenic herbaceous vegetation* |
| |
| V4 – Hedgerows |
| V41 - *Hedgerows of non-native species* |
| V42 - *Highly-managed hedgerows of native species* |
| V43 - *Species-rich hedgerows of native species* |
| V44 - *Species-poor hedgerows of native species* |
| |
| V5 – Shrub plantations |
| V54 - *Vineyards* |
| |
| V6 - Tree dominated man-made habitats |
| V61 - *Broadleaved fruit and nut tree orchards* |
| V62 - *Evergreen orchards and groves* |
| V63 - *Lines of planted trees* |
| V64 - *Small deciduous broadleaved planted other wooded land* |
| |
| **J – Artificial structures** |
| J1 - Buildings of cities, towns and villages |
| J12 - *Residential buildings of villages and urban peripheries* |
| J13 - *Urban and suburban public buildings* |
| J14 - *Urban and suburban industrial and commercial sites still in active use* |
| J15 - *Disused constructions of cities, towns and villages* |
| |
| J2 - Low density buildings |
| J21 - *Scattered residential buildings* |
| J22 - *Rural public buildings* |
| J23 - *Rural industrial and commercial sites still in active use* |
| J24 - *Agricultural constructions* |
| J25 - *Constructed boundaries* |
| J26 - *Disused rural constructions* |
| J27 - *Rural construction and demolition sites* |
| |
| J3 - Extractive industrial sites |
| J32 - *Active opencast mineral extraction sites, including quarries* |
| J33 - *Recently abandoned above-ground spaces of extractive industrial sites* |
| |
| J4 - Transport networks and other constructed hard-surfaced areas |
| J42 - *Road networks* |
| J46 - *Pavements and recreation areas* |
| J47 - *Constructed parts of cemeteries* |
| |
| J5 - Highly artificial man-made waters and associated structures |

| |
|---|
| J53 - *Highly artificial non-saline standing waters* |
| J54 - *Highly artificial non-saline running waters* |
| |
| J6 - Waste deposits |
| J61 - *Waste resulting from building construction or demolition* |
| J62 - *Household waste and landfill sites* |
| J64 - *Agricultural and horticultural waste* |
| J65 - *Industrial waste* |
| |
| **X – Habitat complexes** |
| X07 - *Intensively-farmed crops interspersed with strips of natural and/or semi-natural vegetation* |
| X22 - *Small city centre non-domestic gardens* |
| X23 - *Large non-domestic gardens* |

# Annex 4

*Table A12.1: Overall species list of the 48 plots.*

| | **Name of species** | | **Name of species** | | **Name of species** | | **Name of species** |
|---|---|---|---|---|---|---|---|
| 1 | *Achillea millefolium* | 44 | *Dactylis glomerata* | 87 | *Plantago lanceolata* | 130 | Trisetum flavescens |
| 2 | *Achillea roseoalba* | 45 | *Daucus carota* | 88 | *Poa annua* | 131 | *Ulmus minor* |
| 3 | *Ajuga reptans* | 46 | *Dichondra micrantha* | 89 | *Poa pratensis* | 132 | *Urtica dioica* |
| 4 | *Allium vineale* | 47 | *Elymus repens* | 90 | *Poa sylvicola* | 133 | *Valeriana officinalis* |
| 5 | *Anthoxanthum odoratum* | 48 | *Erigeron annuus* | 91 | *Poa trivialis* | 134 | *Valeriana stolonifera* |
| 6 | *Aphanes arvensis* | 49 | *Erigeron canadensis* | 92 | *Polygonum aviculare* | 135 | *Valerianella locusta* |
| 7 | *Arenaria serpyllifolia* | 50 | *Erigeron philadelphicus* | 93 | *Populus nigra* | 136 | *Verbascum densiflorum* |
| 8 | *Arrhenatherum elatius* | 51 | *Festuca arundinacea* | 94 | *Potentilla indica* | 137 | *Verbena officinalis* |
| 9 | *Artemisia verlotiorum* | 52 | *Festuca pratensis* | 95 | *Potentilla reptans* | 138 | *Veronica arvensis* |
| 10 | *Avenula pubescens* | 53 | *Festuca rubra* | 96 | *Poterium sanguisorba* | 139 | *Veronica persica* |
| 11 | *Bellis perennis* | 54 | *Festuca rupicola* | 97 | *Prunella vulgaris* | 140 | *Vicia hirsuta* |
| 12 | *Bromus arvensis* | 55 | *Galium aparine* | 98 | *Prunus avium* | 141 | *Vicia sativa* |
| 13 | *Bromus hordeaceus* | 56 | *Galium mollugo* | 99 | *Ranunculus acris* | 142 | *Viola arvensis* |
| 14 | *Bromus madritensis* | 57 | *Geranium dissectum* | 100 | *Ranunculus bulbosus* | 143 | *Viola odorata* |
| 15 | *Bromus sterilis* | 58 | *Geranium molle* | 101 | *Ranunculus parviflorus* | 144 | *Vulpia myuros* |
| 16 | *Calamintha nepeta* | 59 | *Geranium sibiricum* | 102 | *Ranunculus repens* | | |
| 17 | *Calepina irregularis* | 60 | *Holcus lanatus* | 103 | *Ranunculus sardous* | | |
| 18 | *Capsella bursa-pastoris* | 61 | *Hordeum murinum* | 104 | *Rorippa sylvestris* | | |
| 19 | *Capsella rubella* | 62 | *Hypericum perforatum* | 105 | *Rumex acetosa* | | |
| 20 | *Cardamine hirsuta* | 63 | *Hypochoeris radicata* | 106 | *Rumex conglomeratus* | | |
| 21 | *Carex distans* | 64 | *Leontodon hispidus* | 107 | *Rumex obtusifolius* | | |
| 22 | *Carex divisa* | 65 | *Leucanthemum vulgare* | 108 | *Salvia pratensis* | | |
| 23 | *Carex divulsa* | 66 | *Lolium multiflorum* | 109 | *Saxifraga tridactylites* | | |
| 24 | *Carex flacca* | 67 | *Lolium perenne* | 110 | *Scabiosa triandra* | | |
| 25 | *Carex hirta* | 68 | *Lotus corniculatus* | 111 | *Sedum sexangulare* | | |
| 26 | *Carex spicata* | 69 | *Lychnis flos-cuculi* | 112 | *Senecio inaequindens* | | |
| 27 | *Carex sylvatica* | 70 | *Lysimachia nummularia* | 113 | *Senecio vulgaris* | | |
| 28 | *Centaurea nigrescens* | 71 | *Lythrum salicaria* | 114 | *Setaria italica* | | |
| 29 | *Centaurea scabiosa* | 72 | *Matricaria chamomilla* | 115 | *Sherardia arvensis* | | |
| 30 | *Centaurium pulchellum* | 73 | *Medicago lupulina* | 116 | *Silene vulgaris* | | |
| 31 | *Cerastium glomeratum* | 74 | *Medicago minima* | 117 | *Sonchus asper* | | |
| 32 | *Cerastium glutinosum* | 75 | *Medicago sativa* | 118 | *Sonchus oleraceus* | | |
| 33 | *Cerastium tomentosum* | 76 | *Mentha arvensis* | 119 | *Sorghum halepense* | | |
| 34 | *Chondrilla juncea* | 77 | *Muscari neglectum* | 120 | *Sporobolus indicus* | | |
| 35 | *Cirsium arvense* | 78 | *Myosotis arvensis* | 121 | *Stellaria media* | | |
| 36 | *Clinopodium nepeta* | 79 | *Ornithogalum umbellatum* | 122 | *Symphytum officinale* | | |
| 37 | *Clinopodium vulgare* | 80 | *Orobanche minor* | 123 | *Taraxacum officinale* | | |
| 38 | *Convolvulus arvensis* | 81 | *Oxalis dillenii* | 124 | *Torilis arvensis* | | |
| 39 | *Crepis biennis* | 82 | *Papaver dubium* | 125 | *Trifolium campestre* | | |
| 40 | *Crepis foetida* | 83 | *Papaver rhoeas* | 126 | *Trifolium dubium* | | |
| 41 | *Crepis sancta* | 84 | *Parthenocissus inserta* | 127 | *Trifolium pratense* | | |
| 42 | *Crepis setosa* | 85 | *Petrorhagia saxifraga* | 128 | *Trifolium repens* | | |
| 43 | *Cynodon dactylon* | 86 | *Picris hieracioides* | 129 | *Trifolium scabrum* | | |

