Project of local ecological network

Case study: Green & Blue Multifunctional Infrastructure for the Sondrio Province

Interreg Co-funded by the European Union

Alpine Space

PlanToConnect

Mapping report identifying the GBI elements, barriers, connectivity measures in pilot areas

Activity 2.3 Case Studies 2nd step: To design a GBI network for connectivity across administrative boundaries or transnational cross-border areas in pilot sites

Reference in AF: D.2.3.1

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GLOSSARY

“Connectivity” (structural and functional)
“Connectivity comprises two components, structural and functional connectivity. It expresses how landscapes are configurated, allowing species to move. Structural connectivity, equal to habitat continuity, is measured by analysing landscape structure, independent of any attributes of organisms. […]. Functional connectivity is the response of the organism to the landscape elements other than its habitats (i.e. the non-habitat matrix). This definition is often used in the context of landscape ecology. A high degree of connectivity is generally linked to low fragmentation.” (EUROPEAN COMMISSION - Technical information on Green Infrastructure (GI), 6.5.2013, Glossary)
(Definition of connectivity see also Deliverable 1.1.1, chapter 8)

“GBI – Green and blue infrastructure”
“Green infrastructure (GI) is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings.”
(EUROPEAN COMMISSION - Green Infrastructure (GI) — Enhancing Europe’s Natural Capital, 6.5.2013)
(Definition of connectivity see also Deliverable 1.1.1, chapter 6)

“Composite multisystemic mapping”
Composite multisystemic mapping refers to the integrated value derived from the overlap of multiple ecological layers within a specific area. This approach synthesizes various ecosystem characteristics, each represented by distinct layers, to produce a comprehensive mapping of the overall capabilities of the area under multiple ecological perspectives. The resultant composite value reflects the cumulative contributions of individual layers, providing insights into the multifunctionality of the landscape.

“Hot spot analyses”

The analyses is a statistical technique used in spatial data analysis to identify areas with a significantly high or low concentration of values or events, often referred to as “hot spots” and “cold spots.” The results of the analysis are then visualized on a map, highlighting areas of high and low concentration. This visualization helps to easily identify patterns and trends within the data.

EXECUTIVE SUMMARY

The multifunctional green and blue infrastructure project has chosen the provincial territory of Sondrio as its pilot region.
The project's goal, coherent with the strategic objectives of the Provincial Territorial Coordination Plan (PTCP), includes the restoration of terrestrial ecosystems, the conservation and enhancement of ecological and ecosystem values, and the development of a green and blue network capable of ensuring ecological-functional connectivity at both local and supra-local scales as well as it multifunctional value.

The methodology adopted seeks to synthesize and leverage two approaches: the study and assessment of local ecosystem services and the analysis of ecological connectivity. Beginning with the assessment of various ecosystem services, including regulatory, provisioning, and cultural services, the project aims to create a comprehensive knowledge base of the current capacity of the provincial soils. This knowledge is ultimately interpreted as a mapping of the most significant multi-systemic values. In parallel, a thorough analysis is conducted on areas of naturalistic importance (protected reserves, habitats, national and regional parks), the regional and provincial ecological network, and the SACA framework of the Alpine Wide Structural Connectivity Model developed by Eurac.

Following this, the two data layers are compared and overlaid to define the framework of the multifunctional infrastructure. This step reveals three distinct characterizations of the territory impacted by the mapping: conservation, multifunctionality, and connectivity. Though still in a preliminary phase, this process has resulted in five macro-classes that define the different functions of the network within the provincial territory.
Emphasizing the multifunctional nature of the project, this categorization is enriched by the overlay of multifunctional elements selected for the project. The next phase will focus on defining strategies and actions for each macro-category, with special attention given to the project area between Morbegno and Tirana.

REPORT

1 Introduction

Biological diversity, as defined by the Rio de Janeiro Convention of 1992, refers to the variety of living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems, as well as the ecological complexes of which they are a part. This definition encompasses diversity within species, between species, and across ecosystems. Mountain areas, as declared by the Alpine Convention, play a key role in the conservation of global biodiversity (Alpine Convention, 1991). However, mountain ecosystems are significantly exposed to the effects of climate change, land use changes, and natural hazards that lead to soil and habitat degradation, as well as significant losses in species diversity and distribution. For sustainable development, the preservation of Alpine ecosystems is crucial and must be pursued through the protection of mountain biodiversity and ecological connectivity (Alpine Convention, 2020).
In the context of Lombardy, a territory of approximately 23,860 km² that includes a variety of landscapes ranging from plains, hills, and mountains, biological diversity is particularly rich. Its environments vary from the glaciers and coniferous forests of the Alps to alpine meadows, large pre-alpine lakes, lowland forests, fluvial environments, and spring zones, as well as the Apennine environments in the Oltrepò Pavese. The Lombardy region, and particularly the Province of Sondrio, play a significant role in the conservation of this rich biodiversity, as they serve as vital transition zones for connectivity with European and alpine ecosystems.
However, according to the latest report by the European Environment Agency, based on monitoring and surveys conducted between 2013-2018, the status of habitats in Lombardy presents a critical picture. Only 15% of the habitats assessed are in good conservation status, while 81% are classified as poor or bad at the EU level. Habitats such as grasslands, dunes, marshes, and lowland bogs show a worsening trend, while forests show signs of improvement. The overall trend is also negative, as compared to the previous period, the percentage of habitats in bad conservation status has increased by 6%. On an international and community level, biodiversity is considered a cross-cutting issue, with restoration and conservation objectives being a responsibility shared by all public and private stakeholders. It is therefore evident that the issue of safeguarding and promoting biodiversity represents a priority at various levels and in different sectors, as envisaged by the strategic objectives identified at regional, national, and community levels for the construction of a coherent and comprehensive network aimed at safeguarding habitats and ecosystems.
Method

The pilot project developed for the Province of Sondrio will specifically focus on the area between Morbegno and Tirano, within a broader context that considers the entire provincial territory. The project is structured around an analysis of the ecosystem performance of the provincial area, particularly the current degree of ecological connectivity and the fragmentation of ecological corridors. The objective is to select priority areas for the protection and enhancement of soils with high multisystemic capacity and to define a strategic design for a multifunctional green network integrated with the broader transalpine ecological connectivity network. The identification of key anthropogenic threats to connectivity functions and biodiversity will guide the definition of the main challenges that the multifunctional green and blue infrastructure will need to address.

The multifunctional nature of the green and blue infrastructure model to be developed is a fundamental aspect of the pilot project, with the aim of incorporating social, biotic, abiotic, and cultural aspects into the functions of the ecological network, thereby supporting the sustainable development of environmental and landscape use activities within the network. The design of the green network is supported by a knowledge base that, through the preparation of maps for assessing the ecosystem performance of the territory, explores a variety of themes such as biodiversity, soil erosion conditions, hydraulic risk, agricultural soil yield and quality, and the distribution of cultural and recreational services. The overlay and integrated analysis of these data will produce a multisystemic reading of the territory, with the aim of highlighting the different vulnerabilities and valuable elements of the provincial area. These elements will define the structure of the multifunctional network design, which will aim to maintain and strengthen existing connections and nodes, and to rehabilitate degraded areas, primarily through the application of Nature-Based Solutions (NBS) and Sustainable Urban Drainage Systems (SUDS) (CIRIA, 2015).

Figure 1: Methodological Framework for the Definition of the Multifunctional Green and Blue Network (Developed by LabPPTE, DAStU – Politecnico di Milano)

The principle of multiscalarity and governance across various levels of territorial management, achieved through the inclusion of different local stakeholders within the project, will support the design of the multifunctional green network. This network may prove valuable to local and supra-local authorities as a knowledge tool and strategic framework to support territorial planning processes at different scales.

Objectives

The primary planning reference for setting multifunctional connectivity objectives is the current Territorial Provincial Plan (PTCP, 2010), which already anticipates some themes of interest for the project and can be further detailed and updated by the PTCP amendment currently being initiated. The PTCP update will directly engage with the guidelines of the “Regional Strategy for Biodiversity” of the Lombardy Region (2022), which incorporates the directives of both European and national biodiversity strategies.

Given the natural richness and landscape values characterizing the area, the current PTCP establishes several priority guidelines for the territory, with objectives that include the restoration of terrestrial ecosystems, the conservation and enhancement of ecological and ecosystem values, and the implementation of a green and blue network capable of ensuring ecological-functional connectivity at both local and supra-local scales.

The overarching goal of conserving, protecting, and strengthening the “overall environmental quality” of the territory lays the foundation for the balanced socio-economic development of the province. This general objective is further broken down into eight macro-actions, among which the following are particularly significant for the project: i) the enhancement of widespread landscape and environmental features; ii) the importance of rationalizing the use of natural resources such as soil and water; iii) territorial rehabilitation aimed at addressing major existing landscape issues.

Specifically, the current PTCP directs municipal planning towards reducing practices that contribute to ecological fragmentation, such as the disintegration of urban and peri-urban fringes and the formation of conurbations.

The multifunctional green and blue infrastructure project undertaken by our research group aims to align with current and future provincial planning strategies, supporting the decision-making process. The objective is to conserve the significant environmental and ecosystem quality by introducing the concept of multifunctionality. A multifunctional network will be capable of preserving and enhancing natural and ecological value while simultaneously integrating concepts of accessibility and public use. This network encompasses not only the system of natural landscapes but also pedestrian and cycling routes, the network of historical assets, and agricultural fabric.

The project will initially encompass the entire provincial territory, subsequently focusing on the area of interest between Morbegno and Tirano. This region is characterized by areas of high natural, ecosystemic, and multifunctional importance, yet it is bisected by the primary urbanization corridor in the valley floor. This division severely challenges the ecological connectivity between the two slopes, compromising their overall ecological value. The previously stated objectives become even more significant when we focus on this specific area, emphasizing the need to reconnect the two slopes through the multifunctional infrastructure project while simultaneously preserving the existing natural heritage.

Barriers

One of the primary threats to ecological connectivity is the progressive degradation of soil, along with its functions and associated ecosystem services. The increasing anthropization and soil sealing exacerbate flood risks, contribute to climate warming, threaten biodiversity, and lead to the gradual loss of rural and natural landscapes ("Land Consumption, Territorial Dynamics, and Ecosystem Services," ISPRA 2016).

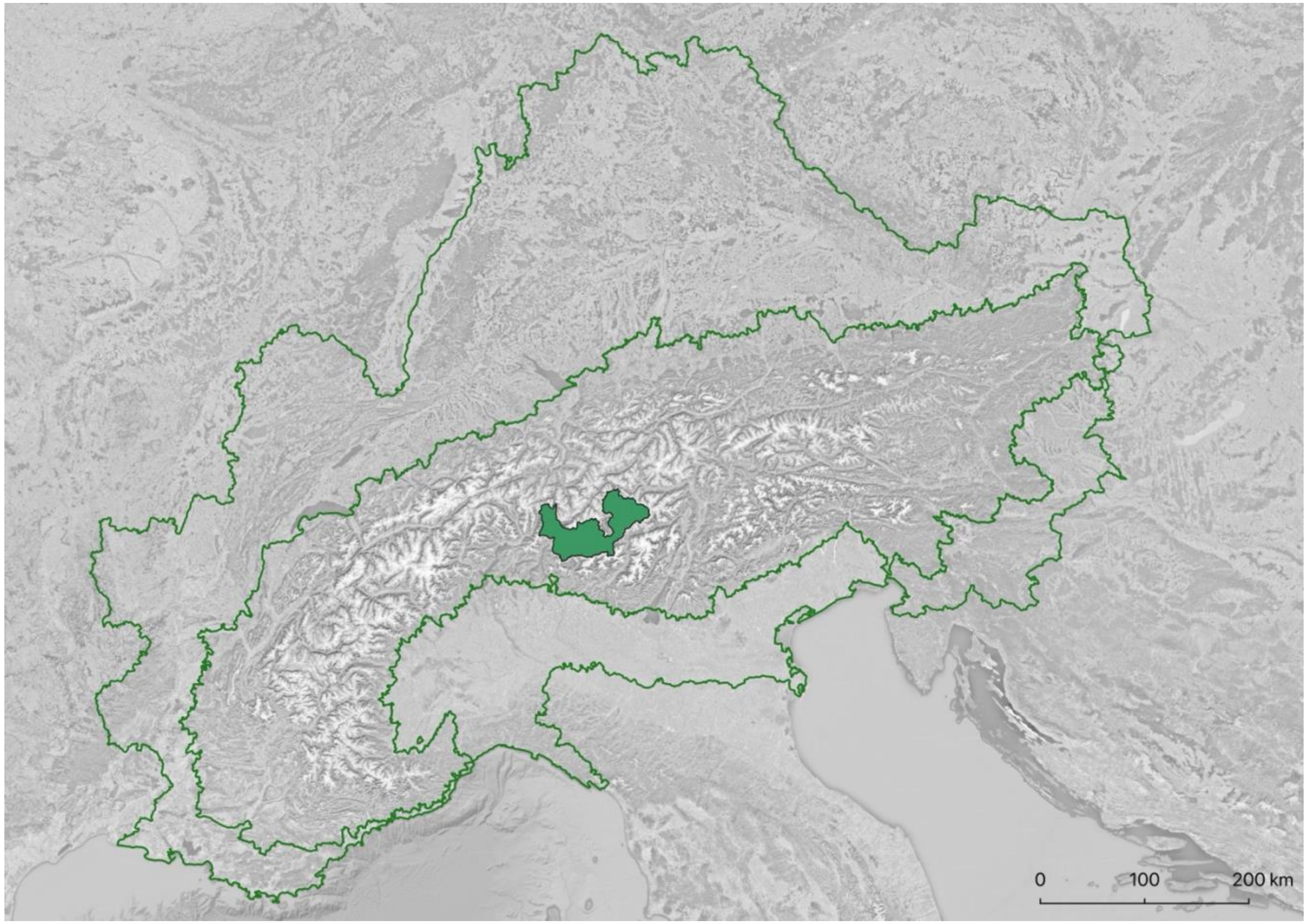
Within the provincial territory, various settlement dynamics can be identified. The areas of mid and lower Valtellina are more urbanized, where the concentration of settlements in the valley floor creates a conurbation that bisects the territory, acting as a barrier to ecological connections between lower/mid and upper Valtellina and Valchiavenna. The dense network of medium- and large-scale road infrastructure around these settlements is one of the primary factors contributing to the fragmentation of ecological corridors, leading to consequences such as the extinction of certain species whose habitats are altered and reduced.

