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TOPICAL COLLECTION

Designing a green infrastructure network for metropolitan areas: a spatial planning approach

Georgia Pozoukidou[1]

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Abstract

Climate change and environmental pressures in urban areas have created the need for new concepts and tools for the management of urban development that ensure the protection of natural and cultural resources while also enhancing urban resilience. Green infrastructure (GI) is often associated with sustainable goals that cities strive to achieve through a combination of natural approaches. A key concept in these approaches is the inherent capacity of the natural environment to carry out several functions, meaning that it can provide a variety of ecosystem services and deliver a wide range of policy objectives. Nevertheless, recent studies on the integration of GI into spatial planning have reported limited acknowledgement of the ecosystem services that GI can offer and a lack of a territorial perspective. This paper therefore provides a methodology that facilitates a spatial planning approach to GI planning in metropolitan areas. Based on the definition of GI proposed by the European Commission, which suggests that connectivity and multifunctionality are key to the effective implementation of GI, a two-step methodological approach to GI planning is proposed. This approach is spatially centered, thus promoting the desired territorial perspective, while it also acknowledges the notion of an ecosystem service as a basic design principle. When applied to the metropolitan area of Thessaloniki in Greece, the methodology was found to facilitate the prioritization of competing planning priorities and to promote certain planning objectives, thus enhancing urban resilience and helping to improve the efficiency of land and resource use.

Keywords Green infrastructure · Spatial planning · Ecosystem services · Functional assessment

Green infrastructure and spatial planning

Interest from researchers in including green infrastructure (GI) in spatial planning has grown rapidly over the last two decades. This is due to the fact that climate change and environmental pressures in urban areas have created a need for new concepts and tools for managing urban development in a manner that protects natural and cultural resources and enhances urban resilience (Ahern 2007; Foster et al. 2011; Beatley 2000).

The main aim of GI is to enhance the health and resilience of ecosystems while simultaneously ensuring that they provide a wide variety of societal benefits through nature-based solutions. The original GI concept had its roots in ecosystem conservation efforts, so GI was defined as parks, forests, wetlands, green zones, and flood zones in and around cities—any area that enhances quality of life or provides ecosystem services (e.g., water filtration and flood control). However, GI has recently acquired new roles that are often related to the environmental or sustainability goals that cities strive to achieve through a combination of natural approaches (Foster et al. 2011).

In 2013, the European Commission (EC) put forward a GI strategy to ensure that the protection, restoration, creation, and enhancement of GI become standard and integral parts of spatial planning and territorial development whenever they complement or offer a better alternative to standard gray choices (European Commission 2013). The benefits of GI and its potential contribution to the implementation of various policies are now recognized. These benefits occur because implementing GI requires an integrated view of ecosystem services, which in turn encourages a balanced

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Georgia Pozoukidou
gpozoukid@plandevel.auth.gr

[1] Faculty of Engineering, School of Spatial Planning and Development, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

approach that emphasizes the multifunctional nature of a territory. Therefore, GI is considered to foster a more coherent approach to decision making when attempting to integrate ecological and sustainability concerns into spatial planning.

Authorities that are responsible for land planning play a critical role when implementing GI. A recent analysis of policy and planning for GI in EU states highlighted the limited deployment and underused potential of GI (ESPON EGTC 2019). Insufficient understanding amongst stakeholders of the way that natural ecosystems function and the limited capacity of decision makers are reported to be major deployment bottlenecks.

Acknowledging the limited integration of GI into spatial planning processes as well as the knowledge gap regarding the application of the GI and ES approach and the scales and phases of the planning process at which it is feasible to use this approach, this paper provides a methodology that facilitates a spatial planning approach to GI planning in metropolitan areas. As GI has the ability to provide multiple ecosystem services within a single policy objective (i.e., mitigating climate change, maintaining biodiversity, etc.) or across policy objectives and human activities (economic, social, and cultural), the methodology provides a systematic approach to prioritizing competing priorities within the spatial planning process across scales.

This paper starts by presenting the basic aspects of GI, focusing on the notion of ecosystem services and its links to spatial planning processes. Based on the three key features that are crucial to the effective implementation of GI into spatial planning, a review of the Greek GI policy setting and spatial planning system is then presented. Since the case study elaborated in the paper considers a Greek metropolitan area, the review aims to highlight implementation gaps and bottlenecks in the Greek spatial planning realm. After that, the proposed methodological approach for planning a GI network is presented, addressing the issues of spatial distribution, functional assessment, and required data sources. The last section of the paper describes the application of the methodology to the study area: the metropolitan area of the city of Thessaloniki in Greece.

Basic concepts and aspects of green infrastructure

The basic underlying principle of GI is that the same land area can offer a variety of benefits, such as environmental, social, cultural, and economic benefits, provided its ecosystems are in a healthy condition. Ecosystem services (ES) refer to the benefits that can be derived from ecosystems, such as the provision of food, materials, clean water, clean air, climate regulation, flood prevention, pollination, and recreation (Bartesaghi et al. 2018; Camps-Calvet et al. 2016; Lin et al. 2015; Tzoulas et al. 2007; Eckart et al. 2017; ESPON EGTC 2019). Thus, the ES concept offers a valuable method of linking humans and nature (i.e., human well-being with current and potential environmental conditions; European Commission 2013), and provides extra impetus to conserve and restore natural ecosystems (Benedict and McMahon 2006).

There are many definitions of GI, such as those proposed by Benedict and McMahon (2012), Kambites et al. (2006), Ahern (2007), Dapolito (2010), and Naumann et al. (2011), as it is a relatively new concept in the field of spatial planning. Embracing the ecosystem concept, the EC defined GI in 2013 as 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 (ES). 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." This definition is based on three key features that are important for the effective implementation of GI in sectoral policies: connectivity, multifunctionality, and links to spatial planning (ESPON EGTC 2018).

Here, connectivity refers to biodiversity enhancement and habitat provision (an ecosystem service). It relates to the ability of species to move between areas, and can be structural (i.e., habitat continuity) or functional (i.e., the ability of landscapes to allow various species to move and expand to new areas without them necessarily being physically connected) in nature (Baró et al. 2015). A lack or loss of connectivity reduces the ability of organisms to move, interfering with pollination, seed dispersal, wildlife migration, and breeding, which also impacts ecosystem services at various scales. In contrast, improving bioconnectivity enhances ecological connectivity and networks, which in turn promotes biological diversity and ecological processes. This concept represents an innovative territorial and governance perspective (Cronato et al. 2019; Tsaligopoulos et al. 2019).

