

Fragmentation Tool to Develop Ecological Network from the Local to the Municipal Scale

A Roadmap for Green Infrastructure Planning and Design

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Abstract. Nowadays, several experiences in the international literature show that a planning approach based on the ecosystem services (ES) paradigm can positively influence social dynamics and contribute to enhancing the quality of life in rural and urban environments. Despite this, in Italy, there is no mandatory-planning instrument that considers the green environmental issue as a priority component in planning and design land transformation. In this context, one possible way to introduce GI in spatial planning instruments consists in the design of the ecological network (EN) as a conceptual tool for nature conservation and sustainable land use planning. To do this, the article outlines a methodological framework to encourage the use of geo-mapping solutions for the spatial definition of the EN at both the territorial and municipal scales.

Results show the benefit of this methodology in the spatial recognition and characterization of territory open areas fundamental to design the connectivity of natural and semi-natural habitats to develop the GI at local and municipal scale.

Discussions highlight the importance of the tool to define new relationships between natural resources and agricultural landscape matrix that support high levels of biodiversity and guide green infrastructure planning.

Keywords: green infrastructure · ecosystem services · fragmentation analysis

1 Introduction

Several experiences in the international literature show that a planning approach based on the ecosystem services (ES) paradigm can positively influence social dynamics and contribute to enhancing the quality of life in rural and urban environments. In this sense, it is consolidated the concept that "in cities, land-use decisions made during the

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planning process determine the availability of ES fundamental to the wellbeing of urban population. Hence, the inclusion of ES in planning is essential to promote sustainable urban development" [1].

Despite the need to refers to new paradigms based on the provision of ES by green infrastructure (GI), [2] in Italy there is no mandatory-planning instrument that considers the green environmental issue as a priority component in planning and design land transformation. This is a consequence of the lack of a national framework law on land use that does not consider the role of GI and ES as fundamental in urban development [3].

In this context, one possible way to introduce GI in spatial planning instruments consist in the design of the ecological network (EN) as a conceptual tool for nature conservation and sustainable land use planning, generally developed by interdisciplinary group of sectoral experts from different specific fields (i.e. biology, agricultural, landscape architecture, planners).

Made by a series of 'environmental components' such as core areas, buffer zones, wildlife corridors, stepping-stones, and restoration areas, the EN forms the 'backbone' of the Urban Green Infrastructures (UGI) defined as 'a network of natural and seminatural areas with other environmental features that is supposed to deliver ecosystem services' [4].

In Italy, the concept of EN and then GI is legally recognized by the Italian law "Rules for the Development of Urban Green Spaces [5] that transposed the contents of COM/2013/249 "Green Infrastructure (GI) - Enhancing Europe's Natural Capital" [4] at the national level.

Here, the EN is considered as the basic instrument to plan and manage environmental issues and values in cities, able to preserve the floristic and faunistic biodiversity conservation at national scale [6].

Despite this, the transposition of these concepts into spatial planning instruments was entrusted by the various Regions and differentiated according to the various contexts which referred to the various sector plans with specific regional and regulatory frameworks. These critical aspects have determined an inconsistent framework of tools that hardly interact beyond regional boundaries.

Therefore, to define a working tool to support the management ecological networks beyond administrative fragmentation and across scales is needed.

Also, since the ecological network is made up of a set of many secondary networks [6] that need to be overlapped with land use at the city scale, this paper analyzes and taste a method to plan and design the environmental components that works across administrative boundaries, starting from the regional scale, to inter-municipal and municipal scale [7–9] that would be effective and replicable in different Italian and European context.

Therefore, with the aim of introducing the concepts of green infrastructure and ecosystem services within the Italian land-use plan, the article outlines a methodological framework to encourage the use of geo -mapping solutions for the spatial definition of the EN at both the territorial and municipal scales.

For this purpose, we describe an experimental study conducted in the municipality of Falconara Marittima (province of Ancona) located in Marche Region, in the central part of Italy, where we tested the tool Fragmentation developed in 'Landsupport' platform, a web-based smart geoSpatial Decision Support System (S-DSS, www.landsupport.eu).

Framed in the field of geo-mapping application to monitoring "land take [10] the use of this tool can give a methodological contribution to a performance-based analysis approach in support urban planning, helping in quantified and qualified places by the development of specific environmental and landscape indicators to support the decision-making process.

Results shows the benefit of this methodology in the spatial recognition and characterization of territory open areas (Unità di Territorio Aperto - UTA) fundamental to design continuity and connectivity [11] of natural and semi-natural habitats to develop the GI [12] at the local scale (*Rete Ecologica Locale, REL*) and municipal scale (*Rete Ecologica Comunale, REC*).

The last session highlights the importance of the tool in defining potential relationships between green resources and natural elements of value within the agricultural landscape matrix that support high levels of biodiversity, diversifying strategies to implement GI in natural and rural landscapes and defining the rules for maintenance, valorization, or regeneration of natural capital.

2 Materials and Methods

2.1 Case Study

With the aim of supporting the public administration in drawing up the Green Plan [13] for the municipality of Falconara Marittima based on the definition of strategies to plan the green and blue infrastructure, we defined a cluster of five neighboring municipalities that has been considered strategical to design the ecological network at the local scale: a) Falconara Marittima, b) Montemarciano, c) Monte San Vito, d) Chiaravalle, e) Camerata Picena.