## Annex 5

*Table A13.1: summary table that compare the averages and standard deviations of chorological spectrum of the groups.*

| Chorotype | Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|---|
| **Adventitious (*alien*)** | 2,33±1,33 | 2,07±1,14 | 2,67±1,03 | 3,9±1,52 |
| **Atlantic** | 0,11±0,32 | 0±0 | 0±0 | 0,1±0,32 |
| **Boreal** | 4,44±1,65 | 4,79±1,31 | 4,67±2,07 | 2,6±1,65 |
| **Cosmopolite** | 3,06±2,07 | 2,71±1,59 | 4,83±2,32 | 5,6±1,9 |
| **Endemic** | 0,06±0,24 | 0,07±0,27 | 0±0 | 0±0 |
| **Eurasian** | 3,06±1,59 | 4,43±1,09 | 4,67±1,75 | 3±0,47 |
| **Mediterranean** | 3,56±1,85 | 3,14±1,41 | 4,67±3,01 | 5,9±1,85 |
| **Orophyte** | 0,17±0,38 | 0,64±0,63 | 0,17±0,41 | 0,5±0,71 |
| **Paleotemperate** | 4,5±1,47 | 5,21±1,37 | 6±1,79 | 5,7±2,45 |
| **S European - S Siberian** | 2±1,97 | 1,64±0,5 | 2,33±0,82 | 2,2±0,79 |

