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Integrating ecosystem services performance into urban planning tools: the case of Varese city (Italy)

Prestazioni ecosistemiche integrate negli strumenti di pianificazione urbana: il caso della città di Varese (Italia)

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ABSTRACT AND KEYWORDS

Integrating ecosystem services performance into urban planning tools
In recent years, Ecosystem Services (ES) mapping and assessment have become essential for supporting the design of multisystemic Green Infrastructures (GI) integrated into urban planning tools and processes.
The present research introduces some relevant analysis and first results dedicated to recognising and assessing natural capital and ES provisions as a precondition to improve Varese's climate adaptive capacity through an urban planning resilient perspective.
The spatialization and interpretation of ES values data allow for the combination of climate proof strategies and regulatory urban planning instruments. The definition of an 'ES oriented' zoning, characterised by clustering homogeneous biophysical performance, establishes a site-specific advanced scientific groundwork able to define 'tailor-made' interventions for preserving, enhancing and improving the ES delivery capacities.

Keywords: ecosystem service, urban planning tools, climate adaptation, vulnerability, resilience

Prestazioni ecosistemiche integrate negli strumenti di pianificazione urbana
Recentemente la mappatura e la valutazione dei Servizi Ecosistemici (SE) sono diventate essenziali per supportare i progetti di Infrastrutture Verdi (GI) multisistemiche integrate negli strumenti e nei processi di pianificazione urbana.
La presente ricerca propone alcune analisi rilevanti e i primi risultati dedicati alla ricognizione e alla valutazione del capitale naturale e la dotazione di SE come precondizione per migliore la capacità climatica adattiva della città di Varese attraverso una prospettiva di pianificazione urbana resiliente.
La spazializzazione e l'interpretazione dei valori ecosistemici consentono la declinazione di strategie climatiche efficaci all'interno degli strumenti regolativi di pianificazione urbana.
La definizione di uno "zoning" ecosistemico, caratterizzato dall'aggregazione di prestazioni biofisiche territorialmente omogenee, fornisce un quadro conoscitivo scientifico sito-specifico in grado di attivare interventi "tailor-made" al fine di preservare, rafforzare e migliorare le capacità dei servizi ecosistemici.

Parole chiave: servizi ecosistemici, strumenti di pianificazione urbana, adattamento climatico, vulnerabilità, resilienza

1. Introduction

Over the past few decades, the global trend of urbanization has accelerated rapidly with more than half of the world's population now living in urban areas. This figure is expected to continue rising, with cities in developing regions projected to absorb 95% of the urban growth (Brenner & Schmid, 2015; United Nations Human Settlements Programme - UN Habitat, 2022).

Urbanization and its associated environmental impacts are one of the major drivers of urban climate change, considering that the land use/land cover changes alter the local land surface and, as a consequence, the surface climate in urban areas (Ernstson et al., 2010; Holden et al., 2014; Marraccini et al., 2015; Ren, 2015). Climate change is highly attributed to anthropogenic activities connected to the increasing concentration of the population in urban areas (Mersin et al., 2022; Pelling & Manuel-navarrete, 2011a).

Cities are increasingly exposed to climate risks, including heatwaves, flooding, biodiversity loss and air quality decline (Fuchs et al., 2019; Maggiotto et al., 2021). As urbanization intensifies and climate change accelerates, urban areas face complex environmental and socio-economic challenges. These escalating trends - urbanization, population growth, and climate change - not only exacerbate existing urban challenges but also introduce new obstacles to achieving sustainability and resilience (Khazai et al., 2015; Leichenko, 2011). Urban challenges are defined as "all factors that limit the capacity of urban areas to protect and conserve the environment, minimize environmental impacts and enhance resource-efficiency, human health, social inclusiveness and equality, as well as harness the productivity of local economies and value-added activities" (Babí Almenar et al., 2021). At the same time, cities, as the spatial concentration of assets, people and economic activities, are responsible for 70 percent of global Greenhouse Gases (GHG) emissions (Butt et al., 2017; Miranda et al., 2015). Therefore, cities are a major cause of climate change and the most vulnerable to its impacts, making them the critical focus for developing and implementing adaptive and mitigating strategies to address urban challenges.

In this context, cities are key players in climate change adaptation and mitigation for several reasons (Newman, 2020; Reckien et al., 2018). Among the many, climate change impacts cities with more frequent extreme events (stormwater, heatwaves, sea level rise, and food and water insecurity), making them the foremost contexts that must develop and implement adaptive strategies to address and mitigate these challenges effectively (Larsen, 2015; van Vuuren et al., 2011).

Strategies and interventions to cope with climate change can either mitigate its effects or adapt to them. Mitigation includes actions for reducing emissions or enhancing sinks for carbon sequestration while adaptation seeks to adjust natural or human systems to reduce harm or take advantage of beneficial opportunities arising from climate variations (Donati et al., 2022; Locatelli, 2018).

These strategies have different priorities, locations, spatial and temporal scales and stakeholders involved, therefore, their adoption requires a comprehensive understanding of the local performances and vulnerabilities of a specific urban area, including environmental, social, and economic conditions (Meerow & Newell, 2016). In recent years, strategies and solutions for tackling climate change that incorporate ecosystem services (ES) and, consequently, natural capital (Vardon et al., 2020), green infrastructure (Grabowski et al., 2022), and nature-based solutions (Dorst et al., 2019) have gained considerable attention among policymakers and planners (Hansen & Pauleit, 2014; Herreros-Cantis & McPhearson, 2021).

The link between climate change and ES is widely acknowledged by outlining ES as a relevant component in addressing climate change (N. D. Crossman et al., 2009; McPhearson et al., 2022). In urban areas, ES play a crucial role by providing essential functions such as air and water purification, climate regulation, water cycle management and biodiversity enhancement (Maes et al., 2012). Despite that, ES are strongly threatened by the rapid change of climatic conditions in temperature, precipitation and climate related disturbances (e.g., flooding, drought and wildfire) in association with other sources of threats (e.g., urbanization, overexploitation of resources).

Vulnerability and risk assessment can determine the extent to which an ecosystem is threatened by climate change and natural hazards, offering valuable insights for enhancing the provision and management of ES (Ahern et al., 2014). These assessments provide joint benefits for both mitigation and adaptation, becoming a valuable tool also for planning practices, as well as quantifying ES has become the basis of ecosystem management and decision-making processes (Cortinovis & Geneletti, 2018; Crossman et al., 2013; Zulian et al., 2018). However, even though the assessment of the ecosystem is time-consuming (as it requires a lot of inputs for modelling) the creation of maps and their usage to support urban planning remain a key aspect.