Their selection considers of the two main environmental system of (1) the north part of the coastal areas of Ancona, (2) the Esino river valley, made up by 4 ecological functional unit (Unità Ecologico Funzionali, UEF) of the ecological network of Marche Region REM (Rete Ecologica Marche, article n. 4, 5 [14]) n. 16, 76, 82, 21 (Fig. 1).

These units summarize the environmental system by integrating information of a vegetational, fauna and anthropic nature to characterize the ecological fabric in its different structural and functional articulations.

They are also considered the constitutive element of the REM, highlighting the interrelation between natural elements and anthropic activities that give rise to the diversity of typical landscapes of the Marche Region.

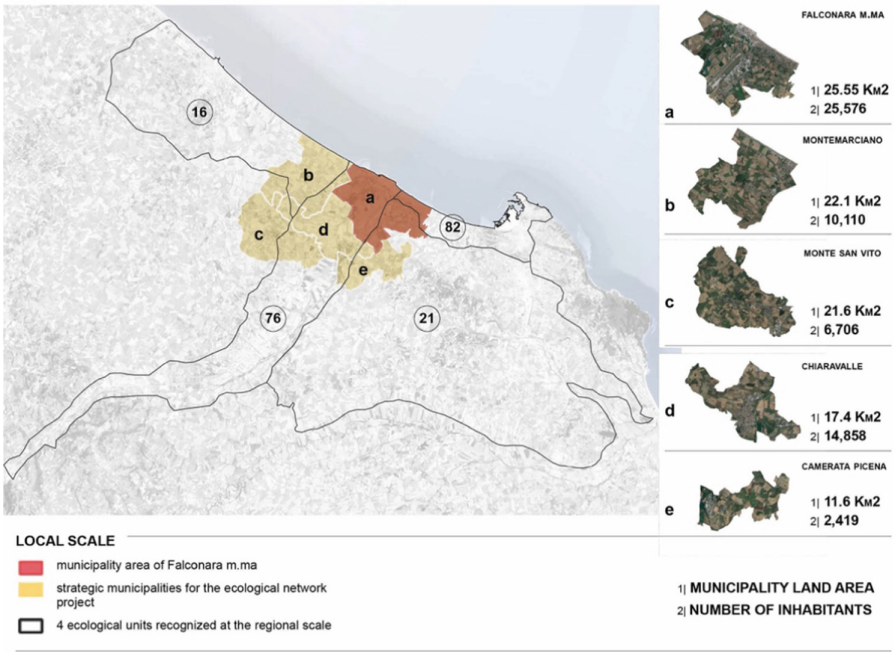

Fig. 1. Four UEF defined by REM, n. 16, 76, 82, 21. In red color: a) municipality of Falconara Marittima. In yellow color: localization of 4 neighboring municipalities interested by the downscaling process: b) Montemarciano, c) Monte San Vito, d) Chiaravalle, e) Camerata Picena.

2.2 Downscaling Method: Referencing from Regional to Municipal Scale

Starting from the selection of the environmental elements of values from the territorial and landscape tools, we grouped the spatial levels from the mandatory and non-mandatory planning instruments in 2 different levels, referring to ES literature [15]:

a) level 1 concerns all natural and ecological resources and mainly contributes to the spatial definition of the EN and so the GI; b) level 2 concerns historical and cultural elements and resources that could add value to the GI and give a specific characterization to a part of it.

At this point, to build the EN at the local scale we just considered the selected spatial levels from level 1, where the downscaling process of the ecological elements [16] have been taken from REM and transposed at the local scale of the ecological networks.

Differently, the downscaling of landscape resources to the municipal scale involved the spatial levels selected in level 1 and level 2 recognized in category (c) of the regional landscape plan (Piano Paesistico Ambientale Regionale – PPAR), and Provincial Territorial Plan (Piano Territoriale di Coordinamento- PTC) which could be physically connected to the primary ecological network (Fig. 2).