Despite being less urbanized due to morphological features and/or regulatory constraints, the upper Valtellina areas experience pressures mainly due to the region's tourism-driven nature. Specifically, Tirano, Livigno, and Aprica are identified as areas of concern, as indicated in the guidelines of the ongoing Provincial Territorial Coordination Plan (PTCP) amendment. Therefore, not only the protection of open spaces near urbanized areas but also their enhancement and rehabilitation are priorities to counter, for example, the spread of non-native plant species or other forms of degradation. Other environmental pressures arise from human activities that exploit natural resources, such as mining operations (active or ceased), energy production or distribution activities, and more generally, industrial activities that can impact the environment and landscape.

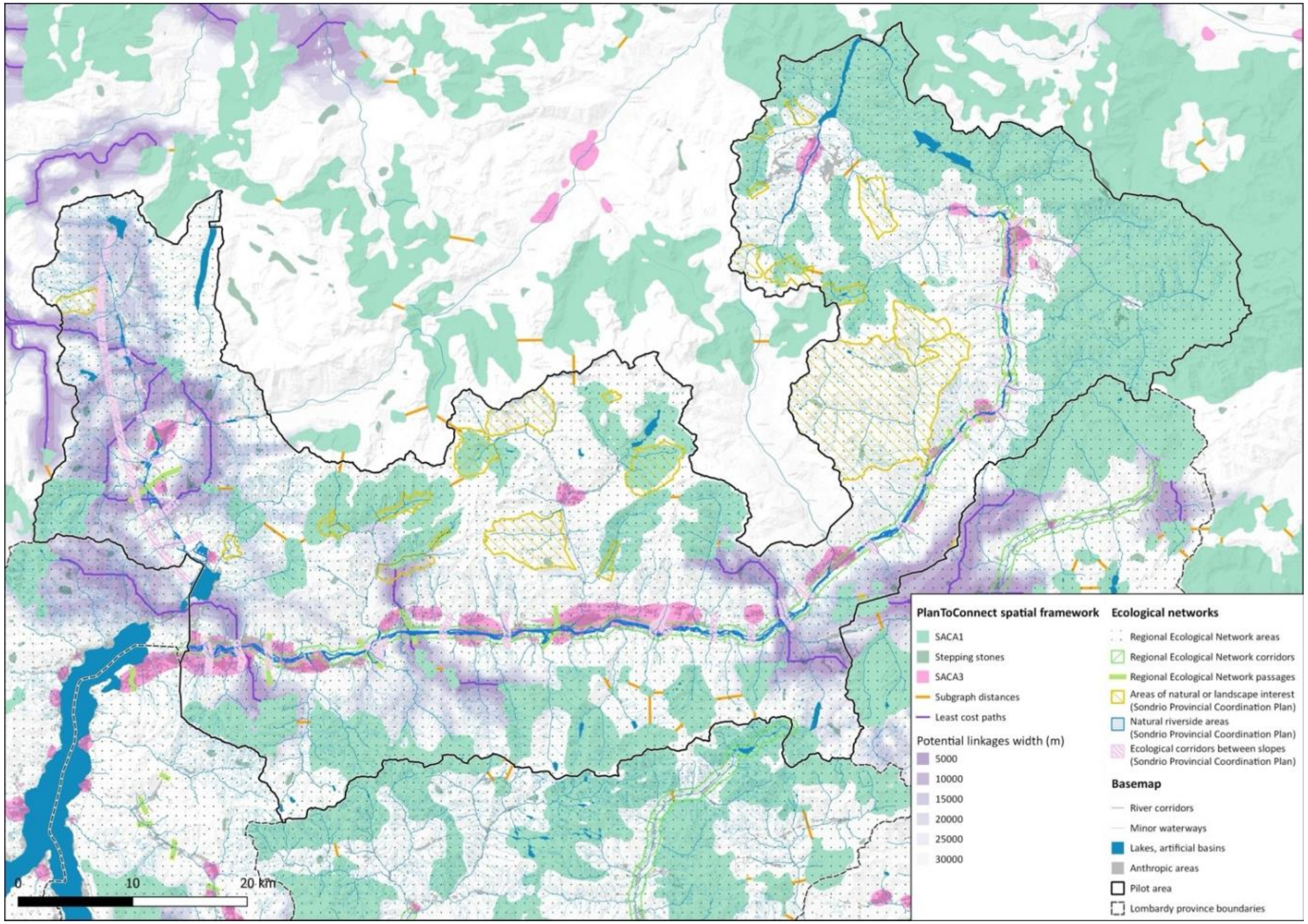
Lastly, ski areas and infrastructure related to high-altitude sports activities can also pose a threat to the ecological connectivity of the Alpine environment, resulting in negative impacts such as noise and light pollution, and anthropogenic disturbances, leading to the deterioration of environmental and ecological quality. In this context, it is also important to consider the potential direct or indirect impacts of the Milan-Cortina 2026 Winter Olympics, which will introduce new environmental pressures on the region. Specifically, some expansions of ski infrastructure are planned in the Valchiavenna mountain community, concerning access to the Val di Lei and the development of facilities and slopes on the northern side.

2 Pilot region

The Province of Sondrio represents an area of interest as a pilot case for the PlanToConnect project due to its high landscape-environmental values, which coexist with elements of fragility and pressure caused by a variety of factors. Moreover, the initiation of the process to update the Provincial Territorial Coordination Plan (PTCP), in force since 2010, provides a key opportunity to test the potential impacts of the project within territorial planning tools, particularly concerning the construction of a multifunctional green and blue infrastructure aimed at strengthening ecological connectivity and preserving the rich environmental and landscape heritage of the area. Several natural elements contribute to defining the rich and diverse biodiversity of the province, such as the watershed of the first stretch of the Adda River, the lateral valleys, and the mountainous slopes forming part of the Alpine arc. Sondrio is the only province in Lombardy with an entirely mountainous territory, covering over 3,000 km^2, with nearly half of it located above 2,000 meters in elevation, reaching the top elevation on the Bernina Mount 4050 mts. The Valtellina is further characterized by a widespread historical and cultural heritage and unique landscapes, which enhances the area's tourism appeal, primarily linked to outdoor recreational and sports activities. In this context, the project aims to develop a multifunctional green and blue network design based on an assessment of the territory's ecosystem performance, identifying areas of high value and critical issues. The project's outcome could serve as a potential contribution to provincial and local planning, identifying priority areas for intervention within a broader framework of transalpine ecological connectivity. Specifically, the multifunctional green and blue infrastructure design developed through the project will aim to enhance the environmental and ecosystem quality of the territory, sustainably leveraging its recreational potential in line with the area's needs. The results of this project will be integrated, on one hand, into the strategic framework defined by the identification of transalpine-scale ecological connectivity corridors and, on the other, into the objectives and strategies set for the provincial territory by existing planning tools at various levels, such as the Regional Territorial Plan (PTR), the Regional Landscape Plan (PPR), the Regional Plan for Protected Areas (PRAP), the current Provincial Territorial Coordination Plan (PTCP), and the Regional Area Territorial Plan (PTRA) for "Middle and Upper Valtellina". The goal is to define a strategic design for provincial-scale green and blue infrastructure capable of translating European and national strategies to a local level, ensuring the protection and conservation of biodiversity and ecosystems, while simultaneously enhancing the natural heritage and cultural landscape. The integration of ecological connectivity and multifunctionality objectives can represent a significant contribution to the territorial planning practices of the provincial area.



Picture 1: Overview – Location of pilot area



Picture 2: Overview – Location of pilot area and SACA areas

3 Methodical approach in the pilot area

3.1 Methodical approach

Multifunctional Green and Blue Infrastructure for the Province of Sondrio
Green infrastructure (GI) represents a transformative approach to land use and urban planning, emphasizing the integration of natural systems into human-dominated landscapes. One of its key strengths is landscape multifunctionality, which enables spatial areas to serve multiple purposes, including climate change mitigation, biodiversity conservation, food production, the creation of recreational greenspaces, and the provision of employment opportunities. Multifunctionality in this context refers to the capacity of green infrastructure to deliver multiple ecosystem services (ES), making it a fundamental principle of the GI approach. This concept is closely tied to physical connectivity, which is essential for facilitating the effective delivery of ecosystem services through ecological flows. Enhanced connectivity not only supports the functionality of GI but also increases ecological resilience to the stressors associated with urbanization and climate change, while bolstering regional economic stability. As an interconnected landscape framework, GI emphasizes the significance of both the quality and quantity of diverse landscapes, highlighting their multiple functions and the crucial interconnections among them. When thoughtfully planned, developed, and maintained, GI has the potential to significantly contribute to ecosystem services and sustainability, identifying and leveraging positive synergies among the ecosystem services present in various landscapes (LeBrasseur, 2022).
In this case the definition of GI is influenced primarily by two factors: multi-scale levels and a multi-functional perspective. The multi-scale approach is necessary when addressing ecological and landscape issues through planning disciplines that correspond to administrative levels. However, natural and landscape processes often do not align neatly with administrative boundaries, necessitating an integrated multi-scale approach. This entails starting from a macro scale, which encompasses the broader ecosystem functions, and moving down to a micro scale that focuses on site-specific ecosystem services.

Furthermore, this multi-scale approach requires a flexible legislative framework for planning instruments. For example, the promotion of a GI framework at the regional level should translate into actionable measures at the local level. In addition, the multi-functional perspective emphasizes the incorporation of ecological, recreational, cultural, and aesthetic functions within GI structures. This perspective recognizes the ability of areas to serve multiple purposes simultaneously, such as providing opportunities for healthy recreation while delivering essential natural services. Achieving this necessitates advancements in both planning analysis and management strategies to optimize these diverse functions effectively (Arcidiacono et al., 2016).
The Green Blue Infrastructure (GBI) project for the Province of Sondrio is grounded in the principle of multifunctionality, guiding the preservation and respectful utilization of the area's rich natural, ecological, and ecosystemic heritage. The definition of the infrastructure is currently underway and involves several steps that inform its characterization and delineation. Initially, an assessment of seven ecosystem services (ESs) was conducted to evaluate the current delivery of ecosystem benefits dictated by soil characteristics and natural components. Subsequently, a composite analysis of these seven values was performed, determining the multisystemic value of the province and identifying areas that exhibit strong multifunctionality as well as those with low ecosystem quality.
This level of information was cross-referenced and overlaid with previously analyzed data, including Strategic Alpine Connectivity Areas (SACA), regional and provincial ecological network data, and multifunctional elements from the regional landscape plan. The overlay of these elements, combined with a hotspot analysis derived from the multisystemic assessment, facilitated the identification of key classes that will shape the core structure of the multifunctional infrastructure. These classes, still in the process of being detailed, are characterized by three primary attributes: conservation, connectivity, and multifunctionality.

3.2 Data used

Ecosystem Service mapping was conducted using the InVEST software (Integrated Valuation of Ecosystem Services and Tradeoffs) (Tallis et al., 2011). The composite analyses and clustering methods were carried out through GIS geoprocessing in ESRI ArcGIS Pro, facilitating the visualization and interpretation of results (Peterson & Ver Hoef, 2014). This paper specifically examines the outcomes of four models: habitat quality, stormwater retention capacity, urban cooling, and sediment retention. During the modeling phase, we conducted preliminary research on the primary datasets used. These datasets were processed to customize the input folder and generate the modeling results. The data sources utilized include:

- 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 (a dataset containing basic and sectoral information and data related to the Lombardy region, open source);
- Geoportale della Provincia di Sondrio (a dataset containing basic and sectoral information and data related to the Sondrio province, open source);

The overlay and interpretation process, on the other hand, utilized additional types of data:

- Strategic Alpine Connectivity Areas (SACA)
- Land use and land cover data (DUSAF 2023, Geoportale della Lombardia)
- Regional Ecological Network (RER 201o, Geoportale della Lombardia)
- Provincial Ecological Network (REP 2011, Province of Sondrio)

3.3 Working steps

WORKING STEPS

1 COMPILATION OF PROTECTED AREAS within the Sondrio province

2 COMPILATION AND ANALYSES OF MULTIFUNCTIONAL GBI ELEMENTS within the Sondrio province

3 DEFINITION/REFINEMENT OF OBJECTIVES FOR MULTIFUNCTIONAL GBI CONNECTIVITY

4 COMPILATION & ANALYSIS OF REGIONAL AND LOCAL DATA

5 BARRIER ANALYSES

6 ECOSYSTEM SERVICES MAPPING & ASSESSMENT

- Habitat Quality
- Stormwater Retention
- Nutrient Retention
- Crop Pollination
- Agricultural Value
- Sediment Retention

7 MULTISYSTEMIC COMPOSITE VALUE ASSESSMENT

8 OVERLAYING PROCESS AND INITIAL CLASSES' DEFINITION

9 MULTIFUNCTIONAL GBI CLASSES' CHARACTERIZATION

Figure 3: Working Steps

Table 1: General Working steps

Working Step	Description
1	**Compilation of the protected areas within the Sondrio province**
	In a first step, all significant core areas within Sondrio province are compiled and briefly described.
2	**Compilation and analysis of GBI elements within the area (connectivity evaluation)**
	In a second step, all GBI elements (based on the categories of CORINE Land Cover 5 ha CLC5 (2018) within the corridor are listed and summarised according to the main categories: • Natural/ Semi-natural grassland • Sparsely vegetated areas • Forests and other wooded lands (shrubs, hedges, trees) • Water bodies (flowing and standing water) • Wetland (marshes, peatbogs)
3	**Definition / refinement of objectives for ecological connectivity**
	Based on the evaluation of spatial data within the selected corridor the objectives for ecological connectivity will be defined in more detail.
4	**Compilation and analysis of regional and local data**
	The analysis and mapping of regional and provincial data concerning ecological networks, as well as other landscape elements with recreational and multifunctional components, contribute to the understanding and

Working Step	Description
	refinement of corridors, gaps, and areas of high natural value. These findings are essential for identifying which features should be included and safeguarded during the definition of the project infrastructure.
5	**Barrier Analysis (based on D 1.2.1 and 1.3.1)**
	Depending on whether the connectivity of structures or species is being considered, there are very different threats or barriers in the landscape. In a further step possible threats and barriers in the selected corridor are compiled and analysed
6	**Ecosystem Services Mapping & Assessment**
	The mapping and analysis of the seven selected ecosystem services for the project area are conducted to understand the ecological qualities inherent to the territory. This phase is characterized by two steps: the first involves data collection and modeling, followed by the comprehension, visualization, and interpretation of the models.
7	**Multisystemic Composite Value Assessment**
	The seven layers of ecosystem information are overlaid and summed to create a map of composite multisystemic values. This step is particularly valuable for assessing the overall multifunctional capacity, enabling the identification of areas with high multifunctional potential as well as those that are deficient and degraded.
8	**Overlaying process and initial GBI classes' definition**
	The map of composite values is interpreted and refined by focusing solely on the highest composite values (Hotspot analysis), which will define the framework of the Green and Blue Infrastructure (GBI). At this stage, the newly generated mapping begins to interact with previously analysed local, regional, and interregional data, allowing for the identification of similarities and differences among them.