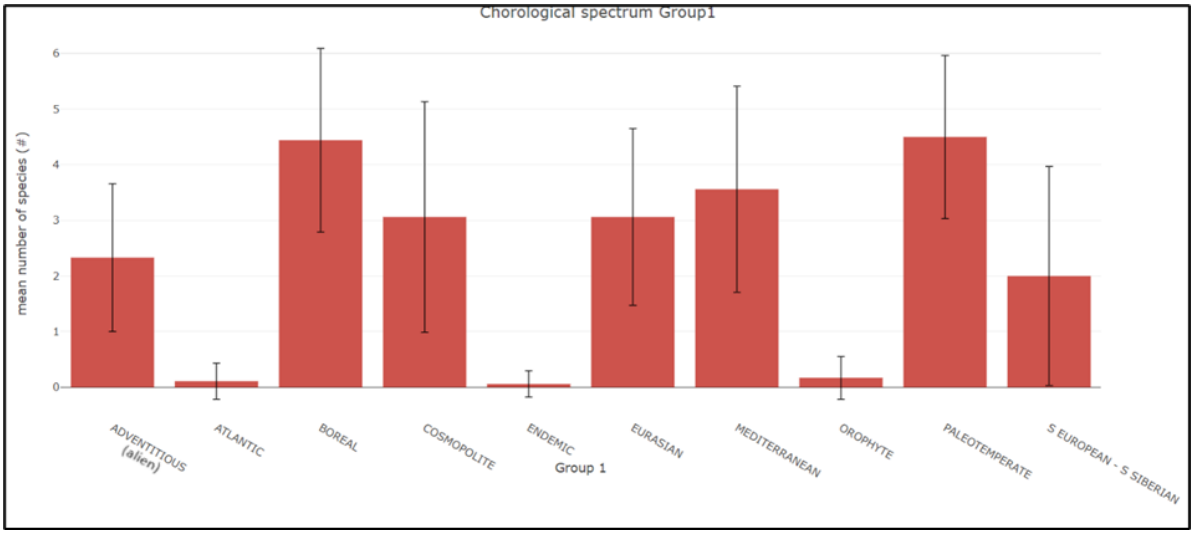

*Figure A13.1: Chorological spectrum of Group 1.*

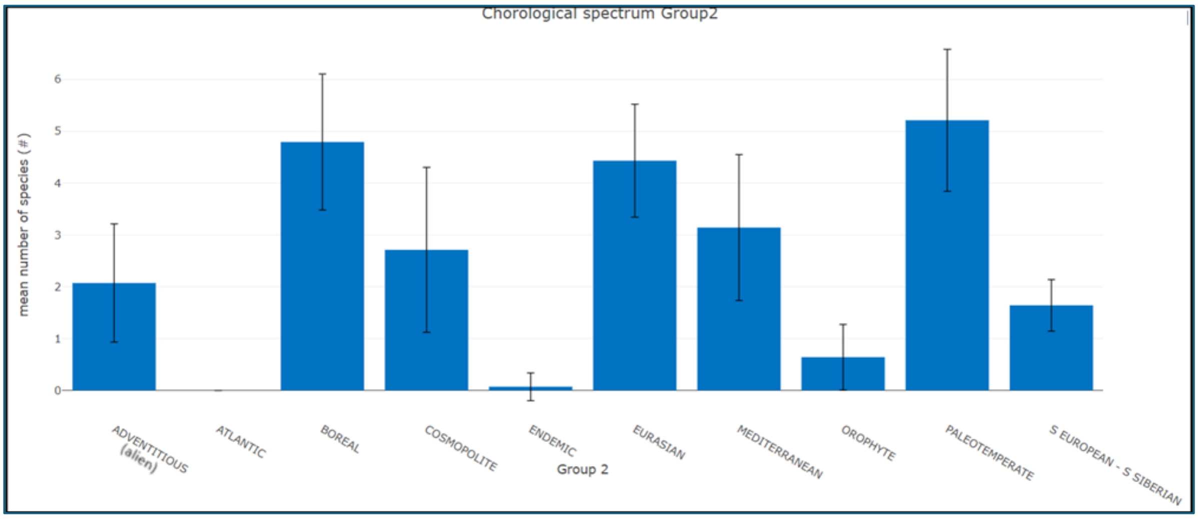

*Figure A13.2: Chorological spectrum of Group 2.*

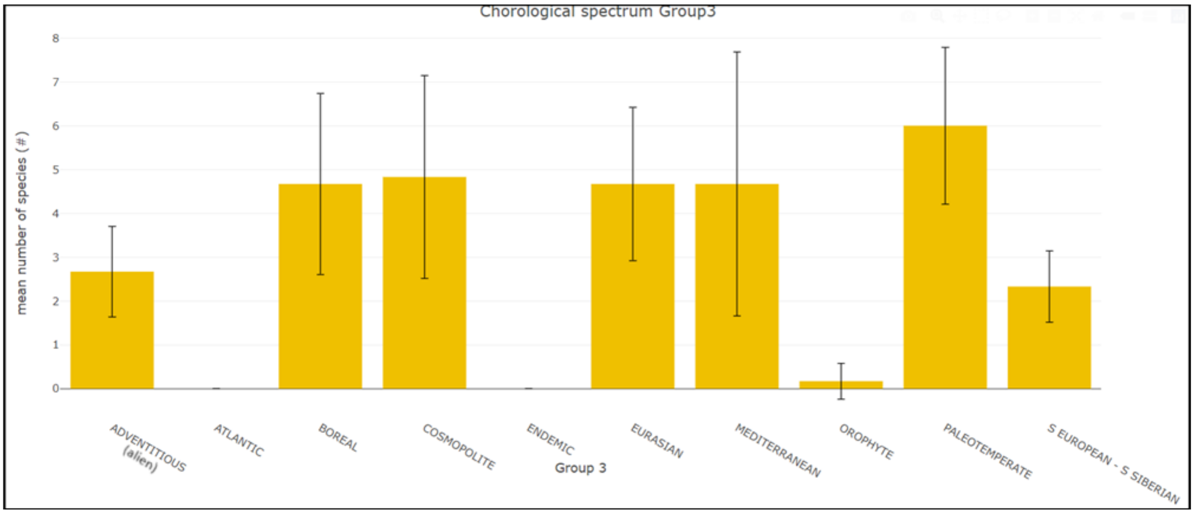

*Figure A13.3: Chorological spectrum of Group 3.*

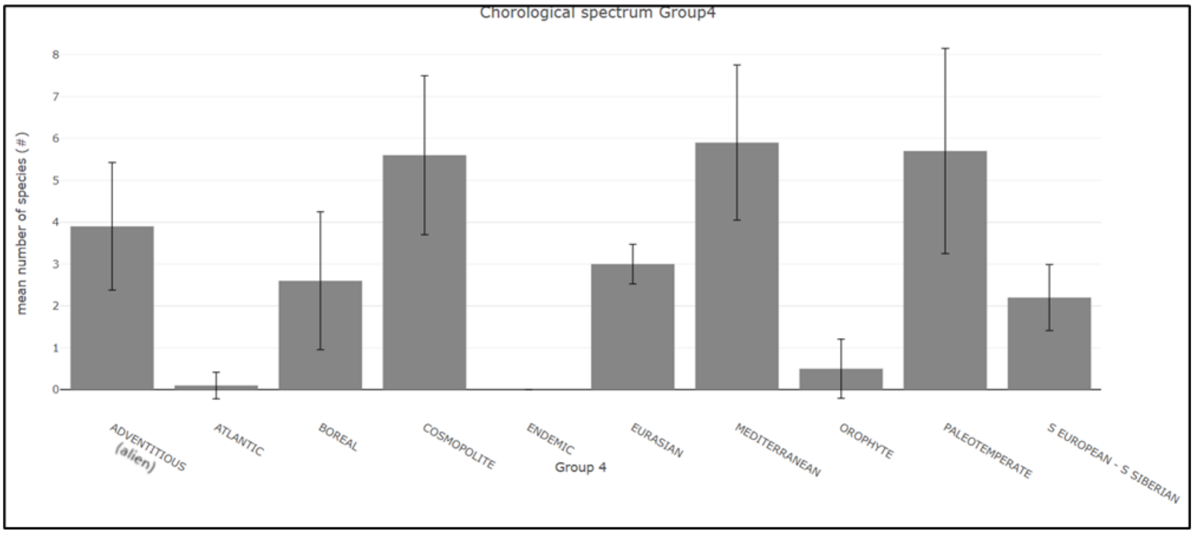

*Figure A13.4: Chorological spectrum of Group 4.*

*Table A13.2: summary table that compare the averages and standard deviations of the biological spectrum of the groups.*

| Life form | Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|---|
| CH | 1,89±0,68 | 1,57±0,65 | 1,83±0,75 | 1,2±0,79 |
| G | 0,89±1,02 | 1±0,78 | 2,17±1,17 | 1,8±1,32 |
| H | 11,56±5,75 | 14,86±3,44 | 13,67±2,58 | 11±4,16 |
| NP+P | 0,28±0,96 | 0±0 | 0,17±0,41 | 0,2±0,42 |
| T | 7,78±4,4 | 7,29±2,49 | 12,17±6,11 | 15,3±4,37 |