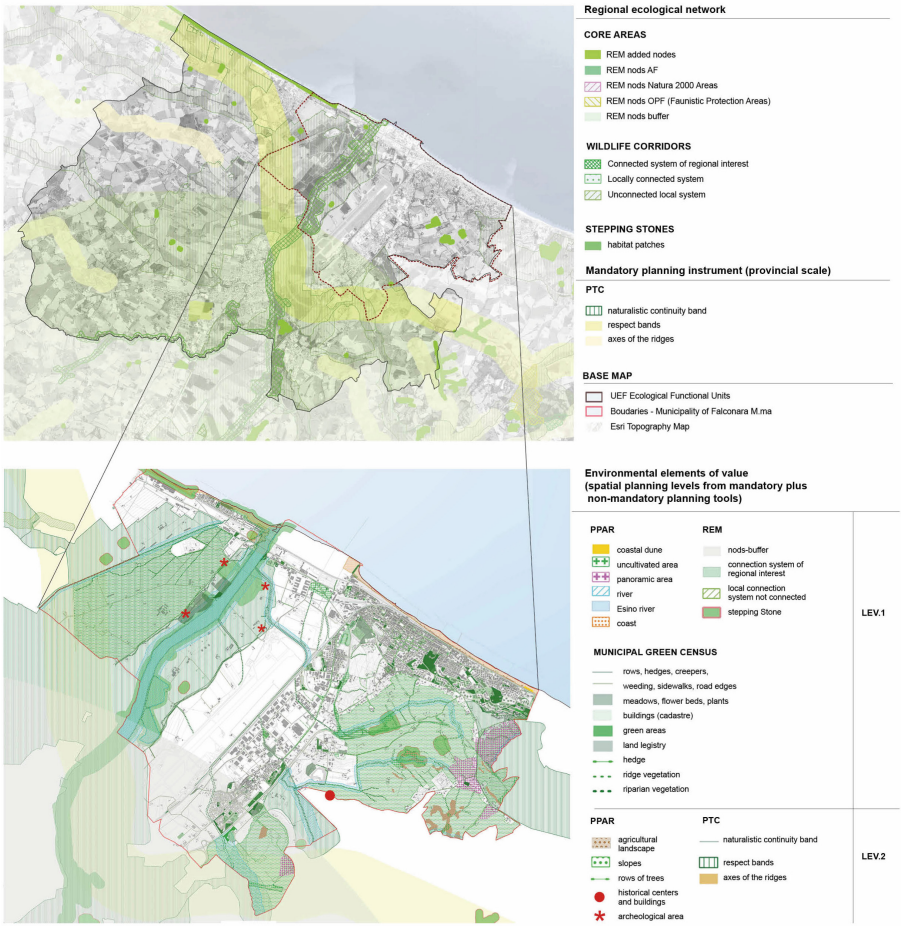

Fig. 2. Downscaling maps of the environmental elements from the territorial and landscape planning tools: local scale (top) and municipal scale (down).

2.3 Geo-Mapping to Help in the Decision-Making Process: The Tool 'Fragmentation' in Landsupport

Using 'fragmentation' tool (k3) from the Landsupport platform (Ka family of web-based geospatial knowledge - smart geoSpatial Decision Support System - S-DSS [17, 18]) we analyzed the continuity of natural areas by exploring a circle between 1 and 1,500 m with a fixed radius set for the five municipalities (defined spatial area – region - in a specific time).

Thanks to this application, we explored the degree of urban and rural fragmentation through an elaboration of an immediate picture of the areas affected by serious degradation processes of the rural territory.

Spatial analysis is based CORINE Land Cover CLC database [19] from EU Copernicus land monitoring services, developed to monitor of land take, land use and transformation, and their interaction within ecosystem services. Data start from year 2006 to 2020 and would be updated to the year 2023. For this case study, we selected images updated to 2020.

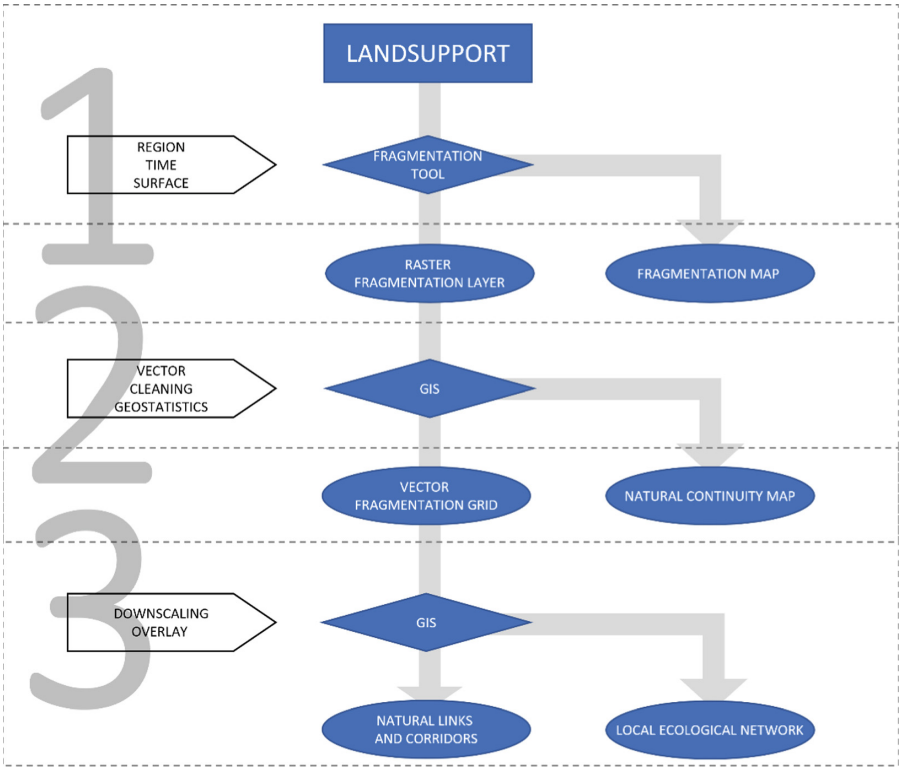

Fig. 3. Diagram of the research methodology based on multiphase and multiscale analysis.