The adoption and integration of these concepts for planning purposes have often been recently supported through Green and Blue Infrastructure (GBI), as a strategically planned network of natural and semi-natural areas with additional environmental features to provide multiple ES (Andersson et al., 2019; Demuzere et al., 2014). For the challenges posed by climate change and ecosystem degradation, GBI, through Nature-based solutions (NBS), has the potential to address a variety of societal challenges in sustainable ways and provide additional co-benefits to urban areas (Elmqvist et al., 2019).

International Union for Conservation of Nature (IUCN) defines NBS as “action to protect, sustainably use, manage and restore natural or modified ecosystems, which addresses societal challenges, effectively and adaptively, providing human well-being and biodiversity benefits” (IUCN, 2020). Moreover, NBS implements an ES-based approach to spatial planning by ensuring the integration of ecological components through a GBI design and strategy (Pauleit et al., 2017; Peng et al., 2010a).

The location and design of NBS can significantly influence urban vulnerabilities, contributing to a range of impacts that modify risk profiles (Albert et al., 2019; Zölch et al., 2017). These solutions include interventions that employ nature or mimic natural processes to address urban challenges and improve, for example, air and water quality improvement, temperature regulation, biodiversity enhancement and aesthetic value enrichment.

While NBS are not the only solution for risk management, they are an essential component within a broader spectrum of strategies and actions that should be considered from an integrated risk management perspective (European Commission, 2016).

Integrating GBI and NBS in urban planning can support transforming existing urban areas into sustainable and resilient ones (Pelling & Manuel-navarrete, 2011b). However, to be effective, NBS should be prioritized where they can reach the maximum result in terms of lowering the vulnerability. Many papers demonstrated how NBS location is key for performance-based planning (Dorst et al., 2019). However, the first step to defining NBS location is to reach a composite assessment of the ecosystem delivery capacity of the site and its understanding through ecosystem characterization/zoning.

This paper wants to deal with this initial step, as it concentrates on the creation of site-specific knowledge of the multifunctional capacity of the city of Varese (Lombardy, Italy) to deliver ecosystem benefits.

Being a new urban plan under development, the case study is an occasion to integrate these considerations into a regulatory planning instrument.

The unique characteristics and processes that shape Varese's territory, combined with ongoing urban dynamics, create a novel field of study focused on addressing urban regeneration through a local Green-Blue Infrastructure (GBI) project as an urban planning strategy.

The research presents key analyses and initial results focused on recognizing natural capital and ES as prerequisites for triggering urban regeneration processes in public space design. The objective is to evaluate the capacity of Varese's territory to provide ES, identify areas most vulnerable to climate change impacts, and propose strategies to enhance ecosystem performance and territorial resilience.

The results of the analysis are essential support for assessing the performance of the areas in providing ES and defining, as a consequence, the best tailored-made NBS to enhance urban resilience and contrast ecosystem degradation.

The paper is structured as follows. Section Two presents the case study's peculiarity and the materials and methods used for ES assessment. Section Three illustrates the main findings. Section Four discusses planning integration, several critical aspects that emerged and some concluding remarks.

2. Materials and methods

2.1 Case study

The research has been developed within the formal commitment of the scientific support undertaken by the Department of Architecture and Urban Studies (DAStU) in the process of revising the Urban Plan (PGT) for the Municipality of Varese.

Varese is a medium-sized city located in the Lombardy region (Italy), northwest of the Milan metropolitan area, near the Swiss border, within a pre-Alpine geographical setting (Zulian et al., 2021) and close to Varese Lake. The environmental system forms a fundamental component of the municipal territory, serving as a critical element within the broader territorial framework. Varese is characterized by a diverse orographic landscape, shaped by the interplay of various environmental systems, with an extensive presence of green spaces, even in densely built areas.

The territory is organized into five primary components: the Olona River corridor, the broader hydrographic network, the lacustrine environments, forested areas, and the peri-urban agricultural system. These open spaces fulfil multiple ecological and environmental roles and are closely integrated with the built environment and its peripheral areas.

This environmental structure reveals a strong north-south axis, primarily defined by the Olona Valley, alongside weaker transverse connections such as the secondary hydrographic network and functional linkages between various urban environmental systems. Notably, the city's green urban fabric -often referred to as a "Garden city"- is organically connected to the north by Sacro Monte (UNESCO site) and to the southwest by a large green area extending toward the Lake area.

The water resources, represented by the hydrographic network and the Lake, constitute an invaluable connective-environmental subnetwork. This network links diverse territorial zones, including urban, peri-urban, rural, mountainous, and lacustrine areas. Within the municipal boundaries of Varese, the hydrographic system becomes a critical element for territorial connectivity, environmental characterization, and as a key resource for policies aimed at improving quality and safety.

Furthermore, the forest system (covering 58% of the municipal surface, authors' elaboration) is a vital resource from both environmental and ecological perspectives, demonstrating a high degree of integrity and conservation. It serves as a central functional and identity-defining component of both the urban and peri-urban landscape (Romano et al., 2017).

The agricultural sector (covering 22% of the municipal surface, authors' elaboration) includes areas of significant natural value with high environmental quality, as well as the peri-urban agricultural landscape, predominantly located in the southern part of the municipality. This system acts as a buffer between urban development and the lake area. However, it is fragmented and discontinuous due to dispersed urbanization, which has compromised its consistency and integrity. The built-up development has posed a significant threat to these lands. Despite this, certain areas retain a strong agricultural identity, characterised by traditional rural landscapes and historically or architecturally significant rural buildings and settlements.

Based on Varese's specific environmental conditions and open space characteristics, an ES mapping session was conducted to evaluate specific thematic domains useful to the measurement and assessment of environmental vulnerabilities and strengths of the territory. The assessment was performed using ancillary data in conjunction with spatial maps generated through GIS geoprocessing to estimate ecosystem performance across a territorial sample that includes both built and open spaces (natural, semi-natural and rural) within the municipality of Varese.

2.2 Methodology

Ecosystem Service mapping has been conducted with the support of InVEST software (Integrated Valuation of Ecosystem Services and Tradeoffs) (Tallis et al., 2011). The data processing concerning the composite analyses and clustering method was elaborated with GIS geoprocessing (ESRI ArcGIS Pro), enabling the visualization and interpretation of results (Peterson & Ver Hoef, 2014).