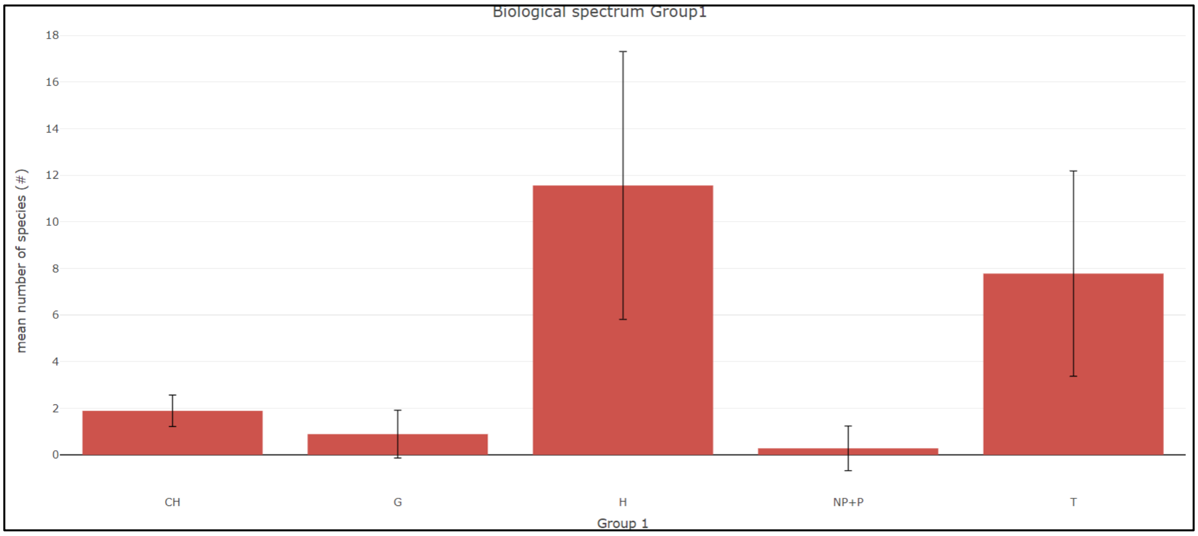

*Figure A13.5: Biological spectrum of Group 1.*

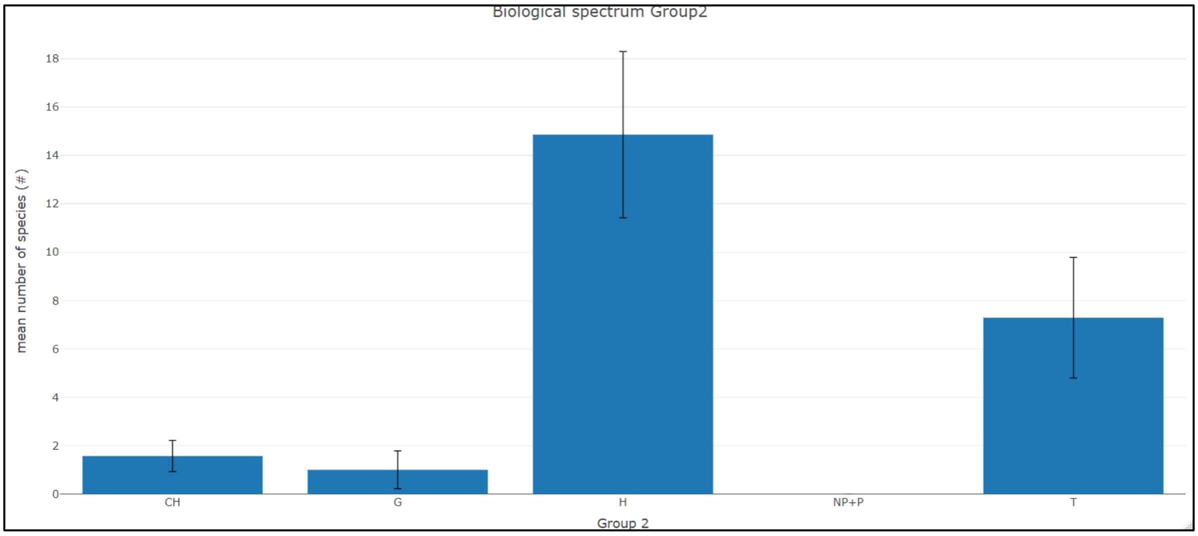

*Figure A13.6: Biological spectrum of Group 2.*

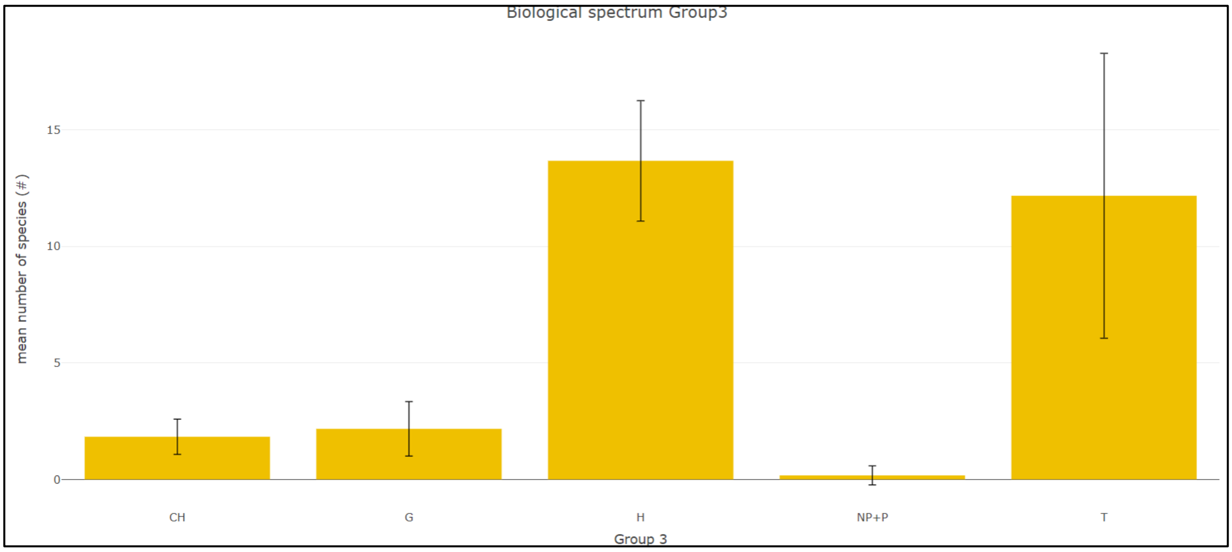

*Figure A13.7: Biological spectrum of Group 3.*

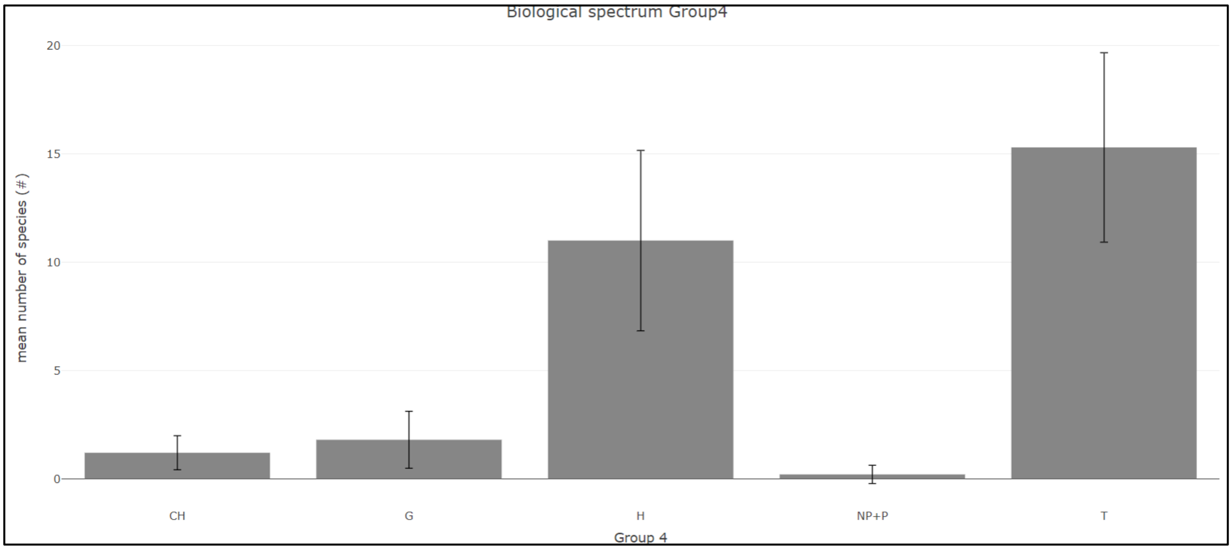

*Figure A13.8: Biological spectrum of Group 4.*

*Table A13.3: summary table that compare the averages and standard deviations of CSR spectrum of the groups.*

| Adaptative strategies | Group 1 | Group 2 | Group 3 | Group 4 |
|---:|---|---|---|---|
| C | 23,66±4,65 | 25,02±3,81 | 26,27±3,67 | 14,95±4,69 |
| S | 34,92±9,62 | 35,85±7,67 | 34,69±4,75 | 45,46±13,81 |
| R | 38,54±9,53 | 38,01±4,79 | 35,61±4,91 | 32,07±7,59 |

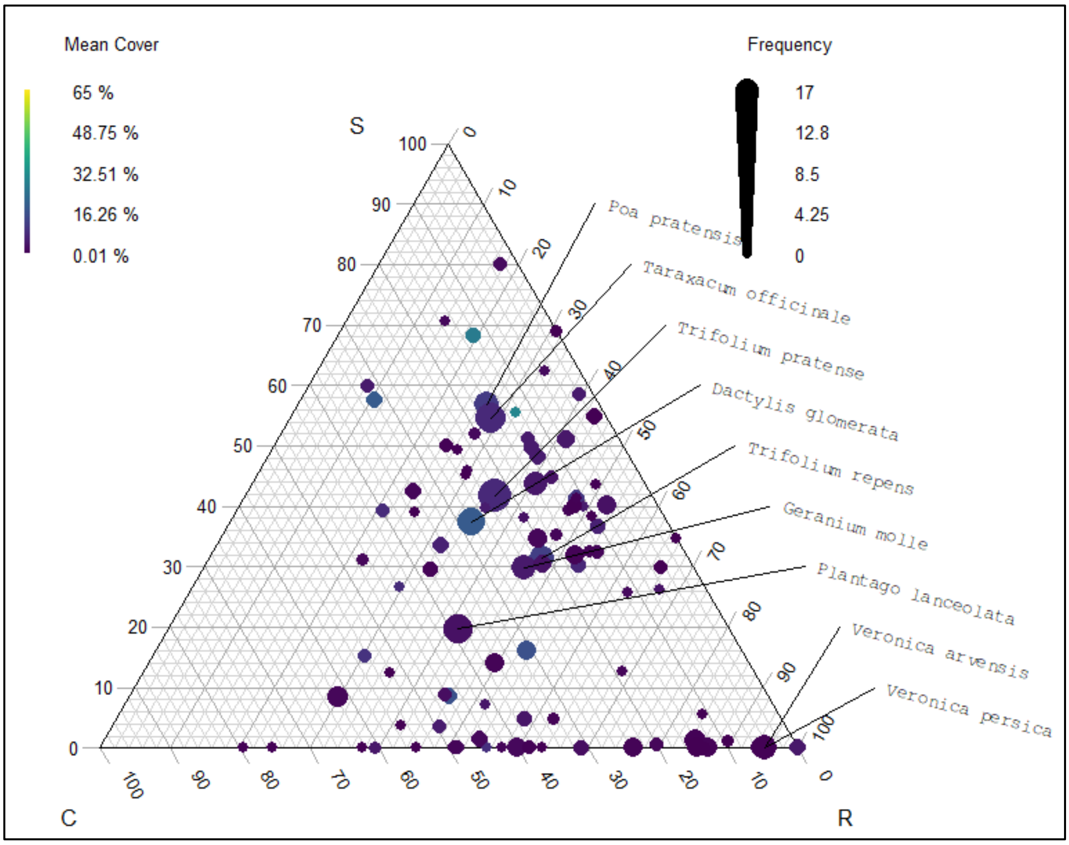

*Figure A13.9: Ternary Grime plot of Group 1 (highlighted species are the species found in more than 66% of the group's plots).*

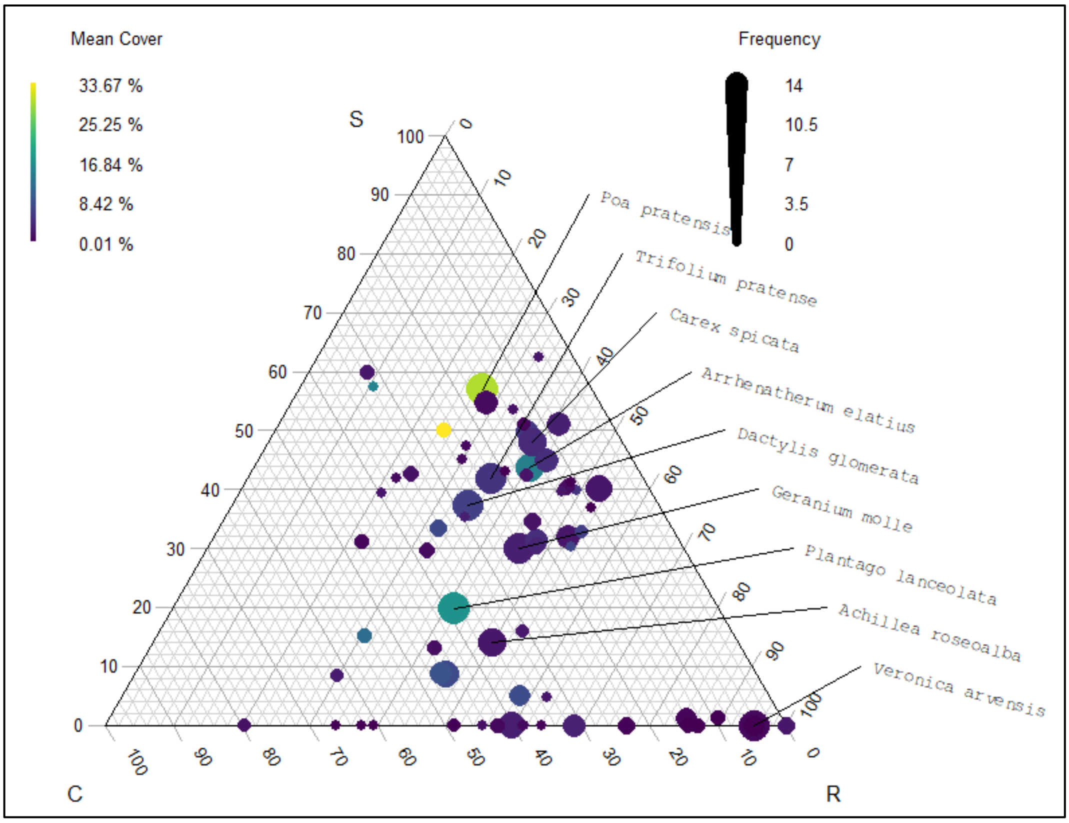

*Figure A13.10: Ternary Grime plot of Group 2 (highlighted species are the species found in more than 66% of the group's plots).*