Here, we adopted a multiphase and multiscale analysis based on the following three steps (Fig. 3):

Step 1 - raster fragmentation layer, consist in the downloading a geo-raster file (year 2020) from the application for all municipalities land area. Raster is set by a grid of 10 m * 10 m pixels with values between 0 and 1 to output the fragmentation level of the rural and natural areas, i.e. continuity of the open landscape areas. The value 0 indicates the maximum continuity of the regular grid model (or fishnet) while the value 1 indicates the maximum level of fragmentation (Fig. 4).

Step 2 - vector fragmentation grid, processed in GIS environment. At this step, we converted the raster file in a vector file to overlay the land-use map and selected all the records corresponding to urban areas or roads. By contrast, the values of continuity that

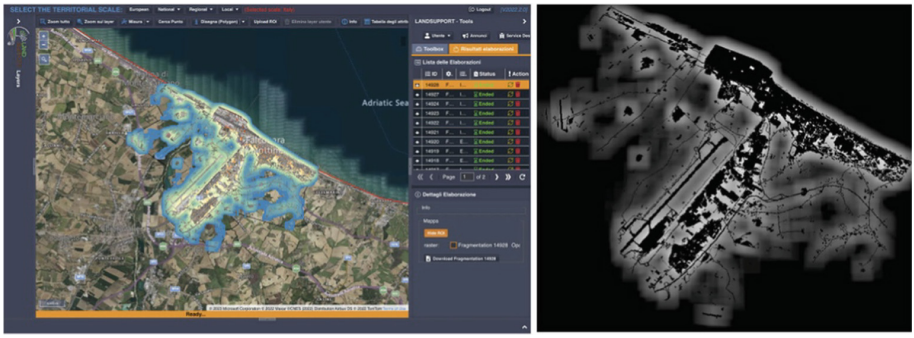

Fig. 4. Geo-raster file of fragmentation downloaded from Landsupport platform (www.landsupport.eu); on the left the graphical interface of the platform on the right an output raster image generate.

fall within these areas have been distinguished from the rural and natural areas of the municipal territory.

So, through specific analysis queries we filtered two different types of classifications functional to divide the urban areas from the natural areas.

Step 3 - geo-mapping the existing barriers and connections of the open landscape areas. At these level, environmental elements that comes from the downscaling process of territorial and landscape planning tools (described in paragraph 2.2) have been overlayed, to identify the potential relationship between the different levels of knowledge investigated with different planning tools at different scales.

3 Results

Starting from phase 1, the first result of the Landsupport implementation is the spatial definition of the levels of 'fragmentation' of natural habitat, identified at the local scale (inter-municipality system) and municipal scale (Fig. 5).

These maps represent the different levels of fragmentation in rural environment for the local and municipal scale, defining a gradient of the continuity index of the rural landscape. Here, the value of the index continuity of the peri-urban areas nearest to the urban areas tends from 1 (maximum level of 'disturb' of ecosystem dynamics) to 0 (highest level of continuity).

Comparing the two different scales of the case study, the range of fragmentation values decreased from 0.16 at the local scale to 0.098 at the inter municipal scale.

Therefore, on a municipal scale it is possible to consider areas with a value lower than 0.06 as continuous, while on an inter-municipal scale the threshold value is 0.03.