Specifically, this paper will focus on examining the results of four of these models: habitat quality, stormwater retention capacity, sediment retention and urban cooling.

During the modelling phase, we conducted preliminary research on the fundamental dataset we employed as the main source for the modelling phase. The data we downloaded were then processed to customize the input folder and obtain each modelling result:

- Copernicus (the European Union's Earth observation program, open source);
- ARPA Lombardia (Regional Agency for Environmental Protection of Lombardy, open source);
- ISPRA (Italian National Institute for Environmental Protection and Research, open source);
- Geoportale Lombardia (dataset collecting basic and sectoral information and data related to the Lombardia region, open source);
- Geoportale della Provincia di Varese (dataset collecting basic and sectoral information and data related to the Varese province, open source);
- Geoportale del Comune di Varese (dataset collecting basic and sectoral information and data related to the Varese municipality, open source).

2.2.1 ES mapping

Habitat Quality

The Habitat Quality model employs habitat quality and rarity as indicators to represent the biodiversity of a landscape. It assesses the extent of different habitat and vegetation types present across the landscape, as well as their level of degradation. The production of the model with InVEST software adhered to the methodology detailed in the article of (Salata, Ronchi, et al., 2017) aiming to identify areas of significant natural value that should be protected or restored.

Urban stormwater retention

The model calculates the volume of annual stormwater retention as the portion of rainfall that is not transpired or evapotranspired from the soil or aboveground vegetation. Special attention was given to this model due to the significant hydraulic vulnerabilities faced by the municipality of Varese, which are exacerbated by climate change. The methodology used closely aligns with the approach outlined in the paper of (Salata, 2023).

Sediment Retention

The Sediment Retention model evaluates a land parcel's capacity to retain sediment by using data on geomorphology, climate, vegetation cover, and management practices. The model operates in conjunction with the digital elevation model (DEM) to provide specific spatial resolution. It first calculates the annual soil loss for each pixel and then determines the Sediment Delivery Ratio (SDR), which represents the proportion of soil loss that eventually reaches the stream. The data and methodology for implementing the model adhered to the research outlined in the paper of (Salata, Garnero, et al., 2017).

Urban Cooling

The Urban Cooling model calculates a heat mitigation index by evaluating factors such as shade, evapotranspiration, albedo, and proximity to cooling islands. The methodology used to run the model follows the procedures described in the paper of (Ronchi et al., 2020).

2.2.2 ES assessment

Single ES maps were then grouped to meet the target of obtaining a real multifunctional ecosystem map that meets the need to check in every parcel of land what is the complex amalgamation of the different ecosystem delivery capacity. In fact, it is well recognized that the composite ecosystem delivery capacity can span from synergic to conflictual situations thus requiring multivariate analysis (Peng et al., 2010b; Ruiz et al., 2012).

The definition of the ecosystem services' composite representation required two main steps in the GIS environment: first of all, the normalisation process of the four indexes of interest (i.e. habitat quality, water retention, cooling capacity, and SDR) bringing them to standard values of 0-1. Subsequently, the rasters were summed up using the "raster calculator" ArcGis function, producing a new output with a range from 0 to 4. The lowest value would indicate a null rating for the four ecosystem services, while a value of 4 would indicate the maximum level for all the ES considered.

The third geoprocessing step consisted of clustering.

Clustering serves as a data analysis technique used to group similar objects or data

points into clusters or segments (Ronchi et al., 2021). Its objective is to partition a dataset into subsets, ensuring that objects within each subset exhibit greater similarity to one another compared to those in other subsets. The classification is attribute-based rather than spatially based, operating through the k-means algorithm. The algorithm iteratively adjusts the classification of observations into clusters and updates the positions of cluster centroids until these centroids stabilize across consecutive iterations (Kwon et al., 2021). This method finds applications across various domains, including machine learning, data mining, pattern recognition, image analysis, and customer segmentation (van Griensven et al., 2006). We employed the clustering method to help the process of interpretation/understanding of the composite values. We aimed to identify what are the land parcels that behave similarly in terms of composite ecosystem delivery capacity (Alam et al., 2016). This, in turn, was used to design an ecosystemic zoning of the city.
The input data presented earlier had to be modified to meet clustering method's requirement and to provide enough flexibility for the Ecosystem zoning. Clustering is fed by vector data thus we converted our composite raster layer into polygons. The individual ecosystem maps were spatialized within the current urban fabric and open spaces' zoning using the "Zonal Statistics" tool. This process assigned an average value for all four ES to each regulated polygon within the plan. While this step inevitably simplifies some information in larger polygons, it supports a cross-view analysis between the biophysical soil performances and the regulatory framework, which is essential for defining the subsequent steps.

Process Settings

- Attribute Clustering: 4 ES average values (classified into the PGT zoning)
- Clustering Method: K-means
- Number of Classes: 8 (after several trials, this number best covered the municipality's diverse characteristics)
- Number of Iterations for K-means: 20
- Threshold: 0.00001

Once the result was obtained, following multiple attempts with various parameter settings, the model was manually adjusted to homogenize the classes. Minor clusters with insignificant surface areas were merged with adjacent major groups to create a more coherent and understandable framework.