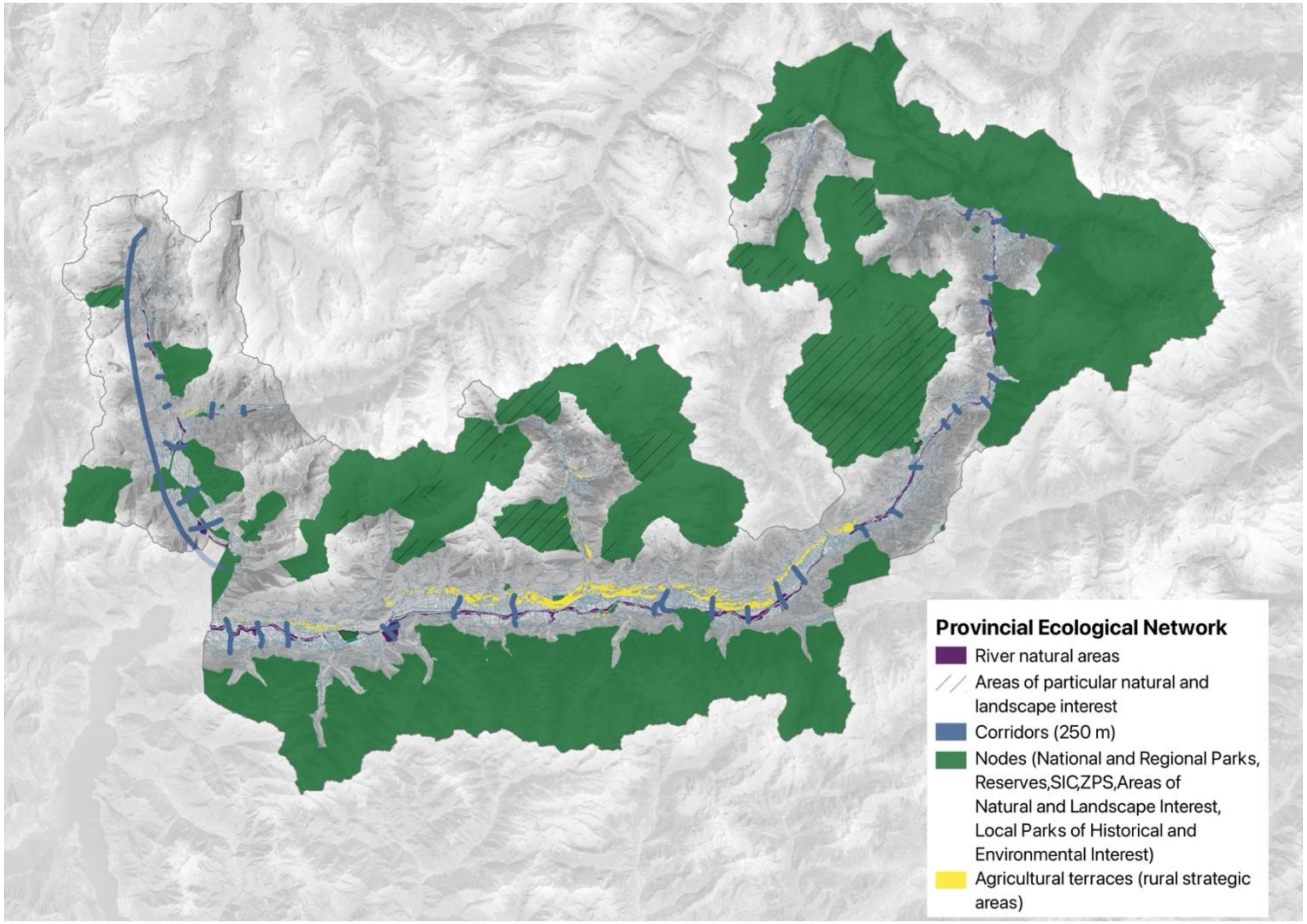
Working Step	Description
9	**Multifunctional GBI classes characterization**
	The map of composite values is interpreted and refined by focusing solely on the highest composite values (Hotspot analysis), which will define the framework of the Green and Blue Infrastructure (GBI). At this stage, the newly generated mapping begins to interact with previously analyzed local, regional, and interregional data, allowing for the identification of similarities and differences among them.

4 Results

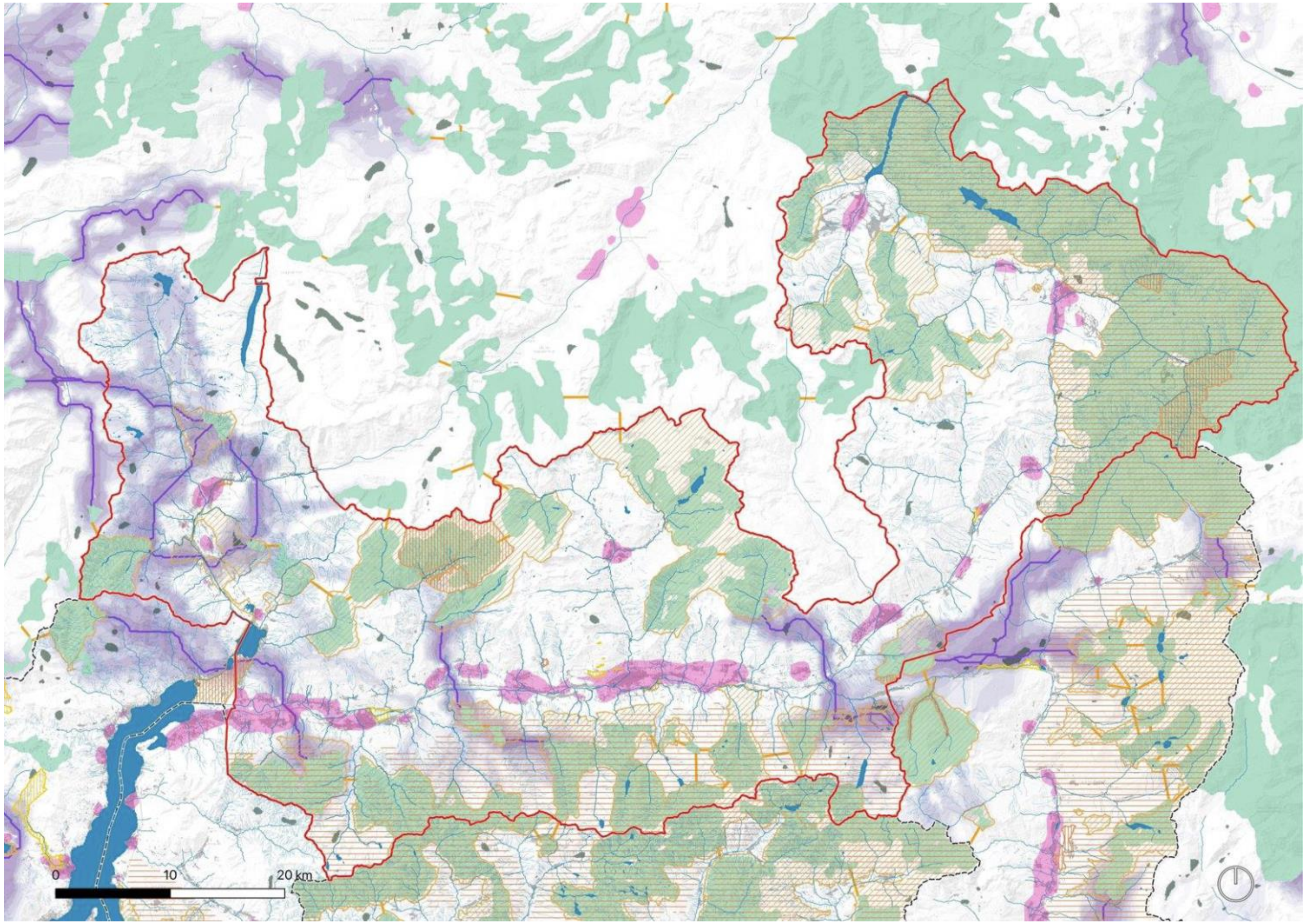
4.1 Compilation of the protected areas within the Sondrio province

The system of protected areas and the regional ecological network are synthesized within the provincial ecological network. The mapped representation highlights the main elements of natural, ecological, and landscape significance within the Province of Sondrio.
The protected areas system in the Province of Sondrio currently covers over 40% (1,300 km²) of the territorial surface (source: Geoportale Lombardia) and includes the Stelvio National Park, the Orobie Valtellinesi Regional Park, nine Regional Nature Reserves (Pian di Spagna-Lago di Mezzola, Bosco dei Bordighi, Paluaccio di Oga, Pian Gembro, Marmitte dei Giganti, Piramidi di Postalesio, Val di Mello, Val Masino), two Natural Monuments (Caurga del torrente Rabbiosa and Cascata dell'Acquafraggia), three Local Parks of Supra-Municipal Interest (PLIS della Bosca, PLIS Parco Incisioni Rupestri di Grosio, and PLIS di Triangia), as well as numerous Natura 2000 sites that partially overlap with the aforementioned protected areas. Other protected areas comprehend The highest level of protection under the Framework Law on Protected Areas (LN 394 of 1991) is actually limited to natural parks, which comprise only 2.93% of the total area across the Lombardy region. The provincial territory, entirely mountainous, is characterized by significant natural and ecosystemic value, which is further defined by important ecological connections to the east with the Swiss National Park, to the south with the Orobie Bergamasche Park, and by the hydrological basin of the Adda River running from east to west. Other protected areas are also determined by the Code of Cultural Heritage and Landscape, such as wooded areas, glaciers above 2000 meters, and buffer zones of 150 meters for rivers and 300 meters for lakes.
The natural value of the pilot area is supported by the mapping of ecological connectivity proposed by the PlanToConnect project, which identifies "priority areas for ecological conservation" (Figure 3) at the scale of the alpine macro-region. These areas are defined as connectivity nodes or central elements within the alpine ecological network system (Alpbionet, 2019).

Picture 3: Provincial ecological network



Picture 4: SACA representation



4.2 Compilation and analysis of GBI elements within the corridor (connectivity evaluation)

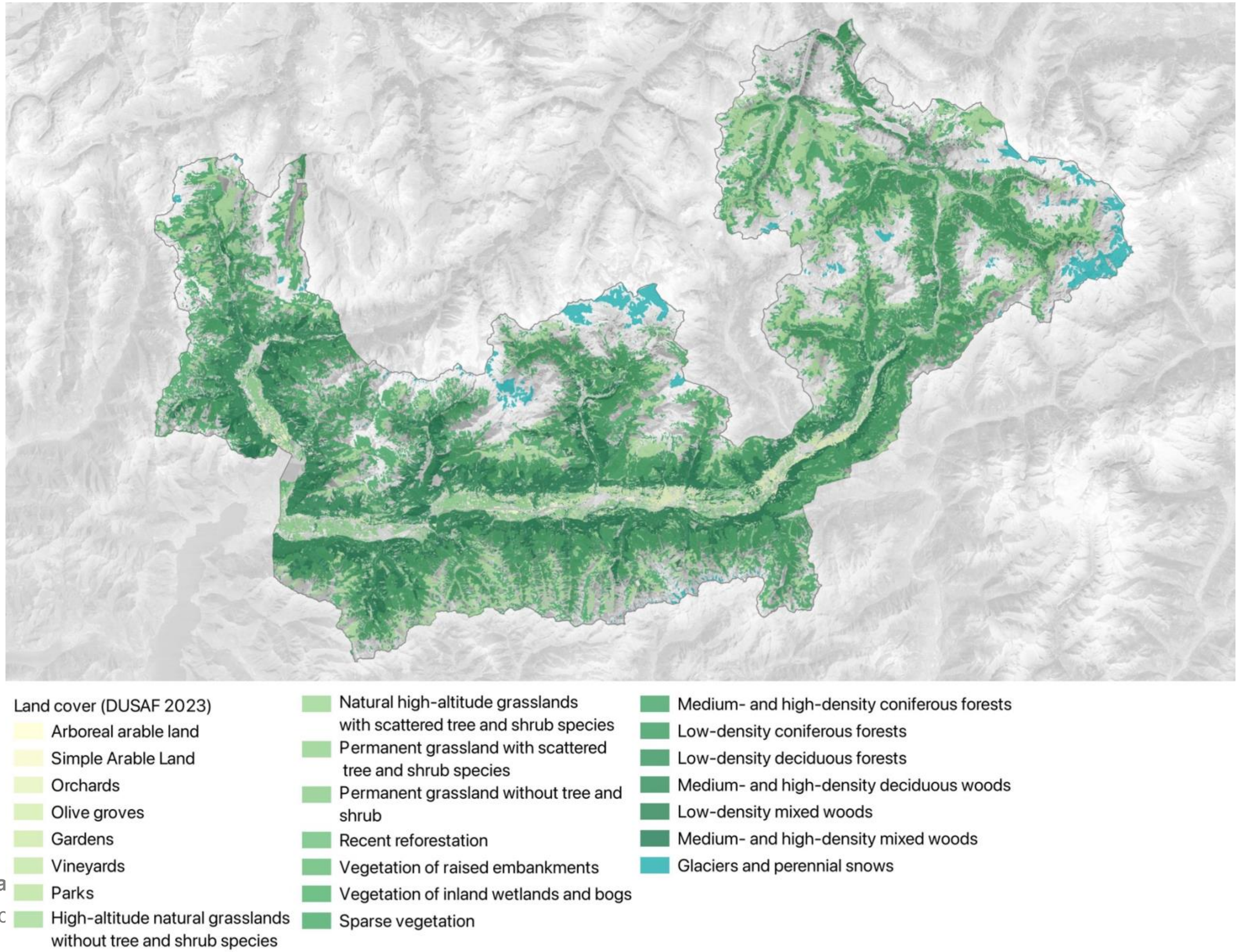
The land use in the province of Sondrio is predominantly shaped by its mountainous terrain, which dictates the distribution of various activities and natural environments. The vast alpine landscapes are characterized by extensive forested areas, particularly mixed and deciduous forests, which play a crucial role in maintaining ecological balance and providing essential ecosystem services such as soil retention and water regulation. Agriculture is also a significant land use, especially in the valley floors and terraced slopes, where viticulture, orchards, and pasturelands are prevalent. Urbanization is relatively limited due to the topography, with most settlements concentrated in the valley floors, particularly in the Valtellina and Valchiavenna valleys.