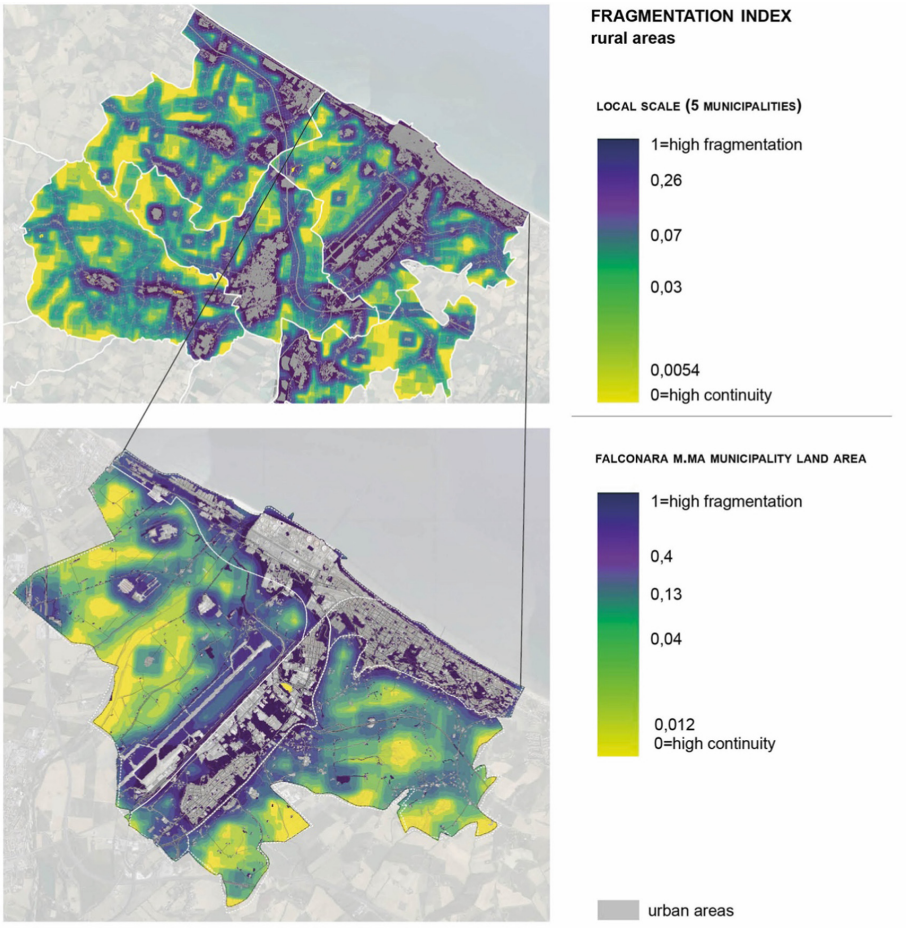

Fig. 5. Fragmentation map for the local scale (top) and municipal scale of Falconara Marittima (down) set in Landsupport platform (year 2023).

The second result consists in the definition of a vector grid processed in GIS environment to characterize rural landscape by applying geostatistical analysis to quantify and describe different areas. Specifically, for the municipality of Falconara Marittima we evaluated: a) average index of fragmentation of extra-urban natural areas; b) the total surface of rural areas with levels of continuity higher than the average fragmentation index; c) the ratio between the level of fragmentation of the rural and the urban areas on the total municipal areas; d) the ratio between the level of fragmentation of the rural and the urban area on the total of rural areas of the municipality (Table 1). These data are essential to quantify the urbanized area at the municipal scale, and to monitor dynamics of soil consumption.

Furthermore, starting from the evaluation of the levels of fragmentation we defined the territory open areas (Unità di Territorio Aperto – UTA) with a high level of connections, as essential components of the ecological network to be interconnected (Fig. 6).

Table 1. Characterization of the rural and natural landscape

Municipality land area (km^2)	Urbanized area (km^2)	Rural + natural landscape (km^2)	Urbanized area (% on the municipal land area)	Rural + natural landscape (% on the municipal land area)	F index*(Mean value)	Territory open area (UTA)**(km^2)	Territory open area (UTA)** (% on rural + natural landscape)
26	6	20	23	77	0,168	13	65

*F index = fragmentation index

**open areas characterized by a low level of fragmentation, that means a high level of continuity

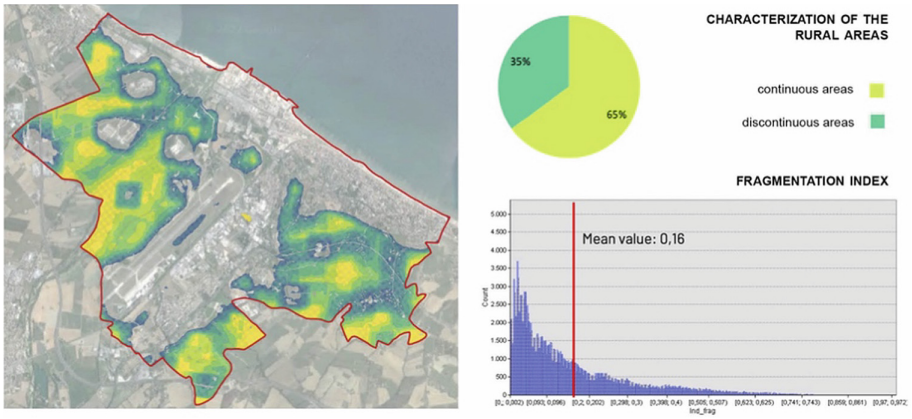

Fig. 6. Spatial definition of territory open areas (UTA) and characterization of the rural area of case study (municipality of Falconara Marittima, Marche Region)

The third result consists in the design of ecological network system at the local and municipal level, obtained from the spatial analysis deriving from Landsupport overlayed to the downscaling elements coming from the different current spatial planning tools.

At the local scale, the matching between spatial levels that comes from the traditional downscaling method and the open territory areas (Unità di Territorio Aperto, UTA, Fig. 7) allows to define the spatial development of local ecological network systems for the five-neighboring municipalities.

Here, the critical elements of the ecological network to preserve as a) core; b) buffer zones; c) ecological corridors, have been reconnected to the environmental matrix of agricultural areas that would support higher levels of biodiversity [20] and more environmental quality.