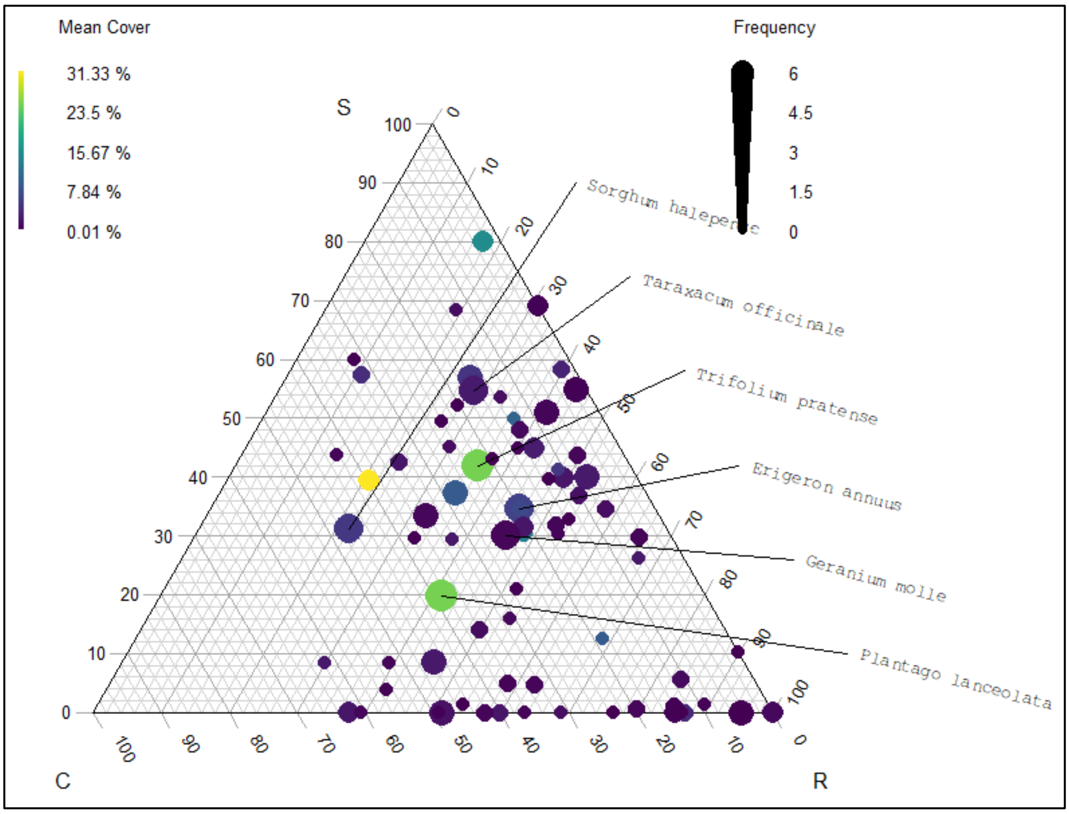

*Figure A13.11: Ternary Grime plot of Group 3 (highlighted species are the species found in more than 66% of the group's plots).*

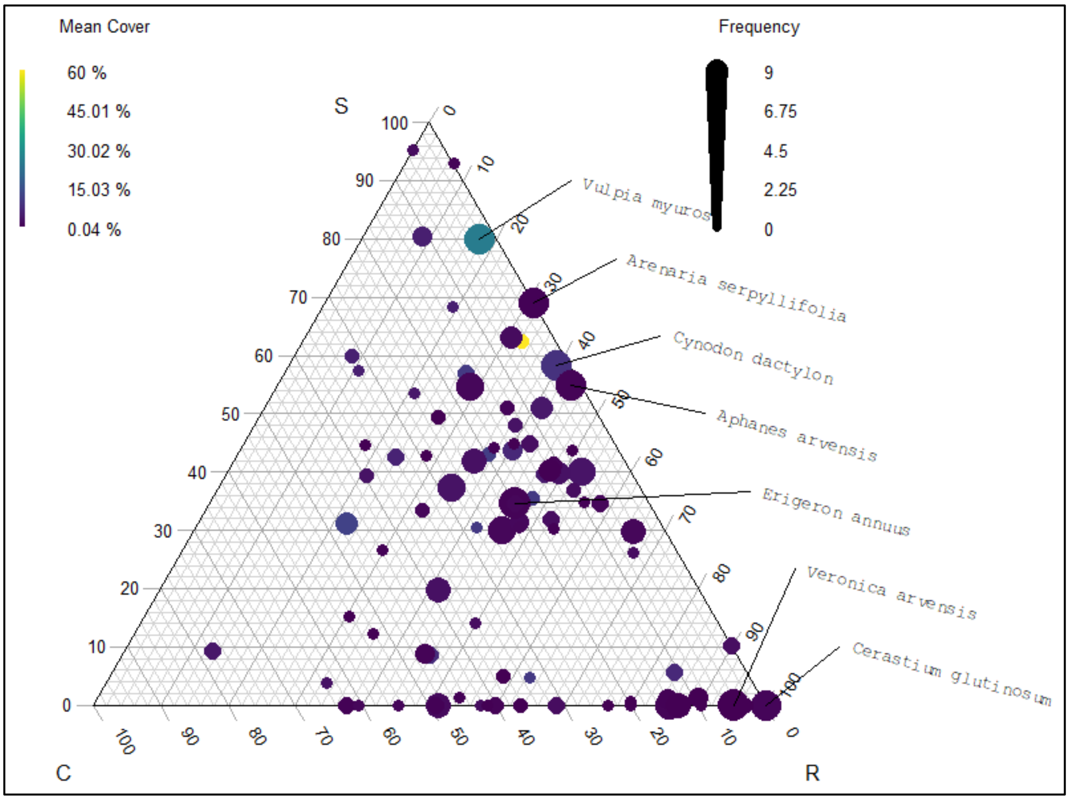

*Figure A13.12: Ternary Grime plot of Group 4 (highlighted species are the species found in more than 66% of the group's plots).*

## Annex 6

Table A14.1: CSR output and strategy class for each species surveyd.

| Species | C (%) | S (%) | R (%) | C : S : R (%) | Strategy class |
|---|---|---|---|---|---|
| *Achillea millefolium* | 24.95 | 45.20 | 29.84 | 25 : 45 : 30 | S/CSR |
| *Achillea roseo-alba* | 36.20 | 14.11 | 49.69 | 36 : 14 : 50 | CR/CSR |
| *Ajuga reptans* | 32.68 | 4.77 | 62.55 | 33 : 5 : 63 | R/CR |
| *Allium vineale* | 55.02 | 3.76 | 41.22 | 55 : 4 : 41 | CR |
| *Anthoxanthum odoratum* | 12.77 | 44.84 | 42.39 | 13 : 45 : 42 | SR/CSR |
| *Aphanes arvensis* | 1.56 | 54.84 | 43.60 | 2 : 55 : 44 | SR |
| *Arenaria serpyllifolia* | 0.00 | 69.10 | 30.90 | 0 : 69 : 31 | S/SR |
| *Arrhenatherum elatius* | 15.71 | 43.74 | 40.56 | 16 : 44 : 41 | SR/CSR |
| *Artemisia verlotiorum* | 31.59 | 59.94 | 8.47 | 32 : 60 : 8 | S/CS |
| *Bellis perennis* | 19.85 | 0.59 | 79.56 | 20 : 1 : 80 | R/CR |
| *Bromus arvensis* | 24.96 | 39.67 | 35.37 | 25 : 40 : 35 | SR/CSR |
| *Bromus hordeaceus* | 7.70 | 51.07 | 41.23 | 8 : 51 : 41 | SR |
| *Bromus madritensis* | 7.38 | 34.59 | 58.02 | 7 : 35 : 58 | SR |
| *Bromus sterilis* | 16.92 | 35.42 | 47.66 | 17 : 35 : 48 | SR/CSR |
| *Calepina irregularis* | 35.91 | 0.00 | 64.09 | 36 : 0 : 64 | R/CR |
| *Capsella bursapastoris* | 23.54 | 0.00 | 76.46 | 24 : 0 : 76 | R/CR |
| *Capsella rubella* | 38.46 | 0.00 | 61.54 | 38 : 0 : 62 | CR |
| *Cardamine hirsuta* | 9.38 | 1.26 | 89.37 | 9 : 1 : 89 | R |
| *Carex distans* | 12.63 | 55.45 | 31.92 | 13 : 55 : 32 | S/CSR |
| *Carex divisa* | 4.78 | 95.22 | 0.00 | 5 : 95 : 0 | S |
| *Carex divulsa* | 44.55 | 0.00 | 55.45 | 45 : 0 : 55 | CR |
| *Carex flacca* | 15.14 | 70.66 | 14.21 | 15 : 71 : 14 | S/CS |
| *Carex hirta* | 25.19 | 50.10 | 24.70 | 25 : 50 : 25 | S/CSR |
| *Carex spicata* | 13.21 | 48.07 | 38.72 | 13 : 48 : 39 | SR/CSR |
| *Carex sylvatica* | 24.47 | 45.90 | 29.63 | 24 : 46 : 30 | S/CSR |
| *Centaurea nigrescens* | 46.21 | 8.77 | 45.02 | 46 : 9 : 45 | CR |
| *Centaurea scabiosa* | 36.29 | 41.84 | 21.86 | 36 : 42 : 22 | CS/CSR |
| *Centaurium pulchellum* | 0.00 | 10.15 | 89.85 | 0 : 10 : 90 | R |
| *Cerastium glomeratum* | 13.96 | 1.13 | 84.91 | 14 : 1 : 85 | R |
| *Cerastium glutinosum* | 0.00 | 0.00 | 100.00 | 0 : 0 : 100 | R |
| *Cerastium tomentosum* | 10.22 | 38.41 | 51.37 | 10 : 38 : 51 | SR |
| *Chondrilla juncea* | 15.09 | 44.87 | 40.04 | 15 : 45 : 40 | SR/CSR |
| *Cirsium arvense* | 52.23 | 8.38 | 39.40 | 52 : 8 : 39 | CR |
| *Clinopodium vulgare* | 16.90 | 42.47 | 40.63 | 17 : 42 : 41 | SR/CSR |
| *Convolvulus arvensis* | 36.61 | 4.97 | 58.42 | 37 : 5 : 58 | CR |