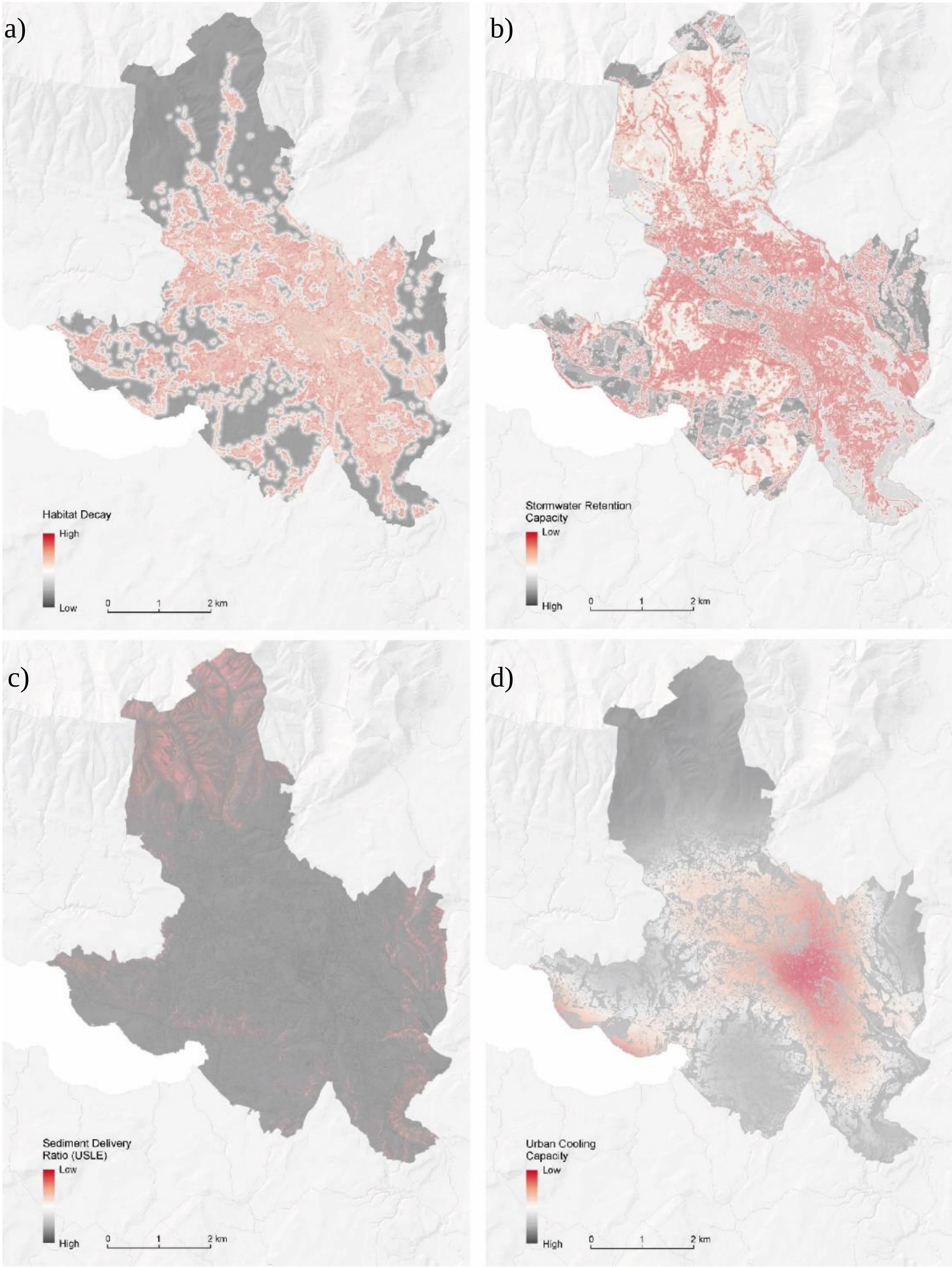
3. Results

3.1 Composite ES capacity

The assessment of the four ES models highlights the crucial aspects of the territory's ecosystem delivery capacities which define the research project. These are instrumental in establishing an advanced scientific groundwork, laying the foundation for a comprehensive understanding of the vulnerabilities and strengths of Varese Municipality. ES mappings (figure 1) show the significant natural capital of the municipal area. Despite the dense and compact urban center, which exhibits low performance across all four indicators, the urban core demonstrates satisfactory values for delivery capacity, particularly in terms of habitat quality and associated cooling capacity. This is due to the high presence of urban green spaces that characterize the "garden city". Conversely, Sediment retention capacity is notably high, especially in areas prone to erosion, such as steep slopes, areas traversed by the hydrographic system, and regions with intensive agricultural activity. Stormwater retention model confirms a low capacity to retain and drain water: 75%

of potential rainfall (based on the annual average) fails to infiltrate the subsoil, resulting in surface runoff phenomena. Hydraulic vulnerability stems from several intrinsic territory features, including its hilly-mountainous morphology and their hydrological soil properties.

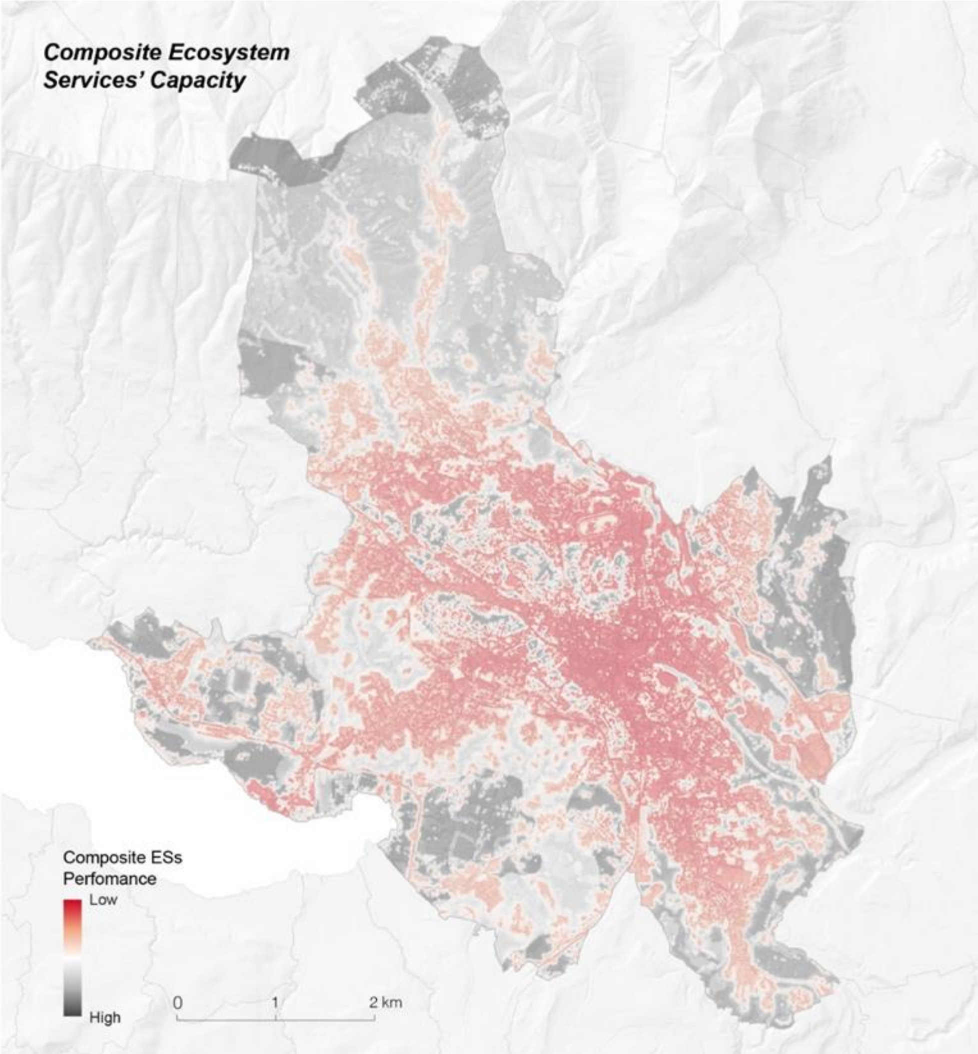
Figure 1. a) Habitat Quality (decay values), b) Urban Stormwater Retention, c) Sediment Retention, d) Urban Cooling