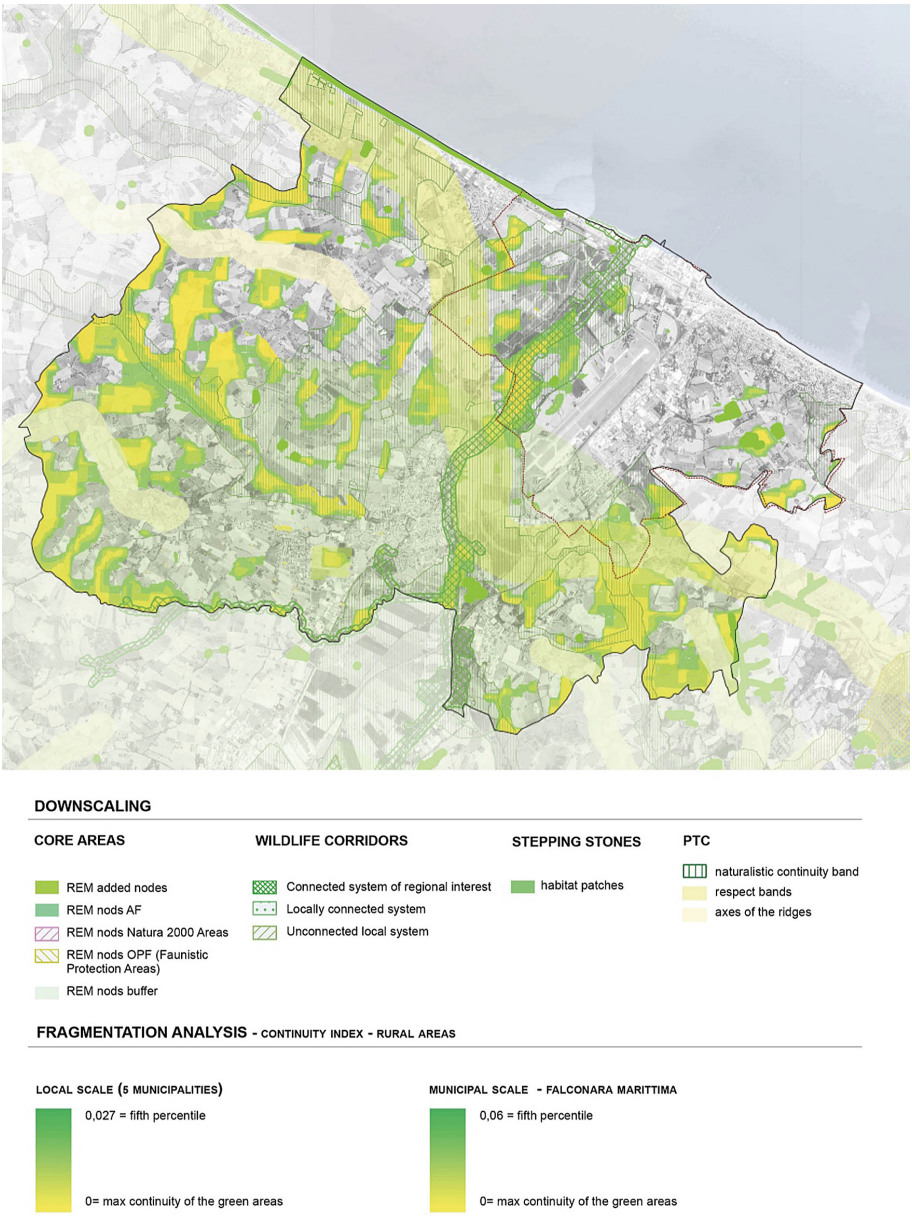

Fig. 7. Definition of the ecological network (REL) for the five municipalities local system. Overlaying of the main component of ecological network at regional scale (downscaling) and the territory open areas (UTA) derived by the fragmentation spatial analysis.

At the municipal scale, this method allows us to: (a) plan the green corridors, (b) improve the potential connections between the existing natural resources and the agricultural areas, c) rebuild the continuity of ecosystems.

Identified as the main components of the ecological network, the use of financial resources on these elements would be necessary for the strengthen multifunctionality and therefore the supply of ES to the city.

At this stage, the spatial level of the primary network systems of green spaces, GI, of the municipal scale (Fig. 8) supported in the definition and develop of strategical actions supported by the employment of nature-based solution (NBS): a) to recognize existing barriers to rebuild the continuity of ecosystems; b) to preserve/reinforce existing connection to strengthen the ecological system; c) to design new connections to achieve ecological connectivity (Table 2).

Table 2. Design lines to implement the ecological network at the local scale.

Elements	Description	Planning design and actions (Existing/Prevision)	
		Existing	Prevision
Barriers	Infrastructure or urbanized areas which block the transition of animal and plant populations	Provide defrag actions (by adopting nature-based solutions i.e. wildlife bridges, underpasses etc.)	Provide mitigation action to avoid fragmentation dynamics (by adopting nature-based solutions i.e. wildlife bridges, underpasses etc.)
Connections	Existing natural elements in non-urbanized areas		Provide design action – NBS solutions starting from the framework of the Ecological Network
	Natural elements in big parks reserve, Natura 2000 site, ecc	Planning intervention to preserve/strengthen the existing natural capital	

Since the fragmentation analysis contributes to the definition of strategic planning actions for GI development at the municipal scale (Fig. 8), we define the multiple ecosystem services provided by the GI planning action (already defined by the downscaling method plus multiphase fragmentation analysis), developed following the cascade model [15] (Table 3).