Multifunctionality is the ability of GI to provide not only habitat (ecological) services but also many other ecosystem services (e.g., ecological/regulating, social/cultural, and/or economic/provisioning services) simultaneously in one locale (Mell 2017). Ensuring healthy ecosystems and maintaining the long-term delivery of multiple ecosystem services within a well-connected GI network supports the objectives of numerous EU policy sectors, such as cohesion, water, energy, transport, agriculture, climate, and biodiversity.

It is believed that GI should ideally be an integral part of spatial planning and territorial development policies. Spatial planning involves integrating various public policies (economic, environmental, and societal) that affect the spatial organization of activities and the governance of a region.

GI has historically usually been perceived as a sectoral policy for spatial planning (in a similar way to transportation and housing), and therefore as one of the objectives of spatial planning (Slätmo et al. 2019). On the other hand, there are cases where GI is considered to result from an integrated approach to planning where developmental priorities and environmental protection are balanced (ESPON EGTC 2019). Regardless of how GI is approached, it is generally accepted that integrated spatial planning should be informed by ecological processes in order to achieve sustainable and resilient environmental, economic, and societal development.

In this context, GI could provide the framework for prioritizing and assessing various ecosystem services, their spatial patterns and distribution. In this regard, a GI approach could be used for benchmarking alternative planning scenarios, utilizing GI and ES as planning criteria. Furthermore, GI enhances strategic thinking and incorporates ES and their benefits as relevant planning criteria for more resilient territorial development.

GI in the Greek spatial planning realm

The GI policy setting

There is no national or comprehensive GI policy or strategy at any spatial level in Greece, and there is no EU directive that enforces the compliance of any national legislation with the EU GI strategy activated in 2013. Therefore, GI solutions and approaches are embedded in various national and sectoral policies and strategies.

The National Biodiversity Strategy and Action Plan adopted in 2014 refers to GI as a different approach to biodiversity conservation that "changes our perception of ecosystems, because it highlights the services they provide, which might be replaced by manmade means, but with greater financial cost compared to the cost of protecting ecosystems. Essentially, it is a network of natural agricultural, freshwater and marine areas, including national parks, forests and other areas, which, as a network, regulate the water cycle, have a role in temperature regulation, decrease the risks of flooding, improve air quality, etc." This strategy acknowledges the multifunctional benefits of GI and prioritizes the promotion, establishment, and maintenance of natural GI in rural and urban areas (Target 13). Furthermore, it considers a GI approach to be a means of avoiding habitat fragmentation (Target 5.5.2), promoting ecosystem restoration (Target 5.5.3), and establishing synergies between GI and tourism services (Ministry of Environment and Climate Change 2014).

On the other hand, in the National Climate Change Adaptation Strategy (NCCAS) adopted in 2016, GI is defined as an approach that alleviates habitat fragmentation through the implementation of appropriate land-use regulations. It also highlights the multifunctional nature of GI and the benefits of an ecosystem-based adaptation approach (Action 4—Land Use Regulations, p. 34). The Greek climate change adaptation policy includes Regional Adaptation Plans to Climate Change, which are regional in scale (NUTS 2) and must comply with the NCCAS. These plans draw from the National Biodiversity Strategy and Action Plan, the National Spatial Planning Framework, and the respective Regional Spatial Plans (Ministry of Environment and Energy 2017c). As such, they emphasize the need to protect ecosystem function in natural areas while highlighting the significance of natural and manmade landscapes such as archaeological and historical sites, forests and forested areas, seashores and beaches, rivers, lakes, streams, as well as areas falling under the remit of the national system of protected areas.

The National Operational Program *Environment—Sustainable Development 2007–2013* includes a section on the protection of natural environment and biodiversity (Priority 9) that aims to protect against loss of biodiversity by ensuring that satisfactory conditions are achieved and maintained for habitats and populations of endangered species and areas of ecological interest. Goal specifications and relevant actions indicate that there is an emphasis on enhancing landscape diversity, establishing networks, increasing accessibility to key protected areas, and creating thematic strategies for wetlands, forests, mountain ecosystems, coastal ecosystems, and rural areas.

European Union project funds that promote GI-related policy include the European Regional Development Fund, the Cohesion Fund, the LIFE program, and Horizon 2020 (ESPON EGTC 2019). While not directly implementing GI, these projects and initiatives have the potential to support basic features of GI such as connectivity and multifunctionality and to help facilitate green infrastructure in Greece.

GI in the context of the Greek spatial planning system

This section explores the insertion of GI into Greek planning texts by incorporating its design principles (connectivity and multifunctionality) and acknowledging the ecosystem services that GI provides. Furthermore, it focuses on the spatial plans that are generally drawn up to regulate areas outside settlements or urban centers (periurban areas) in Greece: Local Spatial Plans, Special Spatial Plans, Regional Spatial Plans, and Master Plans.

It should be noted that the Ministry of Environment and Energy (2016a) is responsible for devising spatial policy, preparing plans and programs, and overseeing their implementation. It is also in charge of developing and implementing environmental policy. At the decentralized level, regional and municipal authorities exercise (within their areas) certain spatial competences and assure the specialization and localization of national and regional plans to local plans and ordinances. Table 1 depicts the structure of the spatial planning system in Greece.

Local Spatial Plans (LSPs; Law 4447/2016; Ministry of Environment and Energy 2016b) and the respective implementation guidelines (Ministry of Environment and Energy 2017a) do not make any specific reference to the concept of GI or tools for implementing it. Nevertheless, there are references to the protection and enhancement of the natural and environmental features of cities, settlements, and suburban areas. In this sense, it could be argued that this law represents a relatively comprehensive approach to natural areas and landscapes at all elaborated scales, although it mainly focuses on the protection rather than the utilization of these areas as part of a multifunctional network. A critical element of these plans that could be utilized as a mechanism to help implement GI is the designation of protected areas that include significant natural and manmade areas and landscapes such as archaeological and historical sites, forests and forested areas, seashore and beaches, rivers, lakes, and streams, as well as areas that fall under the remit of the national protection system. According to the implementation guidelines for LSPs, the aim of these zones is to protect and promote networks of natural and cultural resources in order to protect and/or promote special tourism and leisure activities, walking routes, paths, beaches, swimming, etc. It is worth noting that these zones can include agricultural land and other areas that contain valuable natural resources that could be essential elements of a GI network. However, LSPs do not provide a framework of land-use principles or specific design properties (i.e., connectivity and multifunctionality) as part of the implementation strategy for and amongst the protected areas.