Source: authors' elaboration

At this stage, a cross-reading and organic approach proves useful and necessary for defining a spatialization of the multisystemic values. Understanding the relationships between the different delivery capacities helps to identify, when possible, both positive and negative synergies driven by multiple factors (Burkhard et al., 2013), which are useful in defining targeted actions and objectives aimed at their mitigation or conservation. The composite ecosystem services' output, given by the four ES' overlay ranges from 1.6 to 3.8.

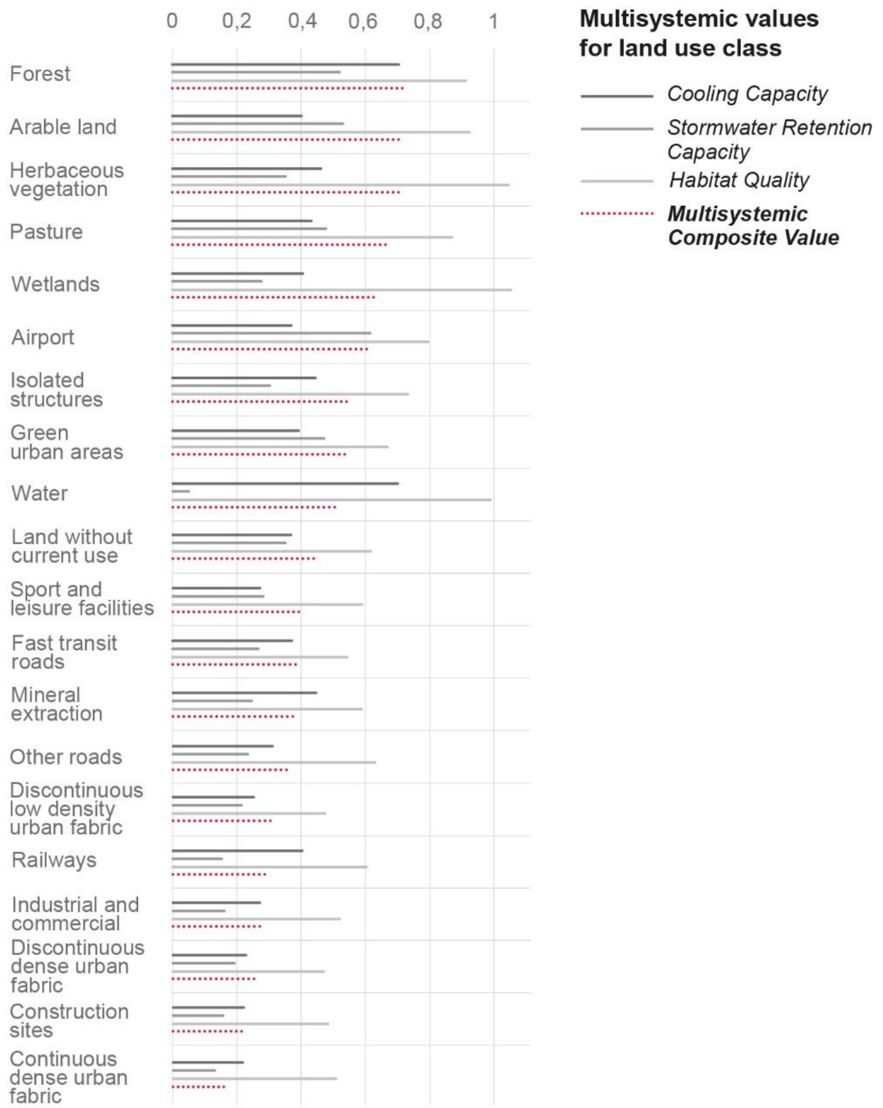
Figure 2. Composite Ecosystem Services' Capacity



Source: authors' elaboration

Lower values are mainly associated with the presence of densely built anthropogenic elements, while higher values are found in protected natural areas in the northern, eastern, and western parts of the municipality. The simultaneous coexistence of high naturalistic environmental characteristics, combined with good urban drainage capacity, erosion control, and temperature mitigation, characterizes areas with high ecosystem multifunctionality, primarily located in natural areas placed at the northern, eastern, and western edges of the municipal area. Conversely, the lowest composite multisystemic values correspond to densely urbanized surfaces, where local characteristics scarcely allow for significant green spaces, stormwater retention, and cooling capacity. The red colour is more intense where the urban area is denser and more compact, and as the mass of the buildings becomes less dense leaving space for open gardens, the composite value increases. However, the correlation between natural areas and high multisystemic capacity is not always proven. A specific case concerns the light grey areas located on the northern and western sides of the urban centre. Despite being predominantly natural, these areas exhibit low stormwater retention values, which adversely affect the overall multisystemic value. The table below summarizes the ecosystem values analysed to date, excluding the avoided erosion value, which was omitted due to its sensitivity to the distribution of altimetric values across the polygons of the zoning, resulting in being flattened by the standardization. Since the values are very similar and close to 1, they appeared almost identical across all classes. The table is organized by descending composite scores, illustrating the shift from natural to anthropogenic environments. The class with the highest multisystem value is identified as forest, while the lowest is represented by dense and continuous urban fabric.