The urbanized area occupies a minimal portion of the total land, primarily concentrated in the valley floors. However, it poses a significant threat to the region's ecological connectivity. The linear configuration of urban settlements disrupts the continuity of vegetation and, consequently, the potential ecological corridors necessary for wildlife movement.

Table 2: Significant Land cover classes

Sparse vegetation	377,57	11,8
High-altitude natural grasslands without tree and shrub species	272,01	8,5
Mixed forests of medium and high density	244,02	7,6
Medium- and high-density deciduous woods	186,54	5,8
Bushes	183,00	5,7
Permanent grassland in the absence of tree and shrub species	182,87	5,7
Glaciers and perennial snows	65,99	2,1
Bushes with a significant presence of tall shrub and tree species	31,94	1,0
Low-density coniferous forests	30,29	0,9
Natural high-altitude grasslands with scattered tree and shrub species	22,00	0,7
Reservoirs	18,16	0,6
Permanent grassland with scattered tree and shrub species	18,07	0,6
Vineyards	16,77	0,5
Orchards and minor fruits	15,14	0,5
Riverbeds and artificial watercourses	12,58	0,4
Sports facilities	11,62	0,4
Natural reservoirs	8,73	0,3
Simple arable land	8,02	0,3
Low-density deciduous woods	7,45	0,2
Riparian formations	6,85	0,2
Mixed forests with low density	3,39	0,1
Vegetation of inland wetlands and peat bogs	1,70	0,1
Recent reforestation	0,42	0,0

Picture 5: Land cover



4.3 Definition / refinement of objectives for ecological connectivity

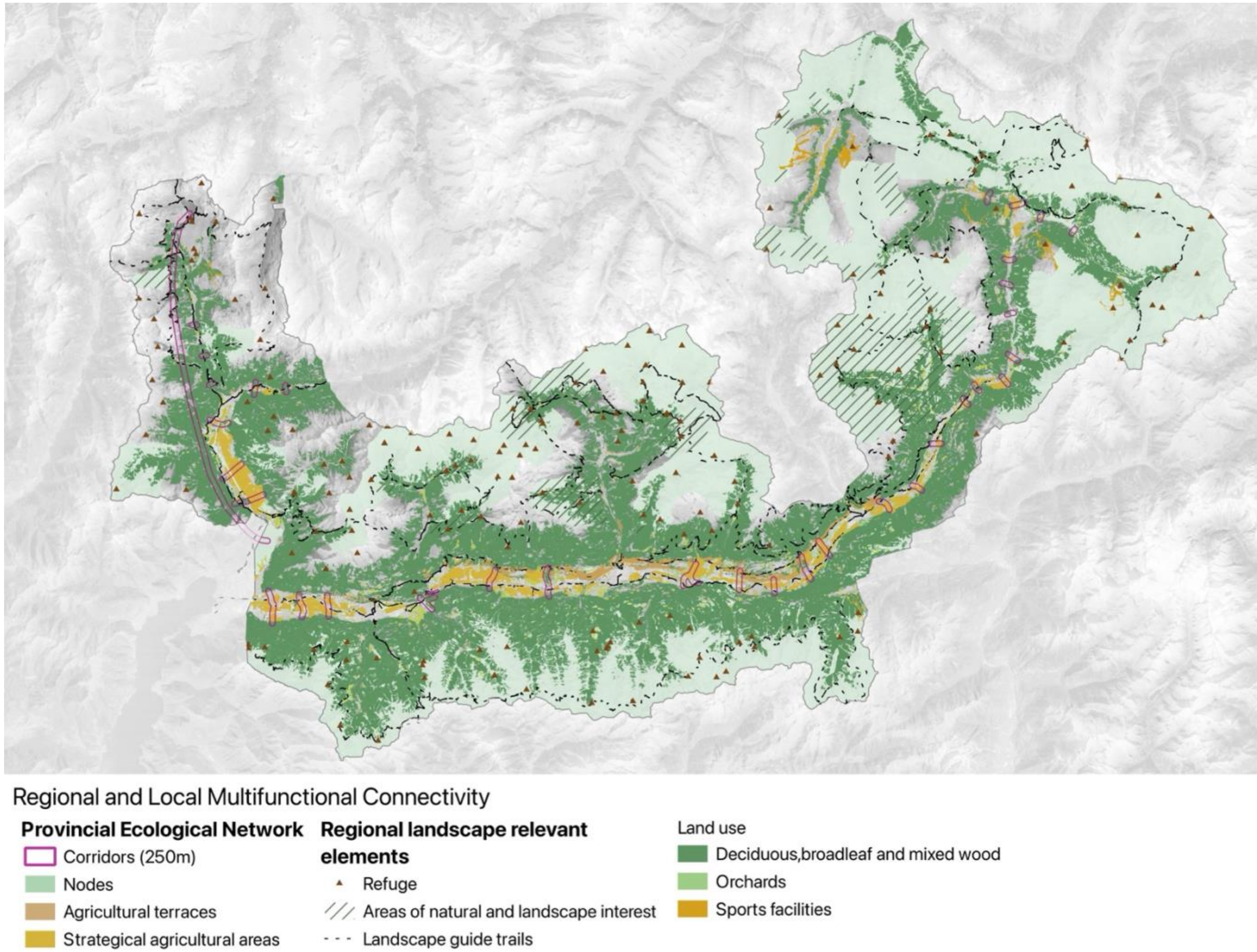
Our project aims to establish a multifunctional green and blue infrastructure that targets ambitious ecological connectivity objectives, focusing on the conservation and enhancement of the region's natural and ecosystem values. This approach synergistically integrates structures and facilities designed for recreation and sustainable, low-impact tourism, thereby creating connections that not only promote biodiversity but also provide opportunities for responsible engagement with the landscape.
A distinctive feature of our project is its alignment with the new provincial territorial coordination plan, which establishes a comprehensive institutional framework. The objectives of our multifunctional infrastructure closely correspond with those outlined in the plan, which emphasizes the protection of natural areas, the safeguarding and rational use of land, and the support for more sustainable tourism practices. Through this integrated system, we aim to foster both environmental and social sustainability, ultimately contributing to a more balanced and harmonious future for Sondrio province.

4.4 Compilation and analysis of regional and local data

The analysis and mapping of regionally and locally significant elements have yielded a concise set of selected features, emphasizing their strategic role within the Green and Blue Infrastructure (GBI) project. Specifically, we began with an analysis of the Regional Ecological Network (RER) established by the Lombardy Region, which identifies corridors, nodes, and stepping stones throughout the regional territory. In particular, the Regional Ecological Network (RER) and the criteria for its implementation provide the Regional Territorial Plan with a framework for identifying existing natural sensitivities and a design of the key elements of the reference ecosystem. This framework facilitates the assessment of strengths and weaknesses, as well as opportunities and threats present within the regional territory.
The regional network delegates the detailed planning to the provinces and municipalities at more specific scales. Accordingly, we subsequently relied on the Provincial Ecological Network (REP) for the identification of nodes, corridors, and strategic ecological areas

within the provincial territory. The REP is particularly valuable in identifying corridors in the valley floor, which will be crucial for redesigning ecological connections between the two valley floors. Terraces and strategic agricultural areas also play a significant role in terms of ecological and multifunctional values.
Additional supporting elements for this analysis were identified within the Regional Landscape Plan (PPR). Specifically, three distinct levels with a strong multifunctional character were selected: mountain refuges, landscape trails, and areas of high natural value. Furthermore, from the dataset related to land use (DUSAF), three additional levels were chosen to define the supralocal multifunctionality: forests (including deciduous, broadleaf, and mixed), sports facilities (with particular emphasis on those located in high-altitude areas), and orchards (which also encompass meadows and pastures).

Picture 6: Multifunctional connectivity



4.5 Barrier Analysis (based on D 1.2.1 and 1.3.1)

One of the primary threats to ecological connectivity is the progressive degradation of soil, along with the loss of its functions and associated ecosystem services. Increasing anthropization and soil sealing, in particular, heighten the risks of flooding, contribute to climate warming, threaten biodiversity, natural disaster such as landslides, and lead to the gradual loss of rural and natural landscapes (as highlighted in “Soil Consumption, Territorial Dynamics, and Ecosystem Services,” ISPRA 2016).
Within the provincial territory, various settlement dynamics can be identified. The middle and lower Valtellina areas are more urbanized, where the concentration of settlements in the valley floor creates a conurbation that bisects the territory, acting as a barrier to ecological connections between lower/middle and upper Valtellina and Valchiavenna. The dense network of medium and large-scale road infrastructures near these settlements is a major factor in the fragmentation of ecological corridors, leading to consequences such as the extinction of species whose habitats are altered and reduced.
The upper Valtellina region, although less urbanized due to its morphological features and/or regulatory constraints, faces pressure mainly from the area's tourism-driven economy. In particular, the areas of Tirano, Livigno, and Aprica are identified as critical zones, as noted in the guiding document for the ongoing revision of the Provincial Territorial Coordination Plan. Protecting free areas near urbanized centers, as well as enhancing and rehabilitating these spaces, is therefore a priority to counter, for example, the spread of invasive plant species or other forms of degradation. Additional environmental pressures arise from human activities that exploit natural resources, such as active or abandoned extractive operations, energy production or distribution activities, and more generally, productive activities that can impact the environment and landscape.
Finally, ski domains and infrastructures related to high-altitude sports activities can pose a threat to the ecological connectivity of the alpine environment, leading to negative impacts such as noise and light pollution, as well as anthropogenic disturbances, resulting in the deterioration of environmental and ecological quality. In this context, it is also crucial to consider the potential direct or indirect impacts of the Milan-Cortina 2026 Winter Olympics, which will introduce new environmental pressures on the region. Specifically, some expansions of ski infrastructure are planned in the Valchiavenna mountain community, concerning access to Val di Lei and the development of facilities and slopes on the northern side.

4.6 Ecosystem Services Mapping & Assessment

The main structure of the green and blue infrastructure for the province of Sondrio is based on the analysis and assessment of a series of ecosystem services selected according to the area's specific characteristics: Habitat Quality, Stormwater Management, Crop Pollination, Nutrient Retention, Agricultural value, Sediment Retention and Cultural value. In this chapter, we will present and briefly describe the seven ecosystem mappings that were generated using the InVEST software, with the exception of those related to 'Cultural Value' and 'Agricultural Value.' The mapping for cultural value was produced manually within a GIS environment, while the mapping for agricultural value is based on a dataset provided by the Lombardy Geoportal.
The *Habitat Quality* model uses habitat quality and rarity as indicators to represent the biodiversity of a landscape. It evaluates the distribution of various habitat and vegetation types across the landscape and their respective levels of degradation. The model was produced using the InVEST software, following the methodology outlined in the study by Salata et al. (2017), with the goal of identifying areas of significant natural value that require protection or restoration.
The model (Picture 7) shows high biodiversity values in areas spanning from the lower to the upper mountain regions. These areas are predominantly characterized by dense forest cover, which contributes to a high multisystemic capacity. In contrast, the upper mountain zones exhibit lower habitat quality values, primarily due to the sparse and low vegetation typical of these elevations. In the valley floors, habitat quality is low or negligible, coinciding with urbanized areas and transportation infrastructure.

The *Stormwater Retention* model calculates the annual volume of stormwater retention as the portion of rainfall that is not transpired or evapotranspired by soil or aboveground vegetation. Special attention was given to this model due to significant hydraulic vulnerabilities exacerbated by climate change. The methodology employed closely follows the approach detailed in the study by Salata (2023).
The stormwater retention capacity depicted in Picture 8 further underscores the crucial role of densely vegetated areas in supporting ecosystem services. In this case, the forested zones exhibit a strong capacity for retaining and absorbing rainfall. Conversely, the upper mountain regions, characterized by sparse or absent vegetation and primarily rocky surfaces, demonstrate a lower overall absorption capacity. Lastly, the urbanized valley floors, marked by impermeable surfaces and minimal green spaces, show a significantly reduced absorption capacity.