There is no explicit reference to GI in Special Spatial Plans either. The implementation guidelines for the facilitation of such plans (Ministry of Environment and Energy 2017b) describe the structure and the content of such plans but do not define a framework of essential principles for the development of GI. Nevertheless, just as for LSPs, the designation of protected areas and appropriate land-use allocation could be used to develop and implement a GI network.

At the strategic level, Regional Spatial Plans and their implementation guidelines (Ministry of Environment and Energy 2018) do not explicitly mention GI or provide tools for implementating it. Nevertheless, it could be argued that recent developments in the perception of the landscape as a complex socioecological system that links nature to culture (Kyvelou and Gourgiotis 2019) have provided the groundwork for incorporating GI into spatial planning through landscape policies. According to Kyvelou and Gourgiotis (2019), the ratification of the European Landscape Convention by the Greek state and the incorporation of landscape

Table 1 The structure of the Greek spatial planning system according to Law 4447/2016: *Spatial planning—sustainable development and other provisions* Source: Law 4447/2016; table created by the author

Strategic spatial planning	
National spatial plans	*The National Spatial Planning Strategy (NSPS).* This plan is the basis for the coordination of the Strategic Spatial Plans, the individual investment plans and programs of the state and local authorities, public legal entities, frameworks, plans, and programs that have significant implications for the development and cohesion of the national territory. In particular, the National Spatial Planning Strategy may include the national strategic directions for a whole range of topics overarching all levels of spatial plans
	Sectoral Special Spatial Plans (SSSPs). These specify directions at the national level for certain productive sector(s). They are harmonized with the NSPS. Spatial plans for industry, tourism, aquaculture, renewable energy, prisons, and mineral raw materials are currently being compiled
	Special Spatial Framework Plans (SSFPs). These specify directions at the national level for certain types of territories. No such plans are currently being compiled
Regional spatial plans	*Regional Spatial Plans (RSPs).* These plans take into account the principles, aims, and guidelines of the NSPS and provide guidelines for spatial development at the regional administrative level (NUTS 2). They need to be harmonized with the Special Spatial Plans
	Master Plans (MPs). These are plans for complex urban systems such as metropolitan areas and functional areas of large urban centers
Regulatory spatial planning	
Local spatial plans	*Special Spatial Plans (SSPs).* These define the spatial organization and development of areas—regardless of administrative boundaries—that may act as recipients of plans, projects, and programs of a supralocal or strategic scale, or areas that require special land uses and developmental regulations and terms
	Local Spatial Plans (LSPs). These define the spatial organization and development of urban functions, land uses, building regulations, and any other measure, condition, or restriction required for the comprehensive spatial development and organization of an area at the municipal level
	Urban Plans (UPs). These constitute implementation plans, and are subject to the LSP or SSP at the urban/settlement scale. They accurately indicate land uses, open and green spaces, public facilities, infrastructure networks, and building regulations

policies into spatial planning have meant that the landscape can now be considered a "space regulator i.e., a parameter to be taken in a systematic way into account by spatial planning processes, promoting the harmonious integration to it of all the changes imposed by socio-economic change and environmental processes." The new RSPs (which are currently in the process of being legislated) encompass an integrated approach to the landscape in which social, economic, and environmental components are closely interlinked. In the search for operational tools to facilitate landscape policies, GI presents a great opportunity to foster a landscape approach, promote ES, and accomplish the aims of RSPs: to protect, promote, and interconnect natural and cultural heritage in order to improve quality of life and achieve sustainable economic activity.

Last but not least, Master Plans are plans for complex urban systems such as urban agglomerations and functional urban areas that include at least one large urban center and a functional periurban area. In Greece, there are two major metropolitan areas: Athens and Thessaloniki. The initial Master Plans for both of these areas were approved in the 1980s, although there was an attempt to revise them in the 2000s. The Master Plan for Athens was approved in 2014, whereas that for Thessaloniki has not been approved. Nevertheless, according to Papageorgiou and Gemenetzi (2018), the plans have the same philosophy and guidelines for the urban environment and green spaces. Their aims are to enhance green spaces, develop a network of green areas in urban and periurban areas, and to incorporate open spaces, natural landscapes, and areas of cultural interest. Thus, despite the fact that they do not explicitly reference the concept of GI as defined in the present paper, both plans incorporate the underlying features of GI network development.

In summary, it is evident that mainstreaming GI into the Greek spatial planning system will be challenging. The absence of a national or comprehensive green infrastructure policy that could provide the strategic vision for embedding GI into sectoral policies and spatial planning has led to the indirect and fragmented integration of GI into several environmental policies and spatial plans. More specifically, the main issues that have been identified as bottlenecks in the application of an integrated GI spatial policy in Greece are:

- The lack of a European directive that would enforce the compliance of Greek national legislation with the EU GI policy. This has in turn led to an absence of common goals and integrated planning for GI development nationally, regionally, and locally.
- Limited acknowledgement of the ES that GI can offer and ignorance of their potential in nature-based solutions. More specifically, GI is currently mainly considered only in the context of the conservation of green areas, rather than in functional approaches that aim to preserve or enhance certain ecosystem services, such as improving ecological resilience and increasing public health outcomes.
- When GI is integrated into environmental planning, it is generally not linked in to spatial planning. This approach ignores the fact that spatial plans directly affect aspects of the natural and manmade environment.
- GI is not considered using a territorial perspective. Sectoral policy is usually expressed and promoted through spatial tools, and more specifically through Regional and Local Spatial Plans, their directions, and measures for implementing these plans.
- There is only a limited understanding that implementing GI requires land, which is not always abundant, especially in urban areas and in intensely developing regions. Thus, competition amongst land uses is a critical influence on the successful implementation of GI.
- A lack of understanding that GI is a scale-dependent concept. For example, the core elements of the GI network for green urban areas in a cityscape will differ from the core GI network elements (e.g., Natura-protected sites) for periurban areas.
- The lack of land-use principles for spatial planning that are based on the key features of the GI concept (connectivity, multifunctionality, and a multiscale approach).

Hence, the multifunctional character of GI, a limited understanding of the ES-based approach, and a lack of a coherent spatial planning approach that includes all planning scales make the planning and management of GI in Greece a challenging process. Therefore, considerable work is needed to formulate and implement territorial policies that incorporate ES-based approaches into spatial planning as well as to support the governance of GI across scales. To this end, Table 2 presents recommended actions that could provide a pathway for integrating the concept and design principles of GI into the Greek spatial planning system.