| | | | | | |
|---|---|---|---|---|---|
| *Crepis biennis* | 60.60 | 0.00 | 39.40 | 61 : 0 : 39 | CR |
| *Crepis foetida* | 27.76 | 30.47 | 41.77 | 28 : 30 : 42 | CSR |
| *Crepis setosa* | 49.04 | 0.00 | 50.96 | 49 : 0 : 51 | CR |
| *Cynodon dactylon* | 1.96 | 58.40 | 39.63 | 2 : 58 : 40 | SR |
| *Dactylis glomerata* | 28.06 | 37.30 | 34.64 | 28 : 37 : 35 | CSR |
| *Daucus carota* | 33.71 | 42.54 | 23.74 | 34 : 43 : 24 | CS/CSR |
| *Elymus repens* | 20.21 | 52.08 | 27.71 | 20 : 52 : 28 | S/CSR |
| *Erigeron annuus* | 19.98 | 34.54 | 45.48 | 20 : 35 : 45 | SR/CSR |
| *Erigeron canadensis* | 11.97 | 40.24 | 47.79 | 12 : 40 : 48 | SR/CSR |
| *Festuca arundinacea* | 31.79 | 57.52 | 10.69 | 32 : 58 : 11 | S/CSR |
| *Festuca pratensis* | 39.70 | 39.34 | 20.97 | 40 : 39 : 21 | CS/CSR |
| *Festuca rubra* | 12.31 | 68.35 | 19.34 | 12 : 68 : 19 | S/SR |
| *Festuca rupicola* | 5.09 | 62.42 | 32.49 | 5 : 62 : 32 | S/SR |
| *Galium aparine* | 10.79 | 5.57 | 83.64 | 11 : 6 : 84 | R |
| *Galium mollugo* | 7.29 | 40.15 | 52.56 | 7 : 40 : 53 | SR |
| *Geranium dissectum* | 13.60 | 32.68 | 53.72 | 14 : 33 : 54 | R/CSR |
| *Geranium molle* | 24.21 | 29.95 | 45.84 | 24 : 30 : 46 | R/CSR |
| *Helictotrichon pubescens* | 23.19 | 47.35 | 29.46 | 23 : 47 : 29 | S/CSR |
| *Holcus lanatus* | 21.37 | 30.42 | 48.21 | 21 : 30 : 48 | R/CSR |
| *Hordeum murinum* | 13.12 | 39.58 | 47.31 | 13 : 40 : 47 | SR/CSR |
| *Hypericum perforatum* | 6.98 | 43.64 | 49.38 | 7 : 44 : 49 | SR |
| *Hypochaeris radicata* | 48.68 | 0.00 | 51.32 | 49 : 0 : 51 | CR |
| *Leontodon hispidus* | 44.96 | 1.34 | 53.70 | 45 : 1 : 54 | CR |
| *Leucanthemum vulgare* | 16.35 | 30.35 | 53.30 | 16 : 30 : 53 | R/CSR |
| *Lolium multiflorum* | 30.72 | 16.03 | 53.25 | 31 : 16 : 53 | R/CSR |
| *Lolium perenne* | 13.21 | 49.79 | 36.99 | 13 : 50 : 37 | SR/CSR |
| *Lotus corniculatus* | 10.20 | 36.82 | 52.98 | 10 : 37 : 53 | SR |
| *Lychnis flos-cuculi* | 42.42 | 0.00 | 57.58 | 42 : 0 : 58 | CR |
| *Lysimachia nummularia* | 11.46 | 25.82 | 62.72 | 11 : 26 : 63 | R/SR |
| *Lythrum salicaria* | 20.12 | 38.15 | 41.73 | 20 : 38 : 42 | SR/CSR |
| *Medicago lupulina* | 10.76 | 39.85 | 49.39 | 11 : 40 : 49 | SR |
| *Medicago minima* | 6.35 | 63.04 | 30.61 | 6 : 63 : 31 | S/SR |
| *Medicago sativa* | 12.98 | 51.10 | 35.92 | 13 : 51 : 36 | SR/CSR |
| *Mentha arvensis* | 18.75 | 12.57 | 68.68 | 19 : 13 : 69 | R/CR |
| *Muscari neglectum* | 41.44 | 0.00 | 58.56 | 41 : 0 : 59 | CR |
| *Myosotis arvensis* | 13.34 | 0.00 | 86.66 | 13 : 0 : 87 | R |
| *Ornithogalum umbellatum* | 60.66 | 0.00 | 39.34 | 61 : 0 : 39 | CR |
| *Oxalis dillenii* | 14.34 | 0.00 | 85.66 | 14 : 0 : 86 | R |
| *Papaver rhoeas* | 27.12 | 20.90 | 51.99 | 27 : 21 : 52 | R/CSR |
| *Parthenocissus quinquefolia* | 63.30 | 3.90 | 32.80 | 63 : 4 : 33 | C/CR |