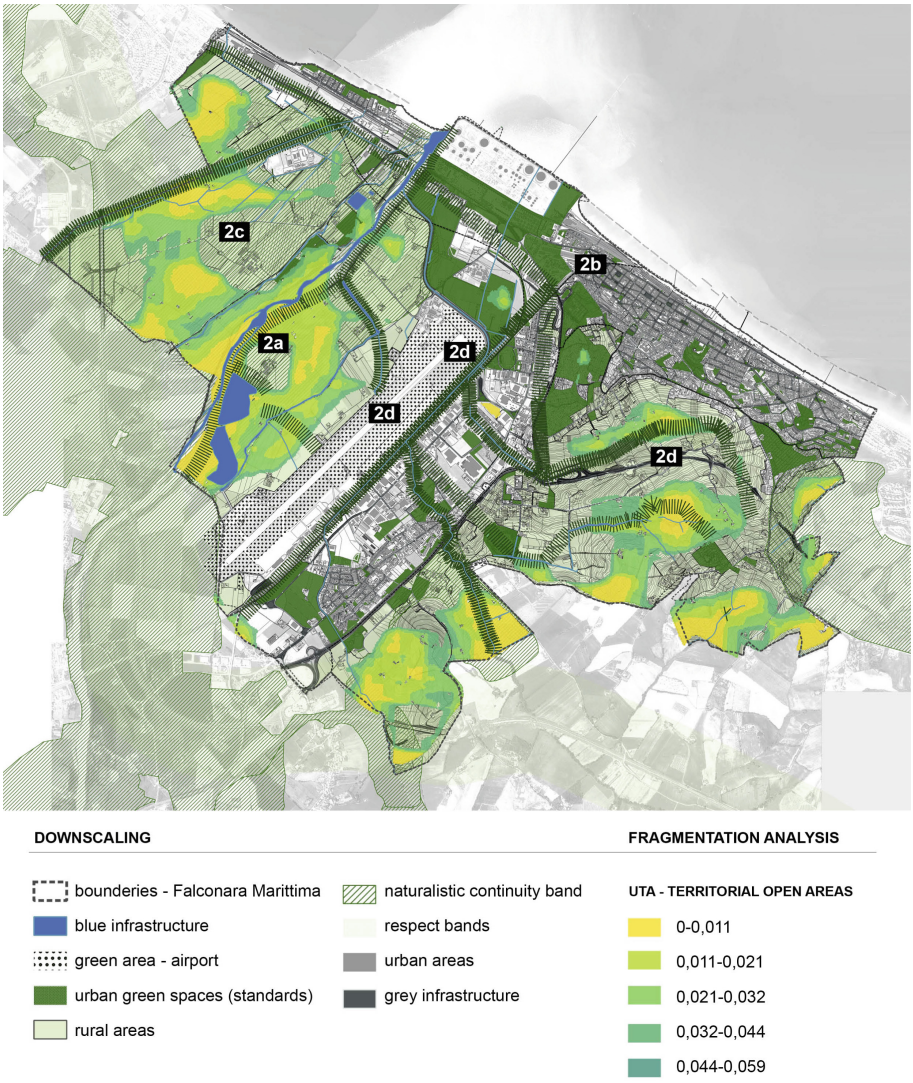

Fig. 8. Definition of the ecological network (REC) for the municipality land area. Overlaying of the main component of ecological network at regional scale (downscaling) and the territory open areas (UTA) derived by the fragmentation spatial analysis.

Table 3. Relationship between GI design action and ES potentially provided by theme [21]

Project area	GI design action (n.)	GI design action (description)	Management strategies	Type of action*			ES provided (prevalent)
				Ma	Va	Re	
Water bodies	**2a**	Strengthening of the role of the blue network of channel and ditches of the Esino river inside the Ecological functional Units identified by the REM	Encourage regeneration of shrub and herbaceous species (spontaneous or planted) [22]			x	Water regulation - Erosion control and sediment retention
			Encourage the planting of mesophiles and hygrophilous species along the riparian strips, also by providing for short rotation plants to produce woody biomass [22]		x		
			Avoid tillage in the buffer zone 4 m from the embankment	x			
			Renaturalization of the banks of lakes and ponds			x	
Woods	**2b**	Upgrading of existing forestry system	Conservation of wooded areas and re-naturalization with native species to enhance floristic richness and stability of the system		x		Pollination and biological control
			Provide shrubby vegetation strip at the edge of cultivated areas		x		

(*continued*)

Table 3. (*continued*)

Project area	GI design action (n.)	GI design action (description)	Management strategies	Type of action*			ES provided (prevalent)
				Ma	Va	Re	
Agro-ecosystems	**2c** **2d**	Strengthening of the ecological network within agricultural peri-urban areas (farm roads, canals and ditches, field border system)	Promote agriculture with a low environmental impact, reducing the use of pesticides and fertilizers	x			Landscape perception (traditional/ cultural value)
			Conserve and restore the traditional elements of the rural landscape in arable areas, such as isolated tree elements, rows, hedges	x			
			Maintain buffer strips at the margins of arable land with the use of mixed native species	x			
			Provide shrubby vegetation strip at the edge of cultivated areas		x		
		Reconstruction of the network of green corridors and natural elements through cultivated areas	Encourage sustainable mobility systems within cultivated areas		x		Recreational

(*continued*)

Table 3. (*continued*)