Planning a GI network: a territorial perspective

Recognizing the need to compose processes that enable GI deployment within spatial planning will lead to the development of a methodology that facilitates such processes. Based on the definition of GI proposed by the EC in 2013, which suggests that connectivity and multifunctionality are key features of GI, a two-step methodological approach to planning a GI network is proposed below. This approach is spatially centered and focuses on the landscape level (NUTS 3 or subdivisions of NUTS 3), thus promoting a much-needed territorial perspective, and it acknowledges the notion of

Table 2 Recommended actions to achieve the integration of GI into the Greek spatial planning system Source: Table created by the author

	Spatial plan	Territorial planning level	Current state	Recommendations
Strategic spatial planning				
National spatial plans	National Spatial Planning Strategy	National	No reference to the GI concept	Incorporate GI as part of the wider landscape and social cohesion policy
	Sectoral Special Spatial Plans	National	Absence of a national or comprehensive green infrastructure spatial strategy	Develop a national spatial strategy for GI that will provide the strategic vision for embedding GI into sectoral policies and spatial plans
Regional spatial plans	Regional Spatial Plans	Regional	No explicit reference to GI within the scopes of the plans, and no provision of implementation tools	Incorporate GI as an operational tool to facilitate landscape policies and foster an integrated landscape approach
	Master Plans	Metropolitan	Plans encompass the underlying qualities needed for the development of a GI network	Enhance the GI concept by promoting an ecosystem-based approach and incorporating a framework of essential principles and specifications for their development
Regulatory spatial planning				
Local spatial plans	Special Spatial Plans	Supralocal	No explicit reference to GI within the scopes of the plans, and no provison of implementation tools	Incorporate a framework of essential land-use planning principles and specifications that promote connectivity and multifunctionality
	Local Spatial Plans	Local	No explicit reference to GI within the scopes of the plans, and no provision of implementation tools	Use protected areas as a tool to promote the GI concept and incorporate a framework of land-use principles and specifications that promote connectivity and multifunctionality

ES as a basic design principle. The steps comprising the proposed methodology are now described.

Step 1: GI identification and spatial distribution analysis involves selecting and classifying the elements that constitute the network. This process leads to better utilization of the individual characteristics of GI elements as structural components of the network and it enables the desired functional flows to be established.

There are two classification models for GI elements: the Benedict and McMahon model and the Ahern model. According to the Benedict and McMahon model (Benedict et al. 2012), there are three distinct elements that comprise a GI network: hubs, corridors, and links. The hubs and the corridors are the most important parts of the network, but without the links there would be no network integration that maximizes the environmental and societal benefits of GI. Special criteria for assessing the feasibility of integrating natural areas into the GI network are also documented. Due to the complexity of the relations and connections that develop between natural areas and between natural areas and the built environment, a number of features are listed and considered as criteria to apply when selecting the areas that will be incorporated into the GI network. Examples of criteria include ecosystem function, accessibility and distance from the main urban center, areal size, amount of existing infrastructure, degree of multifunctionality, and complementary function with other hubs.

Ahern (2007) argues that the matrix-patch-corridor or mosaic model is almost universally accepted as a means to describe and understand spatial landscape formation in landscape ecology. This model uses three fundamental elements to determine the structure of the landscape: patches, corridors, and a grid. A patch is a relatively homogeneous nonlinear space that differs from the surrounding landscape. In the urban environment, patches are incorporated as discontinuities in the dominant landscape (e.g., a green area in an extensive residential, commercial, or leisure area). A corridor is a linear area with a particular type of land cover that is different in content and physical structure from its surroundings. The grid is the dominant type of land cover or land use in the landscape in terms of extent, degree of connection, continuity, and control over the landscape dynamics. The layout or structural form of the grid, patches, and corridors that make up the landscape is a very important influence on functional flows and movements within the landscape and the evolution of its structure and processes over time (Forman 1995).

The Benedict and McMahon typology was developed to classify areas and improve the application of GI as a tool, while the mosaic model is a more general model that is used to analyze GI spatially. Therefore, for the purposes of this study, a typology derived from a combination of the two approaches has been developed. This typology includes the following three structural elements: hubs, corridors, and transition points (Fig. 1).

The *hubs* are homogeneous terrestrial or marine areas of all shapes and sizes that differ from the surrounding landscape and may serve different purposes. For instance, hubs could be:

- *Natural reserves*. Extensive protected areas such as national parks and wildlife sanctuaries, whose main function is to preserve biodiversity.
- *Regional parks and natural landscapes*. Less extensive areas of regional ecological importance that provide ecological benefits, help preserve biodiversity, and at the same time offer significant recreation opportunities.
- *Cultural/historical/recreational areas*. Public/private parks or cultural/historical sites that provide leisure opportunities while highlighting the heritage of a place.

The *corridors* are linear areas of a particular type of land cover that differ in content and physical structure from their surrounding environment but contribute to the creation of the GI network via connectivity and accessibility. Corridors can occur in both terrestrial and marine landscapes. For instance, terrestrial or marine corridors could be:

- *Landscape links*. Extensive protected natural areas that are linear and provide links between preexisting parks and natural areas, thus conserving biodiversity, and serve as corridors between ecosystems and manmade landscapes. Landscape links can also be used to protect historic sites and to facilitate human activities such as hunting, fishing, canoeing, and hiking.

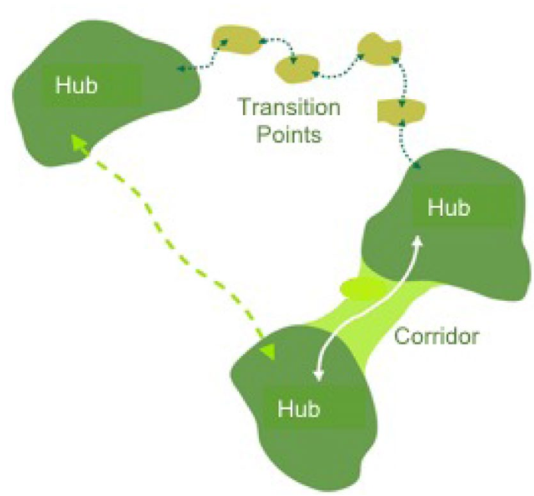


Fig. 1 The structural elements of a GI network. Source: Figure created by the author

- *Conservation corridors*. Less extensive linear areas, such as rivers and streams, that encourage biodiversity and may provide additional opportunities for compatible outdoor leisure activities.
- *Green zones*. Natural or agricultural areas that serve as a framework for growth while contributing to the conservation of natural ecosystems and the organization of urban and suburban development.
- *Trails*. Designed routes—such as railroad tracks and green corridors—that provide access to the natural landscape and other green areas. They present a variety of resources that can be utilized for outdoor entertainment, and enhance our understanding of historical sites and cultural diversity. Designed routes can include linear open spaces that host moderate-to-intense recreational activities for residents and visitors.
- *Usage corridors*. Linear formations such as power lines, ducts, and canals can provide a way of connecting the entertainment, cultural, or physical aspects of the system.