Figure 3. Multisystemic values for land use class



Source: authors' elaboration

3.2 *Clustering and Ecosystem Zoning*

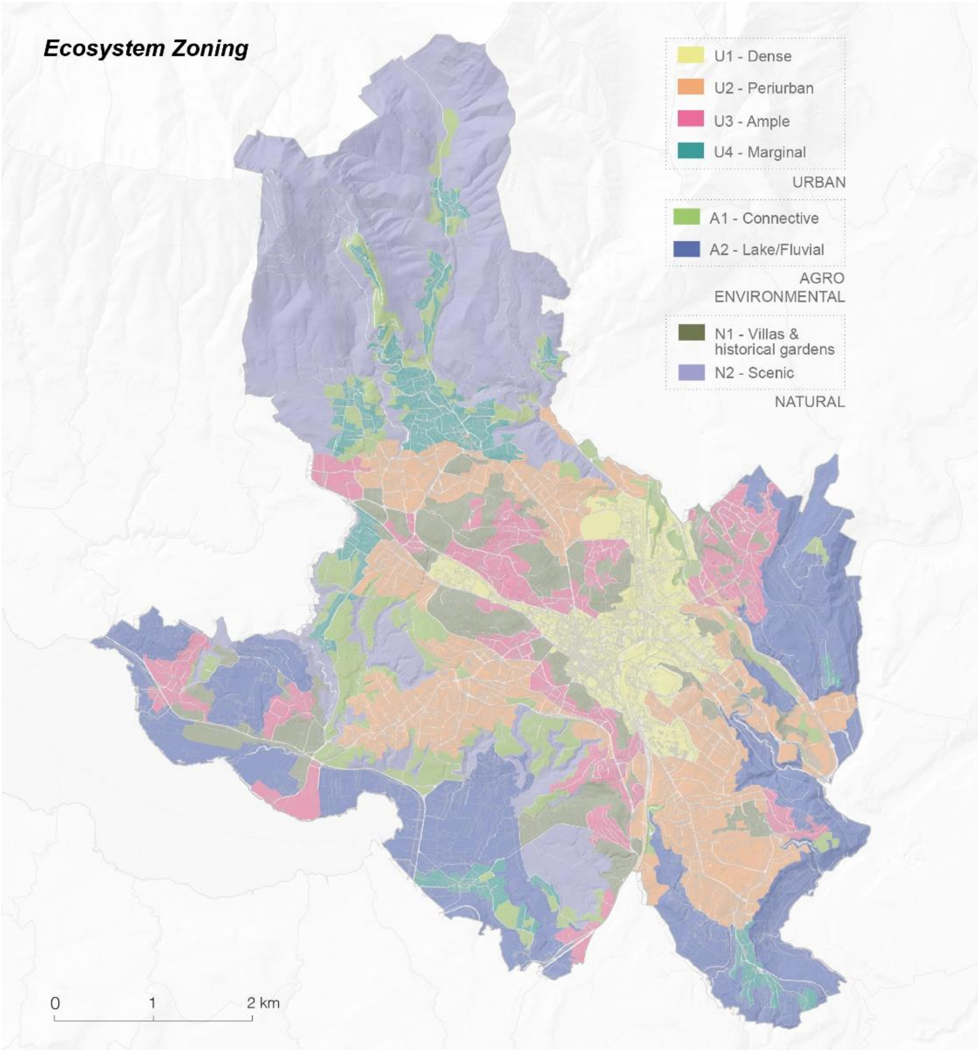
Ecosystem zoning represents the most innovative aspect of this research project, whose primary objective is to integrate climate adaptation within normative urban planning. While the literature does include the concept of a performance-based design approach using ES models (Asleson et al., 2009a; Geneletti et al., 2020; Kendig, 1980; Raymond et al., 2017), studies in this field rarely venture into a systematization of such interventions into regulatory plans. A tool capable of defining the exact location for mitigative or adaptive interventions that can help in strengthening or preventing actions that use the current multisystemic performance as valuable information to cope with climate change effects. The eight classes shape the territory from a new perspective, based on their multisystemic performances. As mentioned, each class is grouped according to similar biophysical values among the regulated polygons, thereby sharing common trends across the four ecosystem services. The interpretation and understanding of these ecosystemic classes is facilitated by dividing them into macro-typologies, which reflect the most representative systems of the territory: urban, agro-environmental and natural.

Figure 4. Ecosystem Zoning frameworks and classes

	URBAN	AGRO-ENVIRONMENTAL	NATURAL
Classes	U1 **Dense**	A1 **Connective**	N1 **Villas & historical gardens**
	U2 **Periurban**	A2 **Lake/Fluvial**	N2 **Scenic**
	U3 **Ample**		
	U4 **Marginal**		

Source: authors' elaboration

Figure 5. Ecosystem zoning



Source: authors' elaboration

The first urban framework consists of municipal areas primarily characterized by urbanized land, divided into four classes: Dense, Periurban, Ample, and Marginal. These classes correspond to different multisystemic performances, features and morphologies of the urban fabric. The classification is influenced by typical elements defining the urban environment as the built-up density, the presence of permeable materials, the quantity and quality of green areas, the sub-soil composition.

The *dense* class represents the historical core of the city, characterized by a highly compact nucleus with minimal vegetation or other permeable surfaces. As illustrated in the schematic diagram (Figure 5), this class is associated with the lowest multisystemic composite value. The class is primarily composed by public and residential land uses. The *peri-urban* class is characterized by a less dense and semi-compact settlement pattern situated at the periphery of the dense urban fabric. Its multisystemic performance is higher due to the reduced built-up footprint, which facilitates the presence of vegetation. This class is frequently adjacent to more natural classes, such as connective or recreational areas, which enhance the region by functioning as effective cooling islands. As depicted in Figure 5, the value associated with cooling capacity is increasing.