Project area	GI design action (n.)	GI design action (description)	Management strategies	Type of action*			ES provided (prevalent)
				Ma	Va	Re	
Urban settlement and infrastructure	**2e**	Design and management of urban green spaces to promote the conservation of biodiversity and soil protection	Provide for environmental compensations for new interventions		x		Climate regulation (air cooling) Gas regulation Soil permeability
			Strengthen the environmental compensations in productive areas		x		
			Reinforce the public and private green spaces in urban areas (zone C - expansion areas)		x		
			Promote the ecological permeability of the soils in project areas	x			
			Encourage the permanence of birds in urban and peri-urban areas	x			Refugia
			Protection of the row of trees and replanting where necessary	x			Disturbance regulation
			Mitigation of infrastructures by planting wooded strips			x	

* Ma = Maintenance; Va = Valorization; Re = Regeneration

4 Discussions

The territorial analysis of fragmentation levels in Landsupport platform is a useful tool for public administrations in facilitate the decision-making process on spatial planning namely to take decision avoiding new land take and enhancing natural assets in urban planning.

In fact, to guarantee the achievement of new quality standards imposed at the regional, provincial, and metropolitan levels of planning in sustainable urban development, it supports both technical and political parts involved in the land use planning and management of natural resources.

Today, the contents and range of territorial plans do not only consist of common updates but require a radical improvement in the potential and conception of the instrument itself to stop dispersion and facilitate compact urban areas. Indeed, spatial, and ecological fragmentation constitutes one of the principal causes of degradation at a regional level, meaning that it will be necessary to aim for defragmentation through numerous initiatives on different scales.

In this perspective, fragmentation map helps to a) increase specific knowledge in dynamics of urban development; b) evaluate the state-of-the-art analysis based on specific indicators to foresee the potential consequences of the various actions to be planned.

In future perspective, a possible implementation of these study consists in the evaluation of the level of proximity of the UTA as restoration areas to the urban green spaces (i.e. urban parks and gardens) In fact, to verify the accessibility but also the availability of the UTA from the rural to the urban areas is necessary to evaluate the provisioning of ecosystem services in relation to demographic dynamics and social *milieu* of the cities inhabitants.

With reference to the case study, the multiphase analysis provides different outputs with different purposes:

Firstly, the spatial definition of land use and land consumption dynamics during the time allows to provide the degree of fragmented areas (compromise area) on a municipal scale showing an historical trend of this dynamics.

Also, the evaluate the discontinuity of ecological connections is fundamental to understand the processes of degradation of ecosystem functions, which are the main cause of land use degradation.

Therefore, considering that the GI is a concrete action to mitigate the effects of soil sealing, [23] fragmentation map would be opportune in supporting the definition of the zones in which establishing protected natural areas of local interest and so in the implementation of strategies to reduce soil consumption, to protect and to preserve soils degradation. In fact, soil consumption and soil degradation are the main cause of the loss of ecosystem services as water regulation and air quality, where the growth of human activities and the sealing process (which causes fine particles and air pollution) counts around 4.2 million deaths every year in Europe [24].

Also, the vectorization of the ‘negative’ of the spatial analysis of the fragmentation defines the UTAs seen as ‘restoration areas’ within the landscape matrix, fundamental for reconstructing the ecological corridors from rural to natural spaces.

About the limitations of this study, we highlight some critical issues related to the implementation of the tool fragmentation:

Firstly, since the analysis is based on the photointerpretation of spatial surface types, in some cases different surfaces with similar colors are still interpreted as analogous.

Secondly, the raster output from the Landsupport platform represents both urban and peri-urban areas with the same values of continuity.

In fact, since the tool analyzes the continuity of the areas, a rural area assumes the same level of continuity as an urban area. Therefore, further refinement of spatial data is required.

This means that it is necessary to carry out geoprocessing operations to separate the urban from the peri-urban areas and to isolate the portions of natural territory characterized by a high level of continuity from the urban ones.

Although these operations are carried out semi-automatically using layers from regional databases such as, for example, the Atlas on Soil Sealing [25] it needs to be corrected with a manual implementation that can be time consuming and requires specific knowledge of the different context. Furthermore, this type of operation is feasible on a municipal scale but much more difficult for wider contexts.

Lastly, the implementation of GI design action supposes a critical selection of the ecological connection to invest in NBS with priority over the others.

This asset required knowledge of the locations (project areas) and integration with the site investigations and specific agronomic and botanic-vegetational studies to support the analysis of local data.

5 Conclusions

Since the inclusion of ES in planning is essential to promote sustainable urban development, a new planning approach that considers the integration of GI as the spatial design tool to deliver ES in urban and peri-urban areas is now required.

The contribution illustrates a potential method for integrating GI within the common European and Italian planning practices. It describes a multi-scale and level approach based on ecological network integration for GI development, starting from the local scale to define the strategic action at the municipal scale to update the current urban plans in force.

Focusing on the analysis of 'fragmentation' using the 'Landsupport' platform to support and facilitate the decision-making process, the case study demonstrates that the use of new planning tools to easily achieve and process specific data and knowledge in the dynamics both urban and environmental development can positively contribute to developing GI strategies within traditional planning tools.

To this end, it could represent a valid method to raise the awareness of the public administration, decision makers and technicians to introduce the concepts of green infrastructure and ecosystem services in spatial planning and properly manage these elements within the mandatory planning tool.

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