Transition points are areas that serve as attraction points and thus points of origin and destination for operational flows. Transition points include selected ecological, recreational, or cultural/historical areas that are equipped with appropriate services for visitors, serve as points of origin or destination, and are connected by routes. These sites may be located in rural, agricultural, or residential areas.

Based on the abovementioned typology, this methodological step includes (a) identifying the individual natural and cultural elements to use as GI components (links, hubs, and transition points) and (b) mapping the components to create land-use patterns that can be checked for any meaningful spatial configurations (i.e., concentrations). Physical mapping and spatial pattern recognition are key to promoting connectivity and establishing functional flows and movements within the landscape. The subsequent step—the functional assessment of each element—is critical to the establishment of the network.

Step 2: GI functional assessment was mentioned earlier that multifunctionality is the ability of GI elements (hubs, links, and transition points) to provide multiple ecosystem services (ecological and recreational services) at the same locale. The functional assessment step involves evaluating the potential multifunctionality of the land, either within a single policy objective (i.e., mitigating climate change, maintaining biodiversity, etc.) or across policy objectives and human activities (economic, social, and cultural). The potential multifunctionality of the land can be calculated as the number of ES supplied by the GI network at a specific location, as each ES can support one or more policy objectives.

In practice, a simple summation of the ES supplied at a locale can be used to assess the functional performance of the GI elements in supporting a specific policy objective at each locale. In a more complex assessment, support for multiple policy objectives is evaluated based on relevant spatial policies. Hence, assuming that the evaluation process includes more than one policy objective, there are two steps in the functional assessment process: (1) identifying the ES supplied at each locale per policy objective, and (2) multiplying the number of ES supplied by the number of policy objectives served. Thus, locales that serve multiple objectives have higher scores. It should be noted that even if an ecosystem service aids multiple policy objectives, it is still counted only once to avoid multiple counts. The following simple function can be used to calculate the multifunctionality score (MFS) per locale (the GI elements with the highest scores are those with the strongest functional performance):

$$\mathrm{MFS} = \sum F_{ij} N_j,$$

where i is the function identified, j is the number of ES supplied by i, and N_j is the number of policy objectives served by those ES.

An important issue that precedes and greatly affects the calculation of the MFS is the process of linking the functions associated with a locale to the ES supplied. There are several readily available classification systems that can be employed for this process. In this paper, the Common International Classification of Ecosystem Services (CICES; version 5.1/18.03.2018) is employed. CICES is designed to help measure, account for, and assess ecosystem services. Although it was developed in the context of work on the System of Environmental and Economic Accounting (which is being led by the United Nations Statistical Division), it has subsequently been widely used in ecosystem services research to design indicators, for mapping, and for valuation (Haines-Young et al. 2018).

Data sources

The proposed two-step methodological approach to planning a GI network can be applied at different geographical scales (national, regional, urban, periurban, local, etc.), while it is important to understand that ES identification and functionality assessment are strongly related to the policy, objectives, and priorities that are adopted as an evaluation framework.

In practical terms, two types of geographical datasets—land use/cover and ES—are needed to apply the proposed methodology. Land-use and land-cover data provide the basis for the potential GI network mapping and are used to identify the three components of the GI network (the hubs, links, and transitional points) and to evaluate their connectivity. These datasets are available from the Natura Network database, CORINE Land Cover, the Urban Atlas (for urban and periurban areas), and the Copernicus High Resolution Layer, all of which are provided by the European Environmental Agency. Land-use data can also be acquired from the relevant Local Spatial Plans for the area under study.

In the second methodological step, data on ES are used to measure the multifunctionality of the GI. BISE (the Biodiversity Information System for Europe) provides data and information on biodiversity to support the implementation of the EU biodiversity strategy. BISE proposes a set of ES indicators based on ecosystem condition and an ecosystem services assessment. These indicators are supposed to be available for every EU country, although this is not always the case. For instance, according to the latest technical report, *Deliverable of LIFE-IP 4 Natura Project*, updated in September 2018 (Dimopoulos et al. 2018), there are no such data for Greece. Due to the lack of appropriate data, an alternative approach was employed. This approach involves recognizing possible ES based on the policy texts that are used to set the evaluation framework (i.e., the National Climate Change Adaptation Strategy) or the respective spatial plans (national, regional, local). Detailed inspection of the policy and strategy plans enabled the assignment of several ES per locale (hub, link, or transition point), thus facilitating the functional assessment (step 2) described above.

Case study of the metropolitan area of Thessaloniki, Greece

The metropolitan area of Thessaloniki (MATH), which has over 1 million inhabitants, is the second largest in Greece after the metropolitan area of Athens. The MATH is located in the northern part of the country, in the region of Central Macedonia, and covers an area of 400 km^2. It constitutes a major economic, commercial, transport, and cultural hub in the Balkans as well as the wider region of Southeast Europe.

The MATH consists of several municipalities in a monocentric urban system. It is dominated by the city of Thessaloniki (a dense urban center) as well as several smaller urban centers and settlements. The structural and functional organization of this urban system is a result of continuous expansion over the last 40 years. The key feature in this development process has been the construction of high-speed highways (in conjunction with no investment in public transit systems), shopping centers, R&D facilities, and company headquarters unregulated across the periurban area. Furthermore, suburban housing has developed next to existing settlements. Due to the outdated Master Plan, no provision was made for the preservation and protection of necessary open space and surrounding agricultural land. The chaotic development process has therefore resulted in fragmented open space in most parts of the MATH.