The *Crop pollination* model focuses on wild pollinators providing an ecosystem service. The model estimates insect pollinator nest sites, floral resources, and flight ranges to derive an index of pollinator abundance on each cell on a landscape. In this case the methodology for the model assessment adhered to the Simulsoil Userguide guidelines (http://www.sam4cp.eu). The model results, as shown in Picture 9, once again reveal a pattern similar to the previous models, where the presence of wild pollinators is denser in areas with vegetation and agricultural cultivation. In this instance, forested areas and agricultural lands in the valley floor are characterized by the highest values.

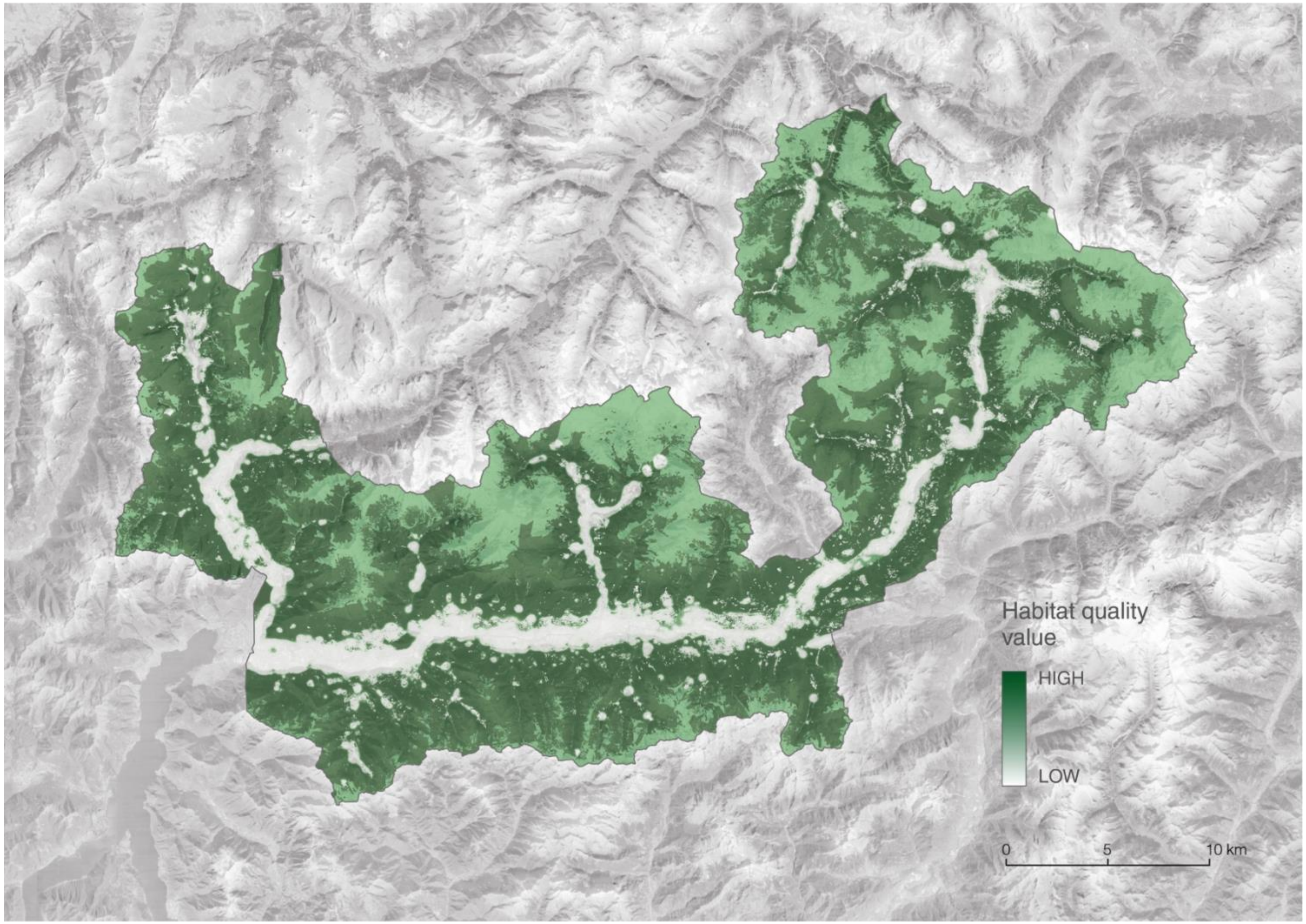
The *Nutrient Retention* model maps nutrient sources from watersheds and their transport to streams, providing spatial information that can be used to assess the nutrient retention services provided by natural vegetation. To inform conservation efforts by identifying areas of soil and vegetation that most effectively purify water supplies, we followed the procedure outlined in the study by Salata et al. (2017). In this instance, the model indicates a high nutrient retention capacity across the entire provincial area, attributed to the significant vegetation cover distributed throughout the region. The lighter areas on the map represent the hydrographic network.

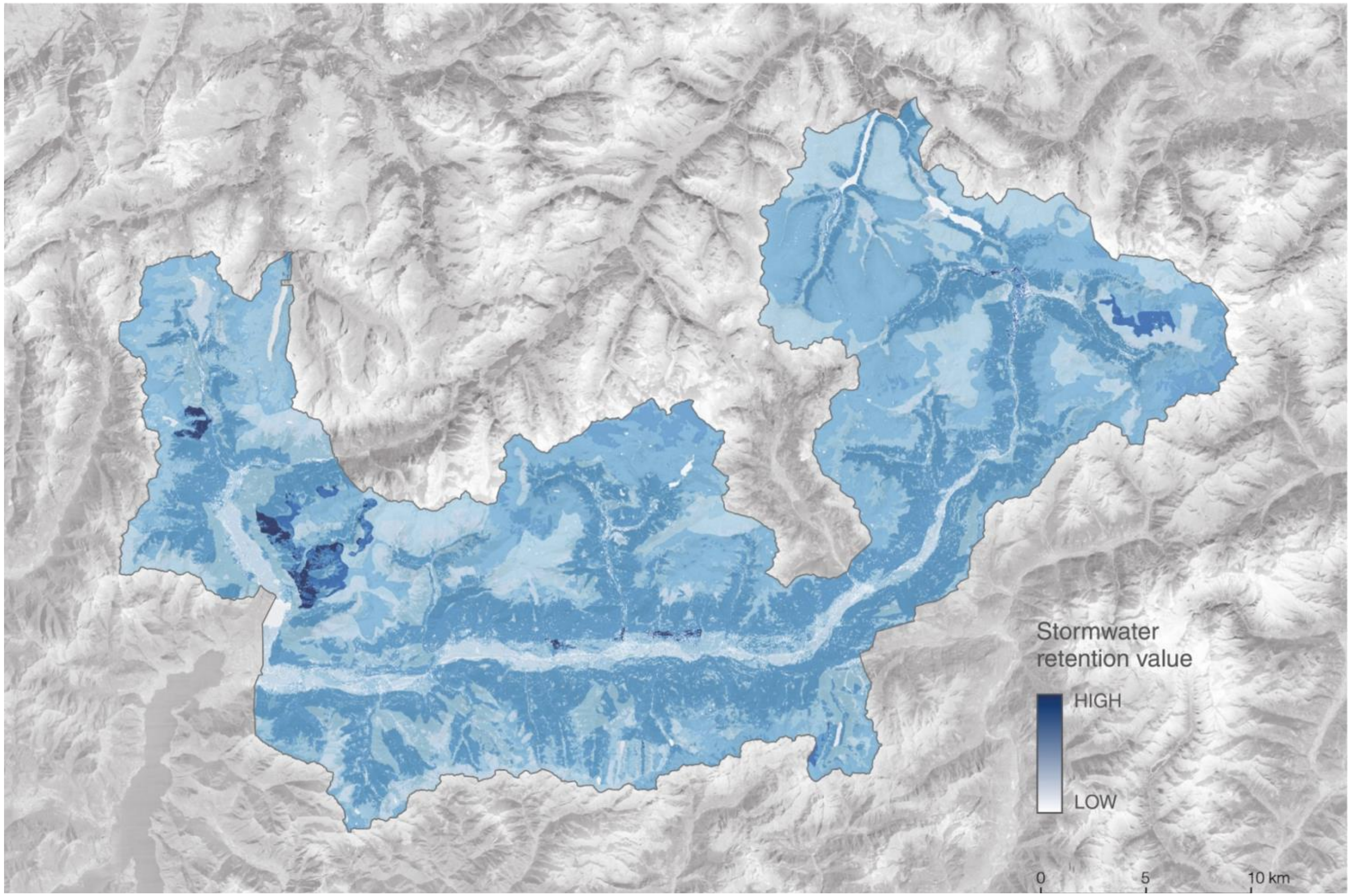
As previously mentioned, the mapping of *Agricultural value* is not the result of a model but is derived from data produced by the Lombardy Region (“Valore agricolo dei suoli”, 2023). This dataset classifies regional agricultural land into six categories, ranging from high values for areas with high land-use capability and productive potential, to moderate values, and finally to those that are urbanized or unproductive. The mapping in Figure 11 highlights the concentration of the highest agricultural values in the valley floor. These areas, adjacent to the urbanized settlements, are where the region's agricultural activities are concentrated. Identified by the provincial ecological network as strategic areas, they are recognized for their high ecological performance.

The *Sediment Retention* model assesses a land parcel's ability to retain sediment by analyzing data on geomorphology, climate, vegetation cover, and management practices. Utilizing the digital elevation model (DEM) for precise spatial resolution, the model first calculates the annual soil loss for each pixel and then determines the Sediment Delivery Ratio (SDR), which indicates the proportion of soil loss that ultimately reaches the stream. The implementation of the model followed the data and methodology described in the study by Salata et al. (2017). The mapping results indicate a higher capacity for sediment retention in areas immediately adjacent to the hydrographic network, where there is a greater likelihood of sediments being carried away by water flow. In these cases, the vegetation along the banks plays a crucial role in mitigating erosive processes.

The *Cultural value*, manually produced within a GIS environment at LabPPTE (Dastu, Politecnico di Milano), aims to address the challenging task of georeferencing the cultural value of the provincial area based on the density of certain historically and identarily significant elements. The elements of interest that comprise this analysis include components of the natural geomorphological system, the system of perceptual historical and cultural values, and the agro-sylvo-pastoral system. The final model in Figure 13 displays various densities of elements that remain recognizable despite the simplified representation. In most cases, these consist of natural areas and reserves, as well as national and regional parks illustrated in Figure 3, which highlight the historical and cultural characteristics of the region, serving as both attractive features and identifiers of the area.