| | | | | | |
|---|---|---|---|---|---|
| *Parthenocissus vitacea* | 67.42 | 16.12 | 16.46 | 67 : 16 : 16 | C/CR |
| *Picris hieracioides* | 41.19 | 7.16 | 51.65 | 41 : 7 : 52 | CR |
| *Plantago lanceolata* | 38.81 | 19.75 | 41.45 | 39 : 20 : 41 | CR/CSR |
| *Poa annua* | 6.64 | 26.26 | 67.10 | 7 : 26 : 67 | R/SR |
| *Poa pratensis* | 16.00 | 56.96 | 27.03 | 16 : 57 : 27 | S/CSR |
| *Poa sylvicola* | 10.98 | 41.21 | 47.81 | 11 : 41 : 48 | SR/CSR |
| *Poa trivialis* | 10.98 | 41.21 | 47.81 | 11 : 41 : 48 | SR/CSR |
| *Polygonum aviculare* | 0.00 | 34.73 | 65.27 | 0 : 35 : 65 | R/SR |
| *Populus nigra* | 42.24 | 43.62 | 14.13 | 42 : 44 : 14 | CS/CSR |
| *Potentilla indica* | 29.05 | 42.77 | 28.18 | 29 : 43 : 28 | CSR |
| *Potentilla reptans* | 34.43 | 33.42 | 32.15 | 34 : 33 : 32 | CSR |
| *Prunella vulgaris* | 12.43 | 32.39 | 55.18 | 12 : 32 : 55 | R/CSR |
| *Prunus avium* | 37.22 | 44.73 | 18.05 | 37 : 45 : 18 | CS/CSR |
| *Ranunculus acris* | 37.84 | 29.56 | 32.61 | 38 : 30 : 33 | CSR |
| *Ranunculus bulbosus* | 45.04 | 13.15 | 41.80 | 45 : 13 : 42 | CR/CSR |
| *Ranunculus repens* | 49.48 | 3.42 | 47.10 | 49 : 3 : 47 | CR |
| *Ranunculus sardous* | 39.36 | 0.00 | 60.64 | 39 : 0 : 61 | CR |
| *Rorippa sylvestris* | 38.65 | 0.00 | 61.35 | 39 : 0 : 61 | CR |
| *Rumex acetosa* | 40.17 | 0.00 | 59.83 | 40 : 0 : 60 | CR |
| *Rumex conglomeratus* | 61.70 | 8.47 | 29.83 | 62 : 8 : 30 | C/CR |
| *Rumex obtusifolius* | 79.48 | 0.00 | 20.52 | 79 : 0 : 21 | C/CR |
| *Salvia pratensis* | 45.60 | 8.58 | 45.81 | 46 : 9 : 46 | CR |
| *Sanguisorba minor* | 25.49 | 53.43 | 21.08 | 25 : 53 : 21 | S/CSR |
| *Saxifraga tridactylites* | 2.84 | 0.00 | 97.16 | 3 : 0 : 97 | R |
| *Scabiosa triandra* | 32.45 | 29.33 | 38.22 | 32 : 29 : 38 | CSR |
| *Sedum sexangulare* | 0.00 | 92.88 | 7.12 | 0 : 93 : 7 | S |
| *Senecio inaequidens* | 20.07 | 0.00 | 79.93 | 20 : 0 : 80 | R/CR |
| *Senecio vulgaris* | 36.57 | 0.00 | 63.43 | 37 : 0 : 63 | R/CR |
| *Setaria italica* | 54.31 | 15.21 | 30.48 | 54 : 15 : 30 | C/CSR |
| *Silene vulgaris* | 31.05 | 0.00 | 68.95 | 31 : 0 : 69 | R/CR |
| *Sonchus asper* | 62.32 | 0.00 | 37.68 | 62 : 0 : 38 | CR |
| *Sonchus oleraceus* | 54.67 | 0.00 | 45.33 | 55 : 0 : 45 | CR |
| *Sorghum halepense* | 46.75 | 31.28 | 21.96 | 47 : 31 : 22 | C/CSR |
| *Sporobolus indicus* | 10.80 | 80.47 | 8.73 | 11 : 80 : 9 | S |
| *Stellaria media* | 5.29 | 0.00 | 94.71 | 5 : 0 : 95 | R |
| *Symphytum officinale* | 75.20 | 0.00 | 24.80 | 75 : 0 : 25 | C/CR |
| *Taraxacum officinale* | 16.70 | 54.57 | 28.73 | 17 : 55 : 29 | S/CSR |
| *Torilis arvensis* | 18.31 | 44.20 | 37.49 | 18 : 44 : 37 | SR/CSR |
| *Trifolium campestre* | 4.70 | 29.89 | 65.41 | 5 : 30 : 65 | R/SR |
| *Trifolium dubium* | 9.50 | 34.91 | 55.59 | 10 : 35 : 56 | SR |

| | | | | | |
|---|---|---|---|---|---|
| *Trifolium pratense* | 22.53 | 41.80 | 35.67 | 23 : 42 : 36 | SR/CSR |
| *Trifolium repens* | 20.88 | 31.46 | 47.66 | 21 : 31 : 48 | R/CSR |
| *Trisetum flavescens* | 13.27 | 53.52 | 33.20 | 13 : 54 : 33 | S/CSR |
| *Ulmus minor* | 35.36 | 39.11 | 25.53 | 35 : 39 : 26 | CSR |
| *Urtica dioica* | 29.61 | 35.23 | 35.16 | 30 : 35 : 35 | CSR |
| *Valeriana collina* | 66.08 | 0.00 | 33.92 | 66 : 0 : 34 | C/CR |
| *Valeriana officinalis* | 52.19 | 12.34 | 35.47 | 52 : 12 : 35 | CR/CSR |
| *Valeriana wallrothii* | 66.08 | 0.00 | 33.92 | 66 : 0 : 34 | C/CR |
| *Valerianella locusta* | 12.90 | 0.00 | 87.10 | 13 : 0 : 87 | R |
| *Verbascum densiflorum* | 77.59 | 9.27 | 13.14 | 78 : 9 : 13 | C/CR |
| *Verbena officinalis* | 23.93 | 49.38 | 26.69 | 24 : 49 : 27 | S/CSR |
| *Veronica arvensis* | 4.75 | 0.00 | 95.25 | 5 : 0 : 95 | R |
| *Veronica persica* | 4.60 | 0.00 | 95.40 | 5 : 0 : 95 | R |
| *Vicia hirsuta* | 19.80 | 42.98 | 37.22 | 20 : 43 : 37 | SR/CSR |
| *Vicia sativa* | 16.02 | 31.80 | 52.17 | 16 : 32 : 52 | R/CSR |
| *Viola arvensis* | 9.65 | 0.00 | 90.35 | 10 : 0 : 90 | R |
| *Viola odorata* | 43.73 | 26.71 | 29.56 | 44 : 27 : 30 | CSR |
| *Vulpia myuros* | 2.64 | 80.04 | 17.32 | 3 : 80 : 17 | S/SR |
| *Clinopodium nepeta* * | | | | | *NA* |
| *Crepis sancta* * | | | | | *NA* |
| *Dichondra micrantha* * | | | | | *NA* |
| *Erigeron philadelphicus* * | | | | | *NA* |
| *Geranium sibiricum* * | | | | | *NA* |
| *Matricaria chamomilla* * | | | | | *NA* |
| *Orobanche minor* * | | | | | *NA* |
| *Papaver dubium* * | | | | | *NA* |
| *Petrorhagia saxifraga* * | | | | | *NA* |
| *Ranunculus parviflorus* * | | | | | *NA* |
| *Sherardia arvensis* * | | | | | *NA* |
| *Trifolium scabrum* * | | | | | *NA* |
| | | | | | |

**species with no data and not considered in the assessment for CSR strategies within plots*

# Annex 7

*Table A15.1: Plot distinction between the four groups resulting from the cluster analysis.*

| Numbers of plot | Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|---|
| **1** | P12 | P02 | P18 | P25 |
| **2** | P27 | P11 | P30 | U24 |
| **3** | P21 | P22 | U20 | U16 |
| **4** | P23 | P24 | U03 | U06 |
| **5** | P01 | P15 | U23 | U30 |
| **6** | P16 | P04 | U27 | U22 |
| **7** | U15 | P17 | | U18 |
| **8** | P08 | P07 | | U19 |
| **9** | P06 | P20 | | U05 |
| **10** | P19 | P09 | | U25 |
| **11** | P28 | P13 | | |
| **12** | U17 | P26 | | |
| **13** | P10 | P03 | | |
| **14** | P29 | P14 | | |
| **15** | U26 | | | |
| **16** | U01 | | | |
| **17** | P05 | | | |
| **18** | U28 | | | |

# Annex 8

*Table A16.1: Summary information (average and standard deviation) of biomass, biodiversity and EIVs attributes values.*

| | **Attributes** | Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|---|---|
| | ***Biomass*** *(g/m$^2$)* | 444.00±152.15 | 481.29±102.11 | 366.19±56.33 | 266.63±77.72 |
| *Edaphic* | ***ELL_M*** | 4.43±0.37 | 4.34±0.23 | 4.32±0.34 | 3.58±0.43 |
| | ***ELL_N*** | 5.65±0.58 | 5.42±0.22 | 5.25±0.35 | 4.57±0.89 |
| | ***ELL_R*** | 6.25±0.30 | 6.07±0.18 | 5.97±0.18 | 6.1±0.66 |
| *Biodiversity* | ***S_plot*** *(#)* | 23.28±8.34 | 24.71±5.08 | 30±7.16 | 29.5±6.17 |
| | ***S_ann*** *(#)* | 8.44±4.69 | 7.29±2.49 | 12.17±6.11 | 15.3±4.37 |
| | ***S_per*** *(#)* | 14.83±6.2 | 17.43±4.03 | 17.67±1.51 | 14.2±4.83 |
| | ***S_gram*** *(#)* | 6.17±2.66 | 7.14±1.92 | 7.33±1.63 | 7±2.16 |
| | ***S_ngram*** *(#)* | 17.11±6.61 | 17.57±4.22 | 22.67±6.25 | 22.5±5.15 |
| | ***S_nat*** *(#)* | 22.56±7.76 | 23.86±4.74 | 28.67±7.53 | 28.3±5.7 |
| | ***S_ali*** *(#)* | 0.72±0.89 | 0.86±0.86 | 1.33±0.52 | 1.2±0.92 |
| | ***C_plot*** *(%)* | 112.55±18.59 | 134.2±19.98 | 125.99±23.11 | 106.17±15.09 |
| | ***C_ann*** *(%)* | 24.6±28.46 | 14.53±8.83 | 22.02±18.78 | 43.61±28.01 |
| | ***C_per*** *(%)* | 87.95±28.46 | 119.67±22.35 | 103.97±34.24 | 62.56±33.4 |
| | ***C_gram*** *(%)* | 55.99±24.35 | 72.15±26.89 | 48.89±22.35 | 63.97±26.37 |
| | ***C_ngram*** *(%)* | 56.57±25.81 | 62.04±31.43 | 77.1±12.71 | 42.2±31.94 |
| | ***C_nat*** *(%)* | 109.75±19.01 | 130.98±19.61 | 121.15±24.84 | 97.38±22.56 |
| | ***C_ali*** *(%)* | 2.81±5.1 | 3.22±5.41 | 4.84±3.06 | 8.79±12.4 |