Nevertheless, there are significant natural areas that shape the physical and artificial flows of this urban system. In the northern part of the MATH is the suburban forest of Seich Schou, an extensive forested area that is protected both as a Natura site and as a Landscape of Outstanding Natural Beauty. With a height of 1201 m, Mount Chortiatis overlooks the MATH from the north and is part of the local ecosystem. To the southwest, there is an extensive river delta consisting of the rivers Axios, Aliakmonas, Loudias, and Gallikos and the plain of Chalastra. This delta is protected by several national and international treaties and is designated a National Environmental Park. While it is a wildlife sanctuary, it also has significant engineered ecosystems such as rice paddy fields and aquaculture. Less extensive but equally significant areas that serve as wildlife habitats are located in the southeastern part of the MATH: the lagoons of Epanomi and Angelochori. Other significant green elements are two linear features: the canals east and west of the dense urban core of Thessaloniki. The eastern one (the Regional Trench) is artificial and was constructed to protect the city from floods, whereas the western one (Dendropotamos) is a torrent that suffers from serious environmental pollution arising from the industrial area adjacent to the canal. Even so, both of these canals are significant green elements that play an important role in alleviating the risk of flooding in the city.

The strategic and regulatory spatial planning framework for the MATH

This section briefly presents the context of the spatial plans that have been used as overarching policy texts for the development of the GI network as well as, where applicable, useful and readily available sources of information that facilitate the identification of GI elements of metropolitan significance.

Strategic spatial planning

In the context of protecting and enhancing the natural environment, the Regional Spatial Plan for the region of Central Macedonia promotes the conservation and promotion of protected areas, endangered species, and the ecosystem services they maintain. Part of the plan's objective is to ensure ecological continuity of protected areas, maintain or secure new ecological corridors that will link the network of protected areas together, reduce strong pressures that are placed on coastal protected areas by tourism and residential development, promote the systematic management of all forest ecosystems, and finally increase the size and quality of the forested ecosystems. To preserve and promote the cultural environment, the plan aims to strengthen the networking qualities of cultural resources as well as the protection of traditional settlements.

Within the context of the Regional Spatial Plan, the strategy for the landscape is to end practices that degrade the value of its elements, take preventive and curative measures that will improve its overall quality, and highlight it as a key resource for the sustainable development of the region. Based on the landscape typology identified in the RSP, particularly prominent landscapes within the MATH include the landscape of wine roads, the mountainous landscape, as well as the rural landscape of the plain of Thessaloniki.

The Master Plan for Thessaloniki provides key information on green areas of metropolitan significance within the dense urban environment and the periurban area. Detailed work by Papageorgiou and Gementzi (2018) has shown that green areas were planned with several intentions: "to form a green buffer zone for the city and in terms of promoting 'multi-functionality' and 'leisure opportunities.'" Nevertheless, they also note that "green spaces within the city, even though they tend to correspond to the national standards, are unequally dispersed, whilst their small size can hardly serve the 'multi-functionality' feature." Although the Master Plan for Thessaloniki was never approved, the scale of the plan and the perspective adopted on the multifunctional management of key natural and cultural resources as valuable landscape elements provided a useful reference for the current study. To this end, the study *Revision of Strategic Plan for Thessaloniki and Environmental Protection Program (phase A—2nd chapter)* was an important reference work for the current study (Master Plan Agency of Thessaloniki 2006).

Regulatory spatial planning

According to the Local Spatial Plans, the study area consists of ten municipalities. For the needs of the present study, the approved LSPs were scoured for information on existing or potential GI elements. As already mentioned, the LSPs focus on the regulation of both urban and suburban areas. Due to the reference scale of the present work (metropolitan), our search through the LSPs concentrated mainly on the suburban area, except for identifying GI elements of metropolitan importance within urban areas.

As an example, the relatively recently approved LSP for the municipality of Pylaia-Chortiatis, and the municipal unit of Pylaia in particular, was studied (Ministry of Environment and Energy 2017d). It should be noted that, due to its adjacency to the dense urban center of Thessaloniki, the municipal unit of Pylaia includes natural resources of supralocal significance, such as the peripheral ditch, part of the Sheich Sou forested area, and part of the metropolitan coastal front system. This plan is short-sighted in that it does not discuss the implementation of a GI network or the integration of existing GI and natural resources into an organized GI network. Areas of special ecological, aesthetic, and cultural value are only considered in the context of their protection as part of the local landscape (usually through their designation as protected areas); there is no mention of the use of GI as a tool for the management and utilization of natural resources in an interconnected and multifunctional network.

Information on all ten municipalities and from their LSPs were utilized to designate the key GI elements of metropolitan importance.

A Special Spatial Plan for a large part of the coastal area both inside and outside the dense urban center of Thessaloniki is currently being elaborated. Since the plan is currently being prepared, there is not enough data for it to be useful in this analysis. However, as already noted, the implementation guidelines in this plan do not promote GI or include any principles that would encourage the development of GI.

Development of the GI network for the MATH

Following the analysis of the spatial planning framework, the two-step methodology described earlier was used to develop the GI network for the MATH.

Step 1: GI identification and spatial distribution. Although a detailed description of all GI elements used in the network for the MATH is not possible in this paper, Table 3 presents a list of the 38 elements that were considered in the proposed GI network. The elements, which are either natural or manmade, are classified into six categories: significant natural landscapes, coastal and marine ecosystems, water corridors, built environment, productive landscape, and accessibility infrastructure. This list is dynamic and can change at any time, and in practice it is imperative to incorporate local stakeholders and community at every step of the planning process. It should be noted that this paper mainly considers the elements that are outside of the dense urban core and settlements. Nevertheless, in order to achieve an integrated network, crucial natural and seminatural elements (the peripheral ditch, military camps, etc.) and significant infrastructure (cultural, recreational, etc.) that are located within the main urban core were also considered.

Structural classification was performed based on the three structural elements of the proposed typology: hubs, corridors, and transition points (Table 3, column "Structural classification"). This process was completed by mapping the elements, thus highlighting their spatial distribution and physical structure. It was crucial at this point to identify probable missing links between the GI elements. As connectivity is a key GI feature, the creation of new functional corridors to link currently unconnected hubs or transition points was considered as a means to enhance functional flows and movements.

Step 2: GI functional assessment. In the second step, a functional assessment was attempted. It was initially necessary to identify the functions that the assessment would be based on. Guided by the literature (Kazmierczack et al.