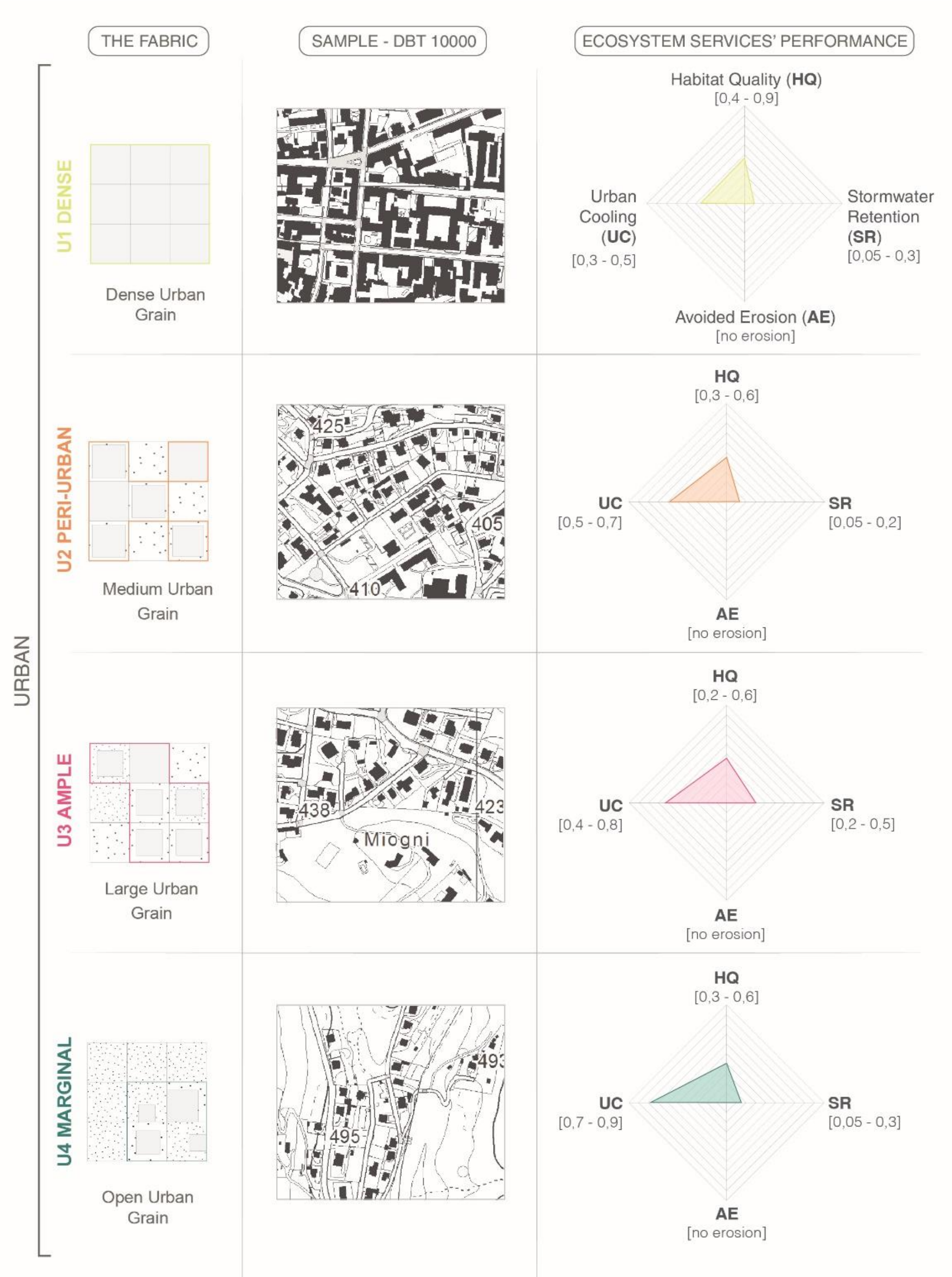
The *ample* class is particularly notable because, despite its proximity to the central nucleus, it demonstrates high multisystemic values that are atypical for an urban residential area. This class is consistently associated with the presence of the recreational class (following), which encompasses the system of villas and parks that characterised the municipality. Although situated in a central area, it holds extensive green spaces with high multisystemic quality, positively influencing the surrounding urbanized areas. This, combined with a leapfrogged settlement system that includes significative private green spaces, characterize the class with notable cooling capacity, water retention, and habitat quality.

The *marginal* class exhibits the highest composite multisystemic value, as it is composed by a significative presence of natural environment compared to urbanized areas. It represents the peripheral residual fabric typical of hamlets, situated at the edges of major routes leading to plains or mountains. Its value is enhanced by its advantageous location, often integrated with natural classes. Nevertheless, rainwater retention remains low due to the characteristics of the subsoil and the presence of sparse urbanized surfaces.

The second macro typology of ecosystem zones is mainly composed of the agricultural system, which is characterized by high-quality soil and biotopes, due to sustainable agricultural practices and the strategic location of the municipality. The local hydrological system plays a crucial role by maintaining rich, moist soils that support both wild and cultivated riparian vegetation, thereby enhancing local biodiversity. Additionally, this framework plays as a buffer zone, bridging urbanized areas with more natural environments through a combination of agricultural land and natural hedgerows. The *connective* class extends between urban framework classes and the agricultural or natural ones. Biotopes, groves, and small to medium-sized rural areas characterize these regions, providing a natural protective buffer for inner natural areas. Despite the area's extensive woodland, its composite performance is suboptimal (see Figure 5b), negatively impacted by nearby urban areas and transportation infrastructure.

The *lake/river* class is defined by the major hydrological features of the municipality, namely Lake Varese to the west and the Olona River to the east. These areas are primarily used for natural conservation and agriculture, exhibiting the highest multisystemic performance. ES in this class benefit from the area's biodiversity richness, high water retention capacity due to the presence of Soil Hydrologic Groups A and B (Sandy/Loamy Sandy subsoil) (Asleson et al., 2009b; Seok et al., 2015), minimal urbanization, and excellent soil nutrient retention capacity.