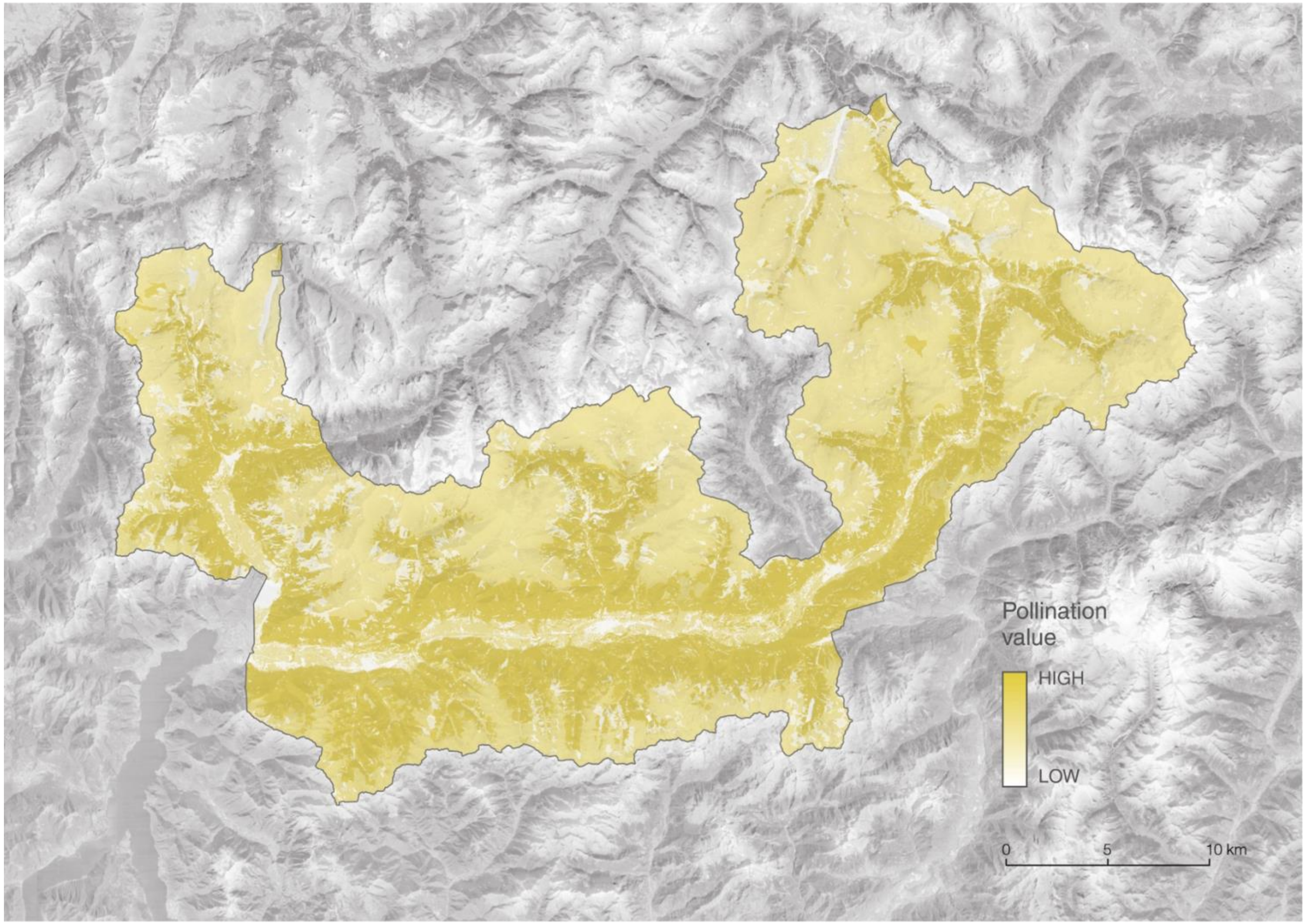
Picture 7: Habitat Quality



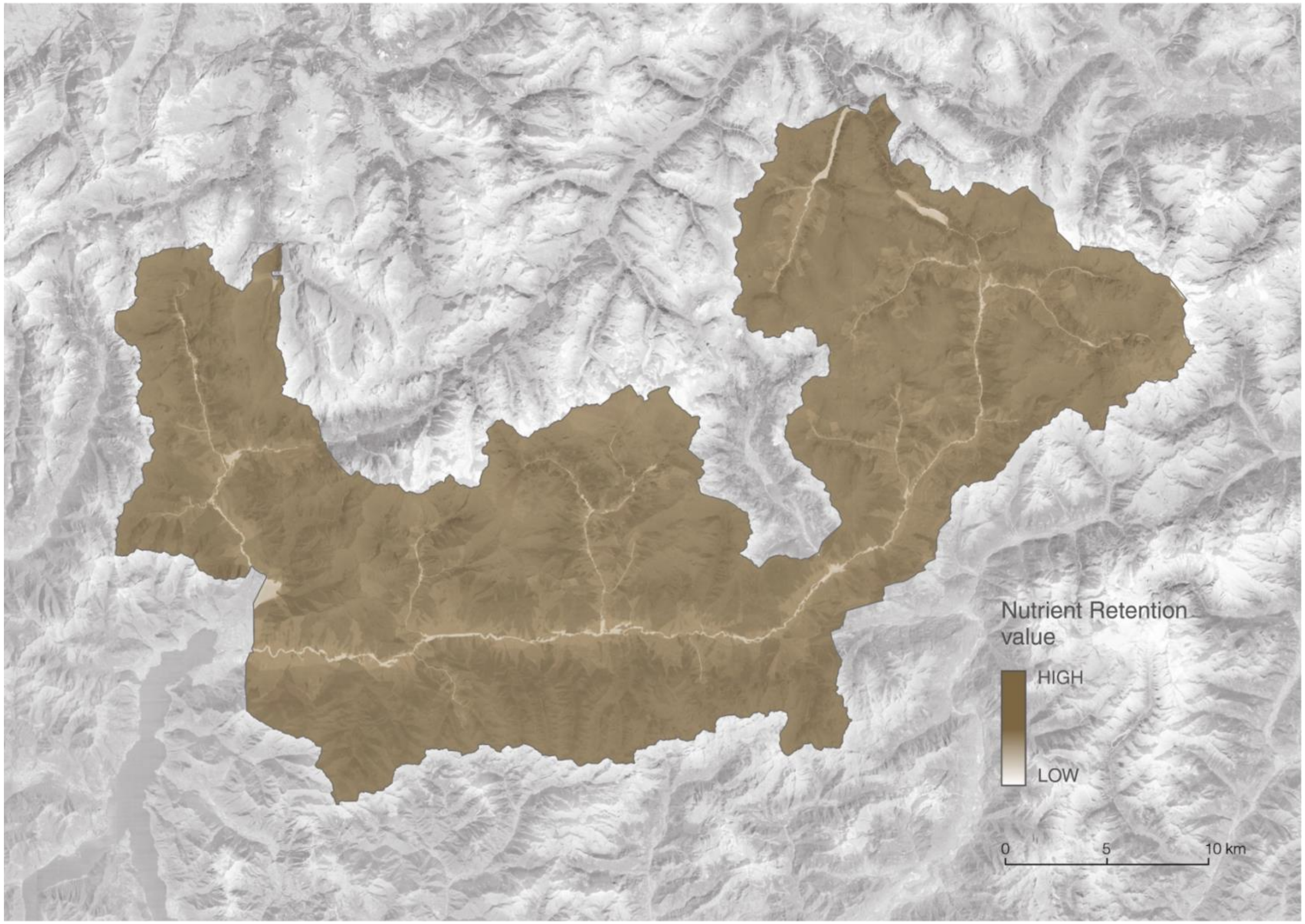


Picture 8: Stormwater Management

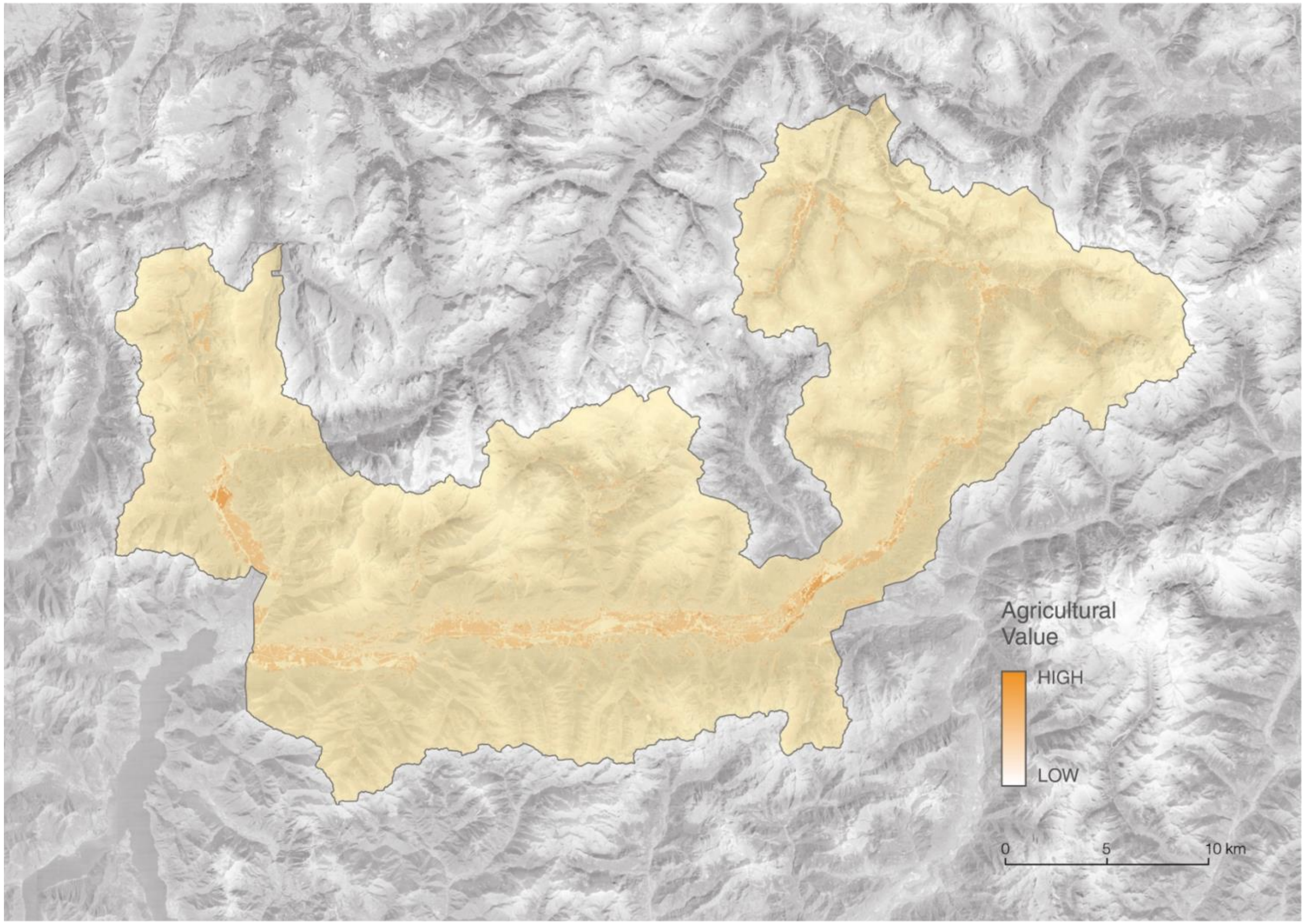
Picture 9: Crop Pollination



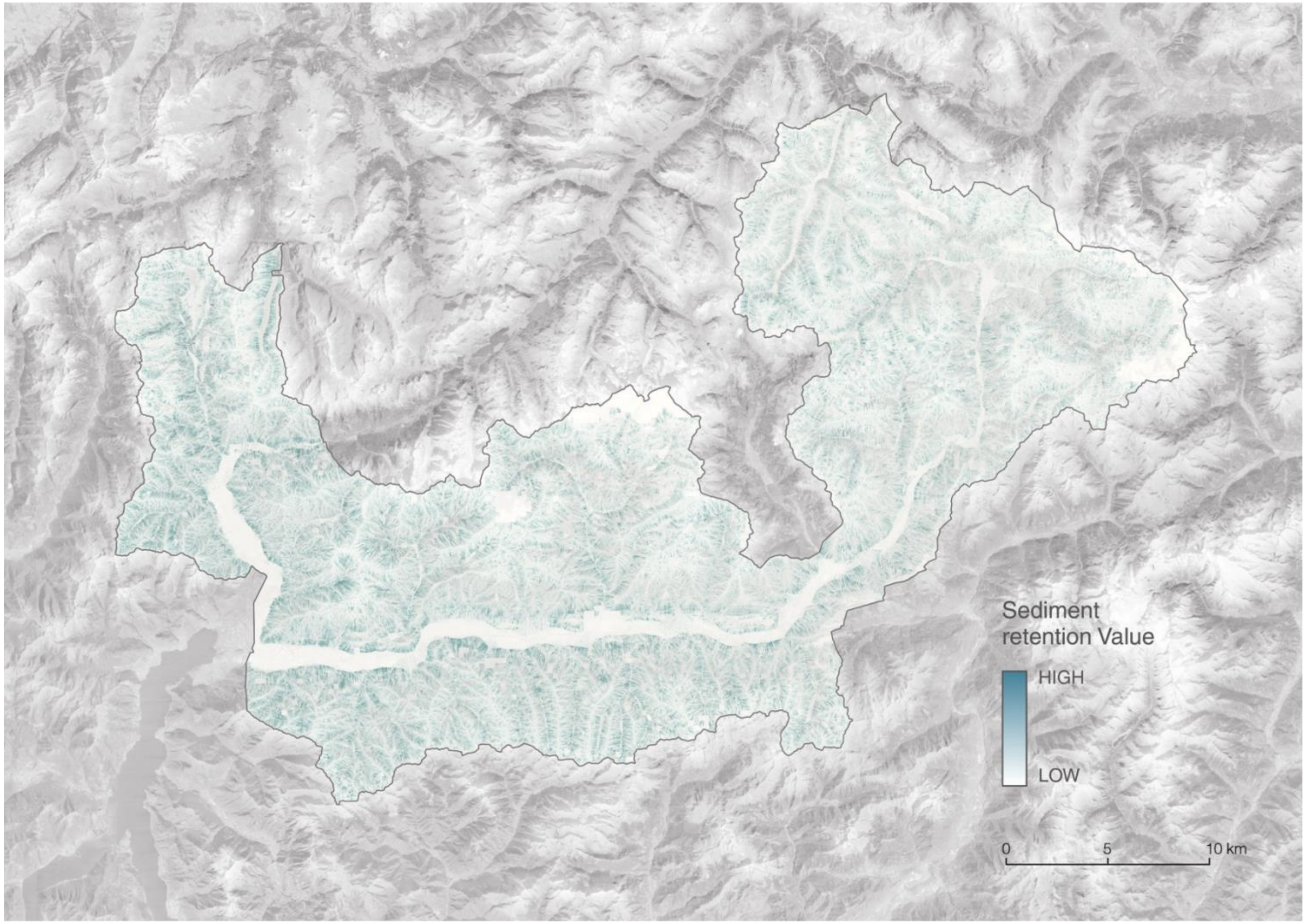
Picture 10: Nutrient Retention



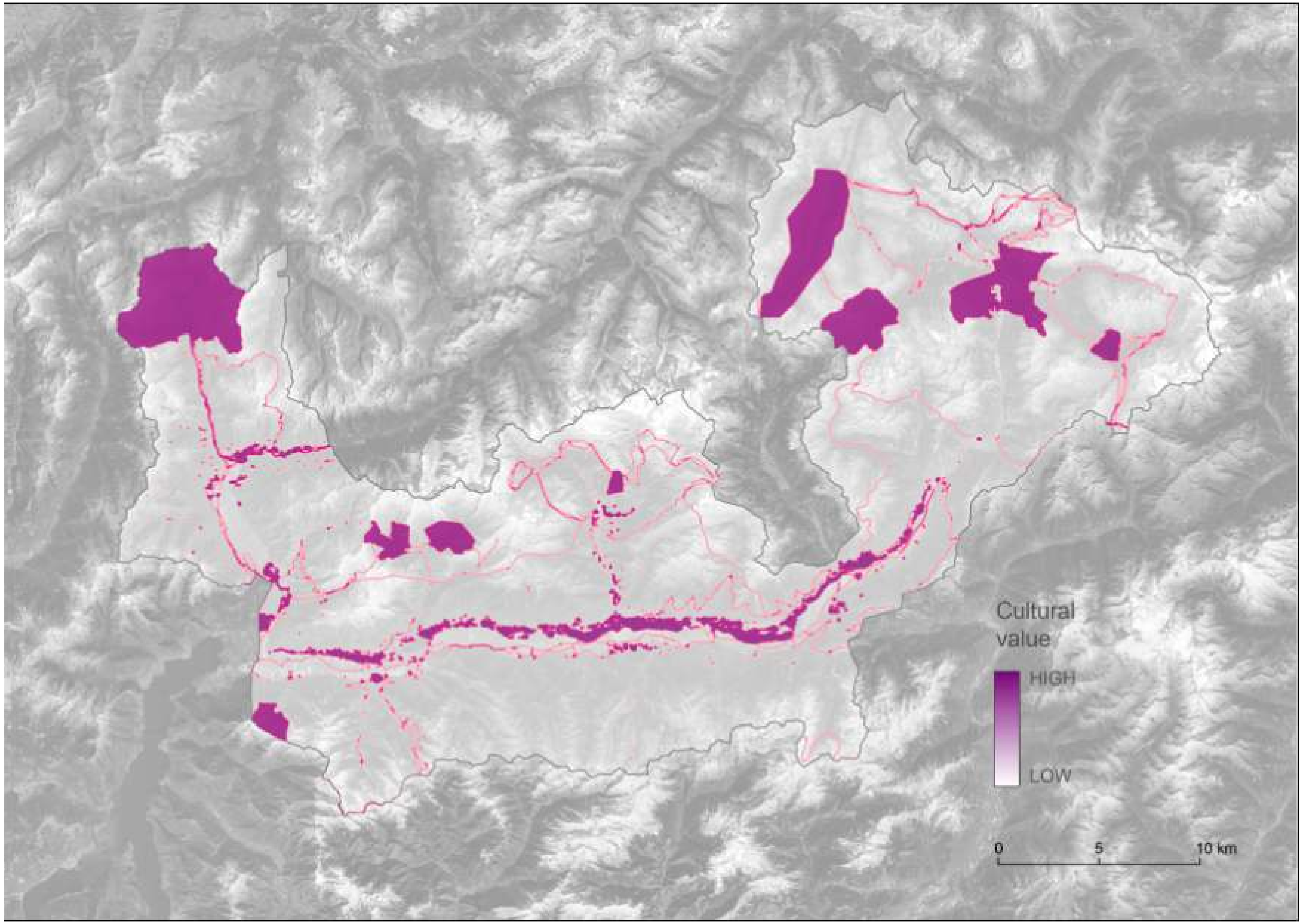
Picture 11: Agricultural value



Picture 12: Sediment Retention



Picture 13: Cultural value



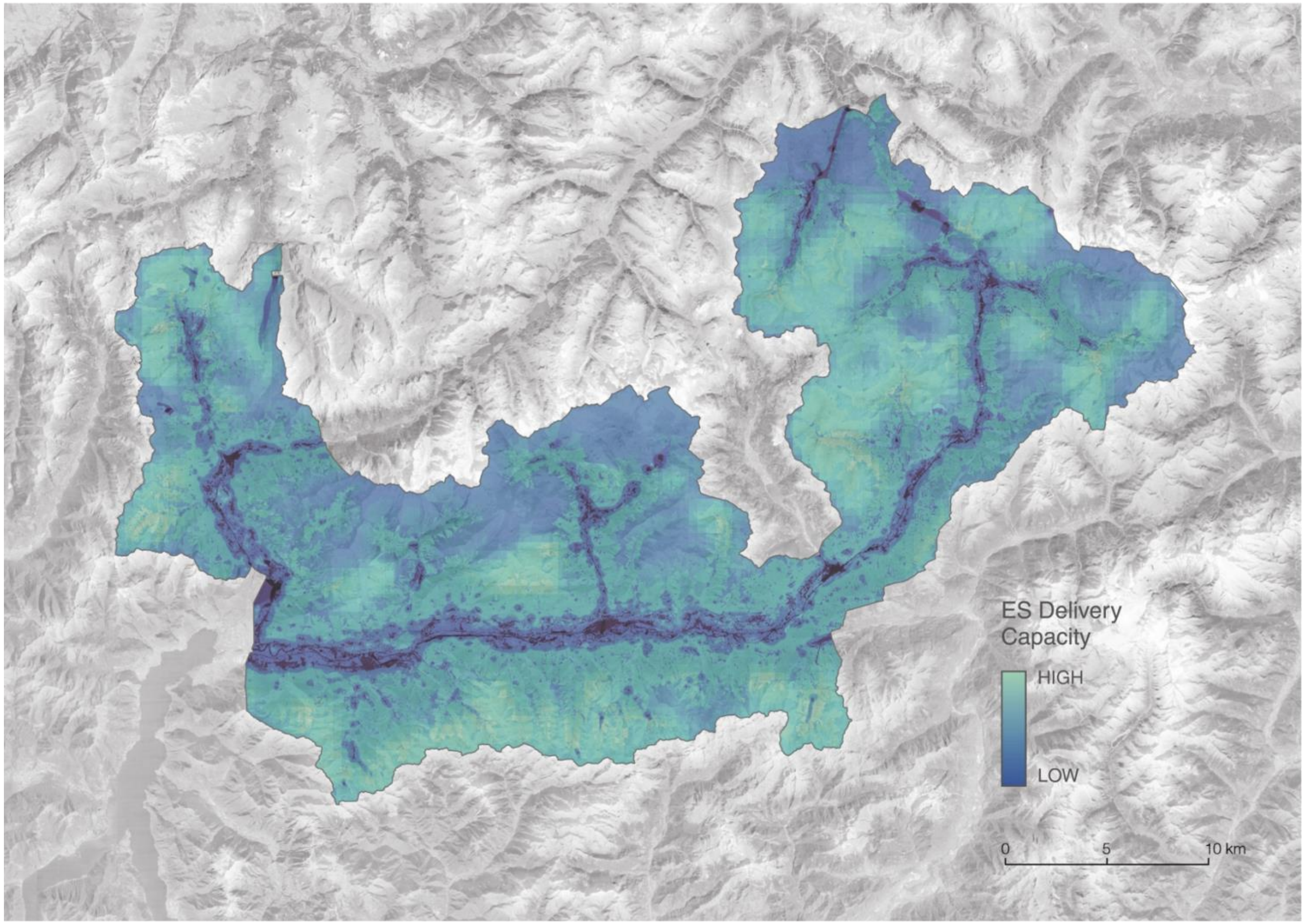
4.7 Multisystemic Composite Value Assessment

The overlay of the seven layers presented creates a map representing the composite multisystemic value. Each ecosystem service was summed without applying any weighting, resulting in a raster with a value range of 1 to 7, which represents the distribution of multiple ecosystem values across the entire provincial territory. This composite analysis is a fundamental first step in defining the multifunctional character of the area.

Notably, the areas with the highest multisystemic value, as indicated by lighter shades on the map, are not necessarily those with the highest ecological or natural value, but rather those that perform well across multiple ecosystem services. Consequently, the high mountain areas to the north and center of the border exhibit medium to low values, while more accessible areas with lush vegetation, cultural attractions, and agricultural landscapes show higher values.

The valley floor areas, which coincide with urbanized zones and the highest anthropogenic pressures driven by urban and suburban dynamics, clearly exhibit the lowest ecosystem values. However, in certain sections, the pressure of the urban corridor lessens due to the presence of natural areas. These interruptions create valuable opportunities for the establishment of ecological pathways and corridors.