Table 3 Classification, functional assignment, and MFS values for the GI elements Source: Table created by the author

ELEMENTS OF GREEN AND BLUE INFRASTRUCTURE		Structural Classification	FUNCTION																MultiFunctional Score
			Recreation	Recreation with restrictions	Viewpoint/Standpoint	Sport activities	Alternative Tourism	Network Connectivity	Network accessibility	Cultural asset	Cultural infrastructure	Habitat for wildlife	Protected area	Special Aesthetic Value	Productive activities	Food Production (Fisheries-Agriculture)	Learning / Experiential Education	Flood Prevention	
1. Significant Natural landscape	Delta - Axios, Loudias, Aliakmonas	H																	1,4
	Kouri forest/Asvestochori	H																	1,4
	Platanakia/Panorama	H																	1,6
	View posistions/Chortiatis	TP																	0,2
	Suburban forest Seich Sou	H																	1,4
	Wildlife Sanctuary Oraiokastro Neohorouda	TP																	1
	Wildlife Sanctuary Tsairi Epanomi	TP																	1
2. Coastal and marine ecosystems	Aggelochori Lagoon	H																	1,2
	Epanomi Lagoon	H																	1,4
	Estuary and River Delta of Axios, Loudias, Aliakmonas	H																	1,4
	Kalochori Lagoon	H																	1,4
	Agia Triada marine ecosystem	H																	0,2
	Coastaland marine exosystem from Axios Delta to Angelochori	C																	3,2
3. Water corridors	Thermaikos Gulf	H																	1
	Axios, Loudias Rivers	C																	1,6
	Anthemountas River	C																	1
	Water Dams (Thermi & Triadi)	H																	1
	Streams within dense urban environment (Peripheral ditch, Dendropotamos)	C																	1,2
4. Build Environment	Significant industrial complexes 19th centuy (FIX etc)	H																	1,6
	Cultural complex of Polihni (Roman forum,Byzantine watermill,Open Folklore Museum ,Hayman Winery,Roman Aqueduct Ruins)	H																	1,4
	Oreokastro - Watermills, Toumpa and archaeological site	TP																	0,6
	Wine road (Mensivria, Gefyra, Achialos,)	C																	1
	Wineries (Epanomi)	TP																	0,8
	Retziki (Baths, Tower House, Watermills)	TP																	0,6
	Chortiatis Byzantine aqueduct	TP																	0,6
	Asvestochori: lime kilns	TP																	1
	Thermi: Ancient settlement, Tumba Gona, Mosque and Minaret &Thermi Dam	TP																	0,6
	Scholari: Tumba Tausan, Konaki Building	TP																	0,6
	Plagiari & Trilofos: Tumba	TP																	0,6
	Angelochori: Lighthouse	TP																	1,4
	Former military camps within dense urban environment (Stavroupoli, Pavlou Mela)	H																	1,2
6. Productive Landscape	Rice Areas - Permanently Irrigated Land	H																	0,4
	Epanomi Vineyards	H																	0,8
	Pasture land	H																	0,4
	Fishing Shelters (Chalastra, Loudia, Kalochori)	TP																	0,4
7.Accessibility Infrastructure	Port of Thessaloniki	TP																	0,8
	Port of Michaniona	TP																	0,6
	Maritime Sports Facilities (Aretsou, Sailing Club, Nautical Club)	TP																	0,8

H: Hub, C: Corridor, TP: Transition Point

Existing functions

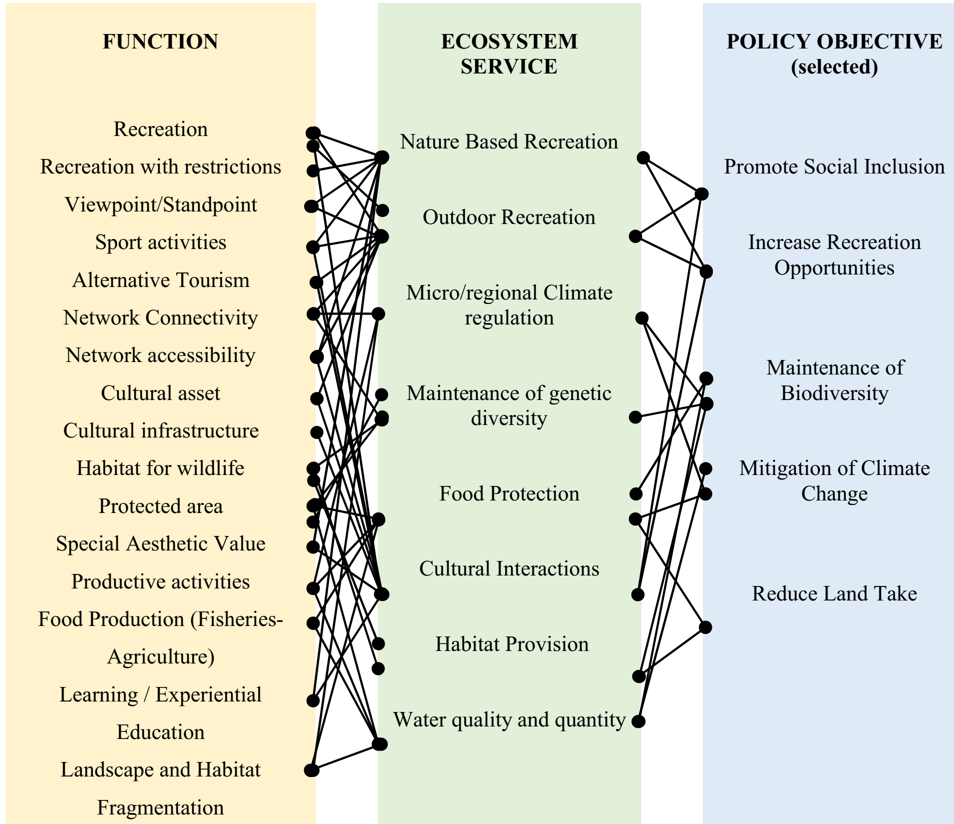
Assigned functions

Source: processed by the author

2010; Davies et al. 2006; Foster et al 2011; Naumann et al. 2011; The Mersey Forest 2018; The Northwestern Green Infrastructure Think Tank 2019) as well as the profile and characteristics of the study area, 16 types of functions were identified. These functions were quite general; some of them are relevant when GI is considered at a macro scale (e.g., food production, flood prevention, etc.) while others are associated with the locale itself. It is also possible for multiple functions to coexist in a GI, leading to multifunctionality, which allows multiple policy objectives to be achieved through spatial integration of land uses and development activities. As explained earlier, multifunctionality is desirable, as it encourages efficient land use, offers wider public benefits, and contributes to partnerships, leading to better GI management and performance. Columns 2–18 in Table 3 present the functions assigned to the study area's GI elements. Existing functions are highlighted in light green, while darker green indicates a potential function as part of the GI network. The existing and potential functions were assigned based on the data provided by the spatial plans for the area.