Figure 6a. Ecosystem Zoning: classes

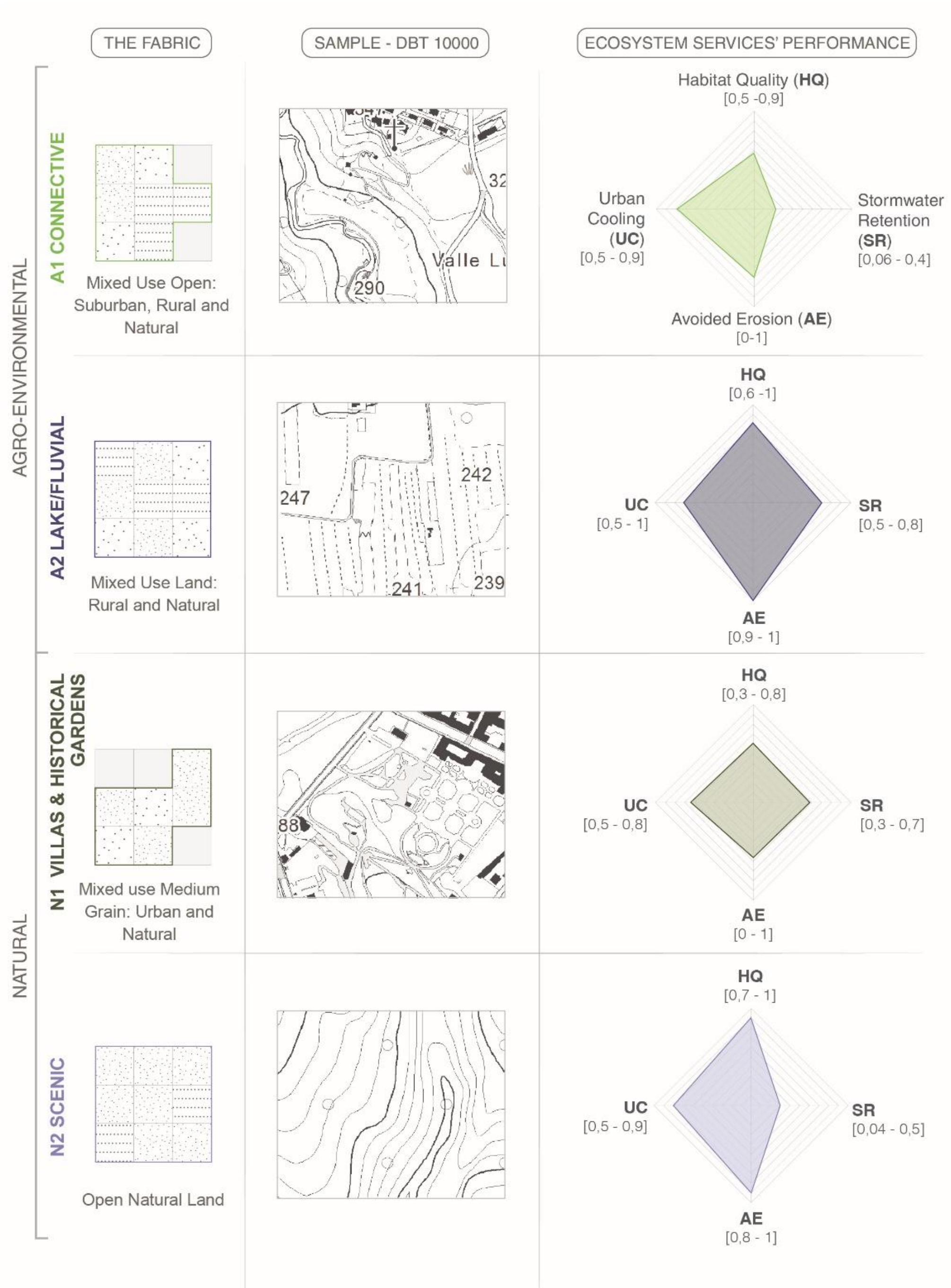


Source: authors' elaboration

The final framework defines the municipality as a "garden city", where the surrounding natural environment positively influences the municipality's overall high habitat quality. Key elements shaping this framework include the Sacro Monte in the northern region, encompassing the "Campo dei Fiori" Regional Park, the natural hedgerows and wooded areas typical of the fluvial and lacustrine environments on the southern, eastern, and western sides, and the system of parks and villas scattered throughout urban and periurban areas.

The *villas and historical gardens* class plays a crucial role in enhancing the environmental and cultural values of Varese. The historic system of parks and villas, covering extensive areas within the urban and suburban cores, owns significant multisystemic value, characterized by high levels of naturalness and minimal urbanization. Despite their large size and proximity to the dense urban fabric, these areas remained largely undeveloped, preserving their high environmental quality and functioning as cooling hotspots for the central urban areas.

Figure 6b. The Ecosystem Zoning: classes



Source: authors' elaboration

The final class is called *scenic*, as it is primarily located in the mountainous region to the north of the municipality, overlooking the valley. This class exhibits very high multisystemic value across most aspects, except for rainwater retention capacity, as the soil is classified as hydrological group D (Clay loam, silty clay, loam subsoils), with low infiltration potential. The area is predominantly forested, contributing to high values of cooling capacity and habitat quality. Human activity in this region is minimal, and being part of the Campo dei Fiori Regional Park, the area is highly protected and preserved.

4. Discussion and conclusions

As previously outlined, the development of an ecosystem-based zoning approach, i.e., a classification of the municipal territory that considers the homogeneous characteristics related to the four ecosystem models presented in the analysis, represents the most innovative aspect of the research. It also serves as a methodological framework for integrating the mapping and evaluation of ecosystem services into planning tools. Specifically, given the inherent environmental features of the city of Varese, the results suggest the definition of zoning that, from a resilience perspective, could be embedded within a regulatory planning framework.
Through this methodology, the traditional classification of urban fabrics, agricultural areas, and forested regions is enhanced by incorporating the ecosystem performance of these areas, particularly with respect to the four site-specific models considered. Classifying the municipal territory and its components in this way not only provides a more ecologically informed understanding of the area, but also facilitates the creation of regulatory frameworks that suggest actions and interventions to promote the use of nature-based solutions (NBS) tailored to each ecosystem class.
The strengths and challenges related to habitat quality, stormwater retention, sediment retention, and cooling capacity are specific to each ecosystem class, as are the potential actions that could be recommended within the regulatory framework. The results demonstrate how an ES-based approach allows the construction of a tailor-made and site-specific knowledge framework useful to define a GI strategy and to activate a multicentric network of interventions for improving ES through a precise definition of the kind, typology and size of actions.

Author Contributions
The paper is the result of the joint research of the authors; specifically: Conceptualization (Andrea Arcidiacono, Laura Pogliani, Silvia Ronchi, Stefano Salata); Methodology (Federico Ghirardelli, Beatrice Mosso); Data Curation (Federico Ghirardelli, Beatrice Mosso) ; Writing – Original Draft, Review & Editing (Federico Ghirardelli, Beatrice Mosso, Silvia Ronchi, Stefano Salata); Visualization (Beatrice Mosso); Supervision and Project Administration (Andrea Arcidiacono, Laura Pogliani).

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Conflicts of Interest
The authors declare no conflict of interest.

Originality
The authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere, in English or any other language. The manuscript has been read and approved by all named authors and there are no other persons who satisfied the criteria for authorship but are not listed. The authors also declare to have obtained the permission to reproduce in this manuscript any text, illustrations, charts, tables, photographs, or other material from previously published sources (journals, books, websites, etc).

Use of generative AI and AI-assisted technologies
The authors declare that they did not use AI and AI-assisted technologies in the writing of the manuscript; this declaration only refers to the writing process, and not to the use of AI tools to analyse and draw insights from data as part of the research process. They also did not use AI or AI-assisted tools to create or alter images and this may include enhancing, obscuring, moving, removing, or introducing a specific feature within an image or figure, or eliminating any information present in the original.

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