# Annex 9

*Table A17.1: Output of ISA of Group 1.*

| Common species Group 1 | stat | p.value | Species type (Tasinazzo, 2014) |
|---|---|---|---|
| *Taraxacum officinale* | 0.376 | 0.041 * | Synanthropic species |
| *Dactylis glomerata* | 0.372 | 0.042 * | Synanthropic species |
| *Festuca rubra* | 0.340 | 0.088 . | Hay meadow species |

****** p-value <0.001; ** p-value<0.01; * p-value < 0.05***

*Table A17.2: Output of ISA of Group 2.*

| Common species Group 2 | stat | p.value | Species type (Tasinazzo, 2014) |
|---|---|---|---|
| *Poa pratensis* | 0.748 | 0.001 *** | Hay meadow species |
| *Arrhenatherum elatius* | 0.536 | 0.004 ** | Hay meadow species |
| *Achillea roseoalba* | 0.514 | 0.004 ** | Hay meadow species |
| *Centaurea nigrescens* | 0.464 | 0.011 * | Hay meadow species |
| *Convolvulus arvensis* | 0.371 | 0.071 . | Synanthropic species |
| *Anthoxanthum odoratum* | 0.350 | 0.095 . | Hay meadow species |
| *Vicia sativa* | 0.339 | 0.095 . | Synanthropic species |
| *Carex hirta* | 0.327 | 0.077 . | Hay meadow species |
| *Plantago lanceolata* | 0.658 | 0.001 *** | Hay meadow species |

****** p-value <0.001; ** p-value<0.01; * p-value < 0.05***

*Table A17.3: Output of ISA of Group 3.*

| Common species Group 3 | stat | p.value | Species type (Tasinazzo, 2014) |
|---|---|---|---|
| *Erigeron annuus* | 0.652 | 0.001 *** | Synanthropic species |
| *Trifolium pratense* | 0.597 | 0.001 *** | Hay meadow species |
| *Sonchus asper* | 0.521 | 0.004 ** | Synanthropic species |
| *Festuca pratensis* | 0.423 | 0.019 * | Hay meadow species |
| *Hypericum perforatum* | 0.385 | 0.040 * | Synanthropic species |
| *Plantago lanceolata* | 0.658 | 0.001 *** | Hay meadow species |
| *Sorghum halepense* | 0.467 | 0.022 * | Synanthropic species |
| *Bromus madritensis* | 0.436 | 0.026 * | Synanthropic species |
| *Cardamine hirsuta* | 0.373 | 0.053 . | Synanthropic species |

****** p-value <0.001; ** p-value<0.01; * p-value < 0.05***

*Table A17.4: Output of ISA of Group 4.*

| **Common species Group 4** | **stat** | **p.value** | **Species type (Tasinazzo, 2014)** |
|---|---|---|---|
| *Arenaria serpyllifolia* | 0.606 | 0.001 *** | Dry meadow species |
| *Trifolium campestre* | 0.593 | 0.002 ** | Dry meadow species |
| *Medicago minima* | 0.563 | 0.005 ** | Dry meadow species |
| *Cynodon dactylon* | 0.550 | 0.001 *** | Synanthropic species |
| *Vulpia myuros* | 0.518 | 0.003 ** | Dry meadow species |
| *Aphanes arvensis* L. | 0.507 | 0.004 ** | Synanthropic species |
| *Oxalis dillenii* Jacq. | 0.429 | 0.020 * | Synanthropic species |
| *Verbascum densiflorum* Bertol. | 0.426 | 0.018 * | Synanthropic species |
| *Festuca rupicola* Heuffel | 0.403 | 0.053 . | Dry meadow species |
| *Vicia hirsuta* (L.) Gray | 0.391 | 0.048 * | Synanthropic species |
| *Sporobolus indicus* | 0.391 | 0.014 * | Synanthropic species |
| *Galium aparine* L. | 0.373 | 0.038 * | Synanthropic species |
| *Sorghum halepense* | 0.467 | 0.022 * | Synanthropic species |
| *Bromus madritensis* | 0.436 | 0.026 * | Synanthropic species |
| *Cardamine hirsuta* | 0.373 | 0.053 . | Synanthropic species |

****** p-value <0.001; ** p-value<0.01; * p-value < 0.05***

## Annex 10

*Table A18.1: Output models of the best model selection procedure.*

| Ranking | AIC | Predictors | Estimate | Std. Error | t value | p-value |
|---|---|---|---|---|---|---|
| **1** | 131.3843 | **AREA** | 0.506169 | 0.189121 | 2.676 | 0.0103 * |
| | | **ECON** | -0.017873 | 0.003917 | -4.563 | 3.88e-05 *** |
| **2** | 136.4747 | **ECON** | -0.023231 | 0.003585 | -6.479 | 5.52e-08 *** |
| **3** | 147.6358 | **AREA** | 0.9472 | 0.1944 | 4.871 | 1.35e-05 *** |

*** p-value <0.001; ** p-value<0.01; * p-value < 0.05

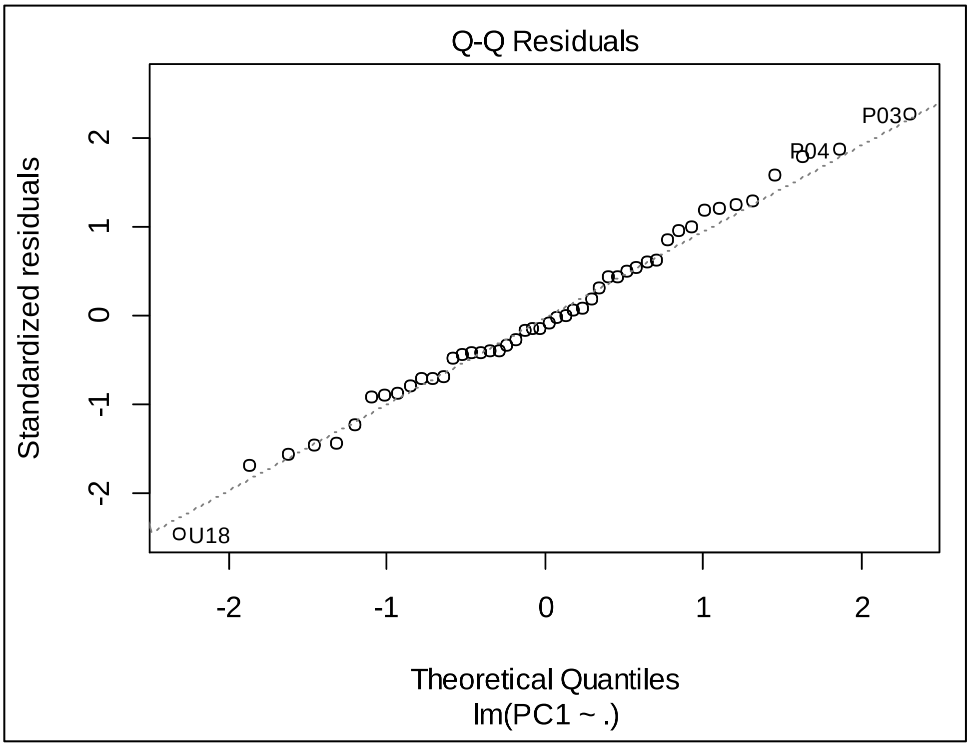

*Figure A18.1: Normality assumptions on residuals distributions.*

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