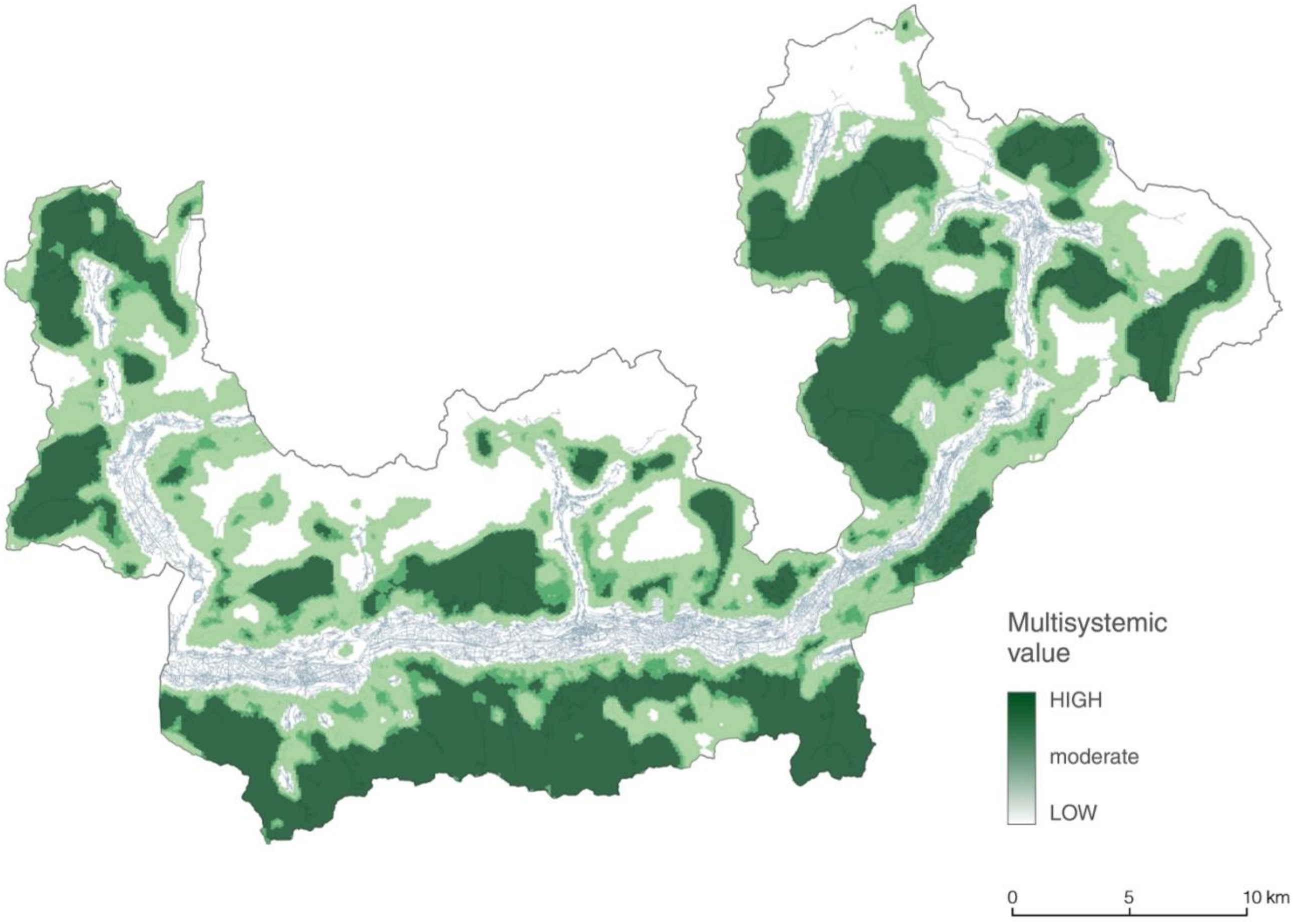
Picture 14: Multisystemic Composite Value



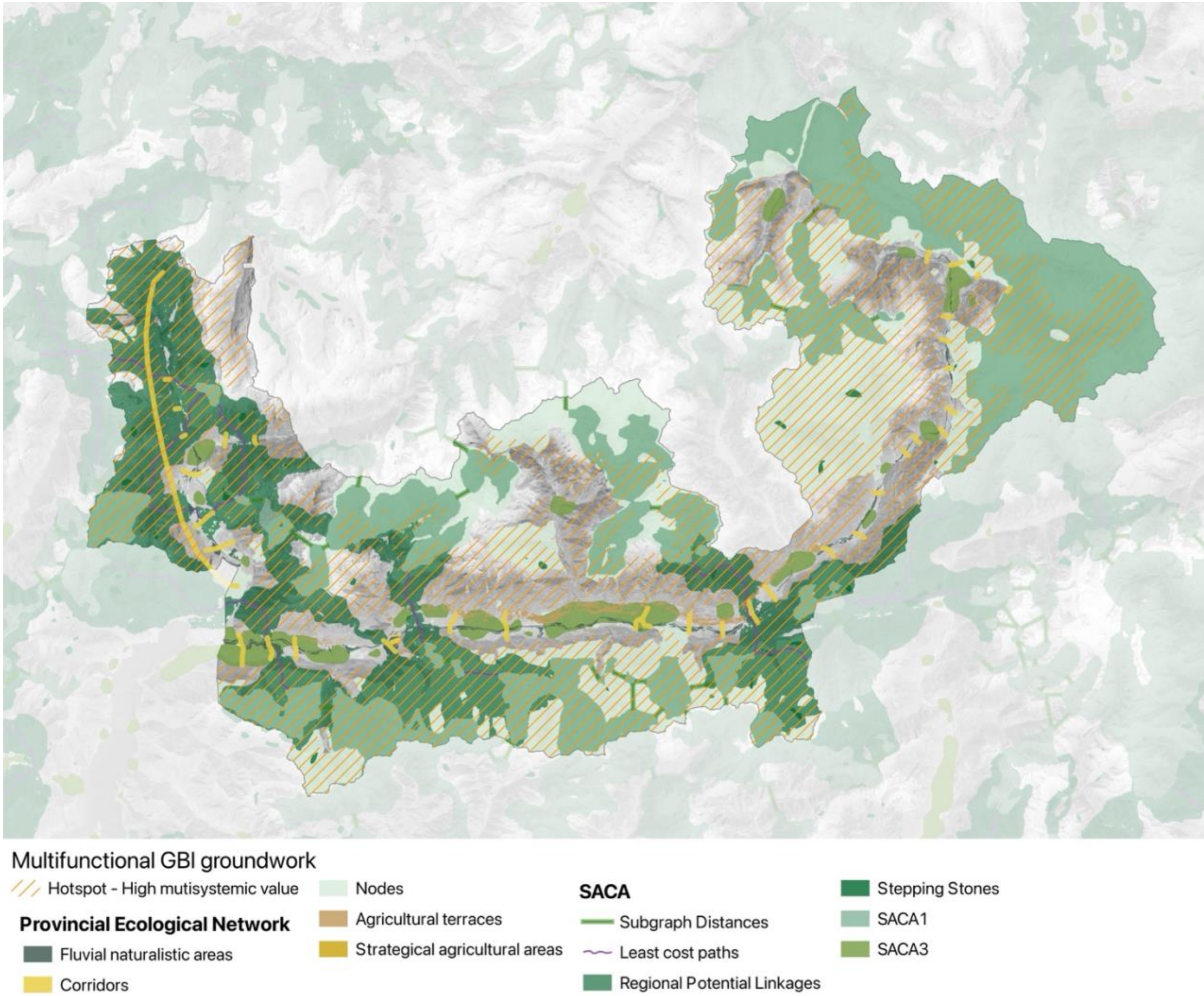
4.8 Overlaying process and initial GBI classes' definition

This chapter marks the transition from the purely analytical phase of the process to the design phase. Until now, a thorough analysis of the ecological elements, natural significance, and multifunctional aspects of the area has been conducted, leading to an assessment of the ecosystem values characterizing the province of Sondrio. Subsequently, a composite analysis was able to synthesize and provide an overview of the individual mappings, thereby identifying areas of high ecosystem and multifunctional value as well as those that currently exhibit lower richness in these respects. The next step involves a further synthesizing of this data and a subsequent integration with the previously analyzed local and regional data (chapters 4.1, 4.2, and 4.4).
In a GIS environment, starting from the composite multisystemic value, an "Optimized Hot Spot Analysis" was conducted to identify statistically significant spatial clusters of high values (hot spots) and low values (cold spots). This analysis automatically aggregates incident data, identifies an appropriate scale of analysis, and accounts for both multiple testing and spatial dependence. In our case, we then selected only the positive values (ranging from 0 to 3), resulting in the outcome presented in the next image.

Picture 15: Hot Spot Analyses



Picture 16: Multifunctional GBI groundwork

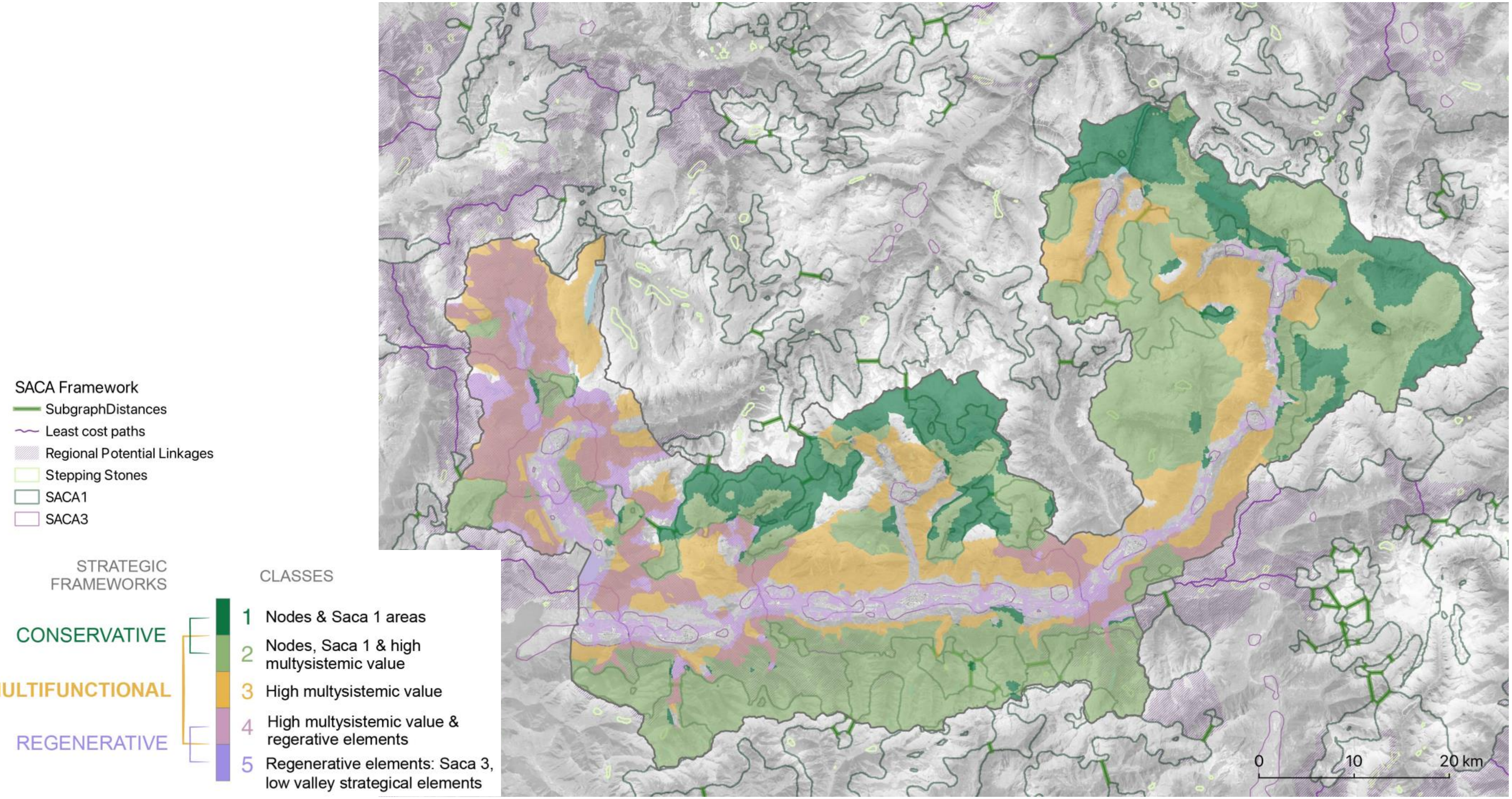


The hotspot analysis effectively identifies and clearly visualizes the provincial areas with high multisystemic capacity, which, as previously noted, shapes the foundation of the project's infrastructure. It is equally important to align and integrate these findings with the previously highlighted natural, ecosystemic, and multifunctional elements. An overview reveals the overlap between this newly generated data and several key components of the provincial green network system and the SACA (System for the Assessment of Conservation Areas) classification. The interaction between different mapped elements is particularly notable, with significant overlap between nodes and SACA 1 areas in the high mountain regions, which largely correspond to areas of high multisystemic value. In the valley floor areas, multiple connectivity elements converge, including zones of high fluvial naturalness, ecological corridors, terraced landscapes, strategic agricultural areas, SACA 3 zones, and regional potential linkages. Although this mapping is preliminary, it begins to delineate some of the fundamental characteristics crucial to the multifunctional infrastructure project.

4.9 Multifunctional GBI classes characterization

The objective of the previous chapter was to consolidate and synthesize all data of significant importance in terms of ecological and multifunctional connectivity for the province of Sondrio. The overlaying of these datasets reveals new relationships and dynamics among the various elements, which are instrumental in defining a categorization of the network. In this preliminary and ongoing step, we will introduce an initial categorization that will serve as the framework for the project.
The previously presented data have been divided into three main categories to delineate the functions and characteristics of each area: high-altitude areas with significant ecological value (nodes and SACA 1); valley floor areas with regenerative features (corridors, regional potential linkages, SACA 3, terraced landscapes, strategic agricultural areas, and riverine natural zones); and areas with high multisystemic capacity (Hotspot Analyses output). In the GIS environment, the three data categories were processed using the "Erase" and "Intersect" tools to spatialize their overlaps and distinctions. This process resulted in five classes: the first consists exclusively of SACA areas and nodes; the second represents the overlap between class 1 and areas with high multisystemic capacity; the third is comprised solely of areas with high multisystemic capacity; the fourth represents the overlap between areas of high multisystemic capacity and valley floor regenerative elements; and the fifth is made up exclusively of the valley floor regenerative elements.

Picture 17: GBI initial classification



This type of interpretation enhances the understanding of the key characteristics that define the multifunctional green and blue infrastructure project. The classes that represent the exclusivity of a single category outline the three primary attributes: conservation, multifunctionality, and connectivity. The first class (1) has a predominantly conservation-oriented role, as the areas of high ecological value located in the high mountains must be protected and preserved from potential anthropogenic uses. The third (3) class, derived from the overlap of multisystemic layers, is the primary bearer of the network's multifunctional character. The composite value is multisystemic, integrating natural, agricultural, and cultural components to create a fabric that reflects ecological, natural, recreational, and productive values. The final class (5) is defined by a regenerative character in the valley floor, shaped by the strategic roles of the river and adjacent agricultural areas, as well as existing and potential ecological corridors. The connection between the two valley floors is the responsibility of this last class, both in terms of ecological continuity and accessibility. The classes resulting from the overlap of different layers (2,4) currently represent a hybrid between their original categories and the multifunctional class, which serves as the cohesive element binding the other two, as illustrated in the accompanying diagram.

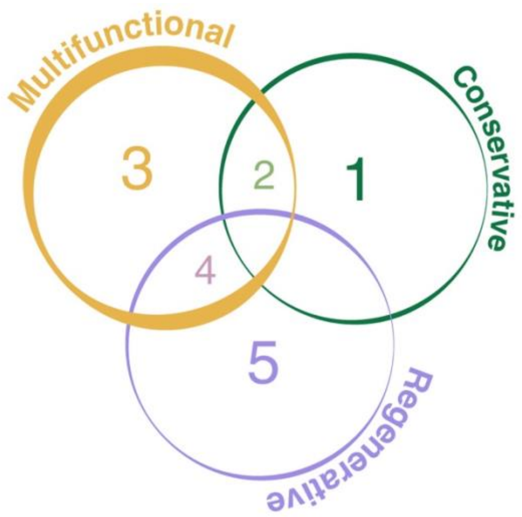
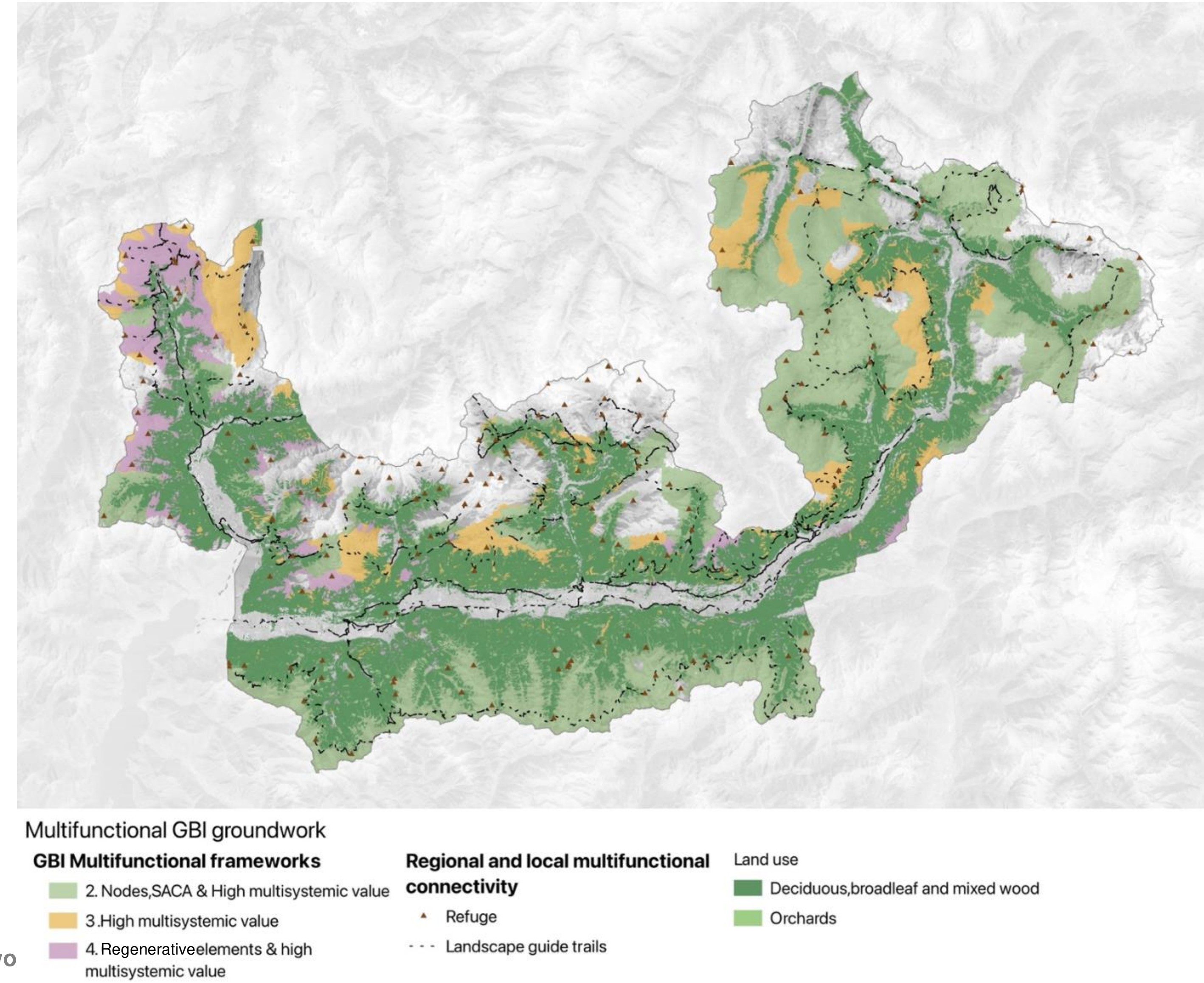


Figure 4: GBI frameworks

Picture 18: Multifunctional frameworks



Picture 18 offers an illustrative view of the relationship between the multifunctional or hybrid classes and the local and regional multifunctionality elements discussed earlier in the document. The alignment of these elements within the boundaries of the macro classes underscores the effective characterization of the framework, which predominantly emphasizes multifunctionality.
Mountain lodges, scenic trails, forests, and pastures will serve as essential components to be integrated into the project's network. Notably, the project area between Morbegno and Tirano exhibits a relative abundance of these elements, which could play a crucial role in supporting the restoration and enhancement of the area's ecological and ecosystemic quality.

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D 2.3.1 Project of local ecological network
Case study: Multifunctional Green and Blue Infrastructure for the Sondrio Province

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