Next, the process of linking the identified functions to ES was performed. Based on the CICES classification, Table 4 presents the links between functions, ecosystem services, and policy objectives. Note that, since the purpose of this section is to demonstrate the proposed methodology, the policy objectives presented here are only a selection of the multiple policy objectives set in the context of applicable

Table 4 Links between functions, ecosystem services, and policy objectives Source: Table created by the author



Source: processed by the author

spatial plans for the area (LSPs, RSP) and the Master Plan (which has not been approved). Having established the links, the subsequent functional assessment was relatively simple. The multifunctionality score (MFS) was calculated using the function presented earlier. The MFS per GI/locale is presented in the last column of Table 3, which shows that the MFS values ranged from 0.2 to 3.2. An overview of the scores achieved per locale indicates that elements within or close to the built environment show greater potential for multifunctionality. As an example, the Regional Trench scored 1.2 due to the multiple ES it supplies (outdoor recreation, microclimate regulation, and maintenance of genetic diversity), which in turn results in the realization of multiple planning objectives (promote social inclusion, increase opportunities for recreation, maintain biodiversity, and mitigate climate change).

Based on the structural classification introduced in step 1 and the multifunctional score per locale calculated in step 2, spatial development of the GI network was attempted. Special emphasis was placed on the coastal zone extending from Kalohori to Angelochori, which yielded the highest MFS value (3.2). Due to its length, influence, and the significance of the recreational uses hosted in this area, it was proposed that this zone should be the main route for interconnecting hubs and corridors and should also act as a starting point for the further development of the network at all scales (local, metropolitan, and regional). In practice, the coastal corridor functions as an integrating element for the plain of Chalastra, the endpoints of the green corridors of the Dendropotamos Torrent, the Regional Trench, the Anthemountas River, the Lagoon of Epanomi, and the Lagoon of Aggelohori (Fig. 2).

The estuary and river delta of the rivers Axios, Loudias, and Aliakmonas (1.4) is a large region containing river estuaries, agricultural areas, and natural vegetation. While this region is connected to some extent with the rest of the GI network via the coast, it would be useful to develop a overland connection to the rest of the GI network in order to improve accessibility and exploration options in the area (i.e., develop more cycling routes). On the eastern side of the dense urban center, the Anthemountas River (1) crosses a fragmented, flood-prone agricultural landscape. This indicates that a multifunctional green corridor would be useful for alleviating floods and increasing connectivity to the rest of the GI system.

The green corridors that extend along the Regional Trench (1.6) and the Dendropotamos Torrent (1.6) as well as the hubs represented by the suburban forest of Seich Sou (1.4) and the former military camps within the dense urban environment of the city of Thessaloniki (Stavroupoli,

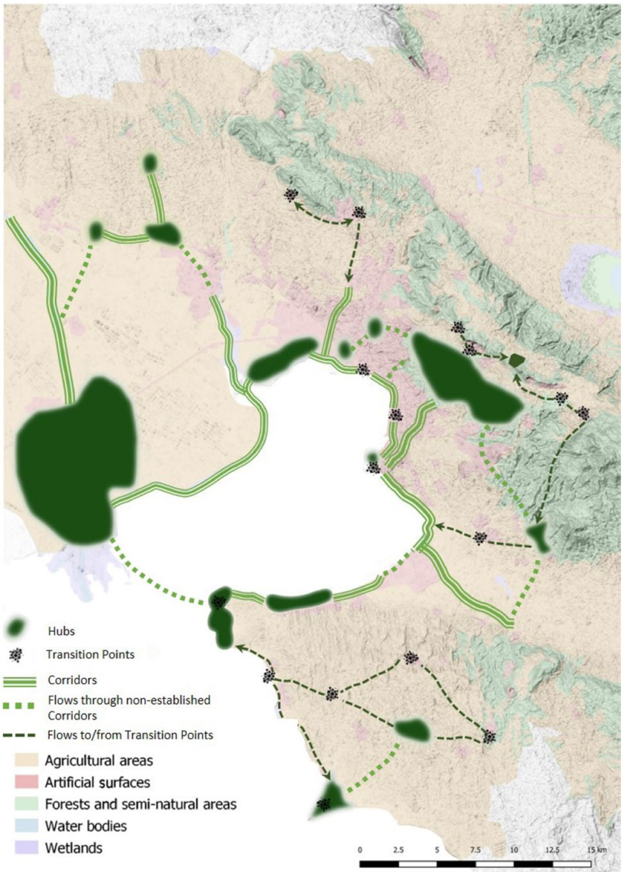


Fig. 2 Spatial and functional configuration of the GI network. Source: Figure created by the author

Pavlou Mela) (1.2) are critical elements of the GI network due to their proximity to the city center. Thus, a coherent link between the coastal zone, the green corridors, and the suburban forest is recommended in order to facilitate the unobstructed movements of pedestrians and cyclists and the development of recreational activities lengthwise along the zone, while also providing much-needed infrastructure for water management and flood alleviation. In addition, new links to integrate the military camps into the system are proposed. The purpose of these links (both existing and proposed) is to create a GI network within the urban environment that will be of metropolitan importance and will greatly improve the aesthetics, quality, and functionality of the dense urban landscape.

In addition, the proposed GI network connects the suburban forest of Seich Sou (1.4) with the mountain shelter of Hortiatis, which is a transitional point of low significance (0.2). Nevertheless, this link is proposed to be a natural mountain path, while the development of more natural routes and shelters around the metropolitan area is advised in order to encourage outdoor activities.

Epanomi's vineyards (0.8), with their multiple ecosystem services (nature-based recreation, habitat provision, and regional climate regulation), are proposed to be the focal hub for the eastern part of the metropolitan area. Due to their attractions, these vineyards could provide the perfect link between the metropolitan area and the eastern coastal front.

The water dams of Thermi and Triadi (1), along with the water corridor of Anthemountas (1), provide significant flood prevention infrastructure for a large and important area in which food is produced for the city of Thessaloniki. In an effort to increase the multifunctionality of the dams, it is proposed that their interconnectivity should be enanced by improving and developing the walking and cycling paths between the two natural areas. Moreover, it is proposed that Thermi's dam should be connected with the coastal front, meaning that there is a link through the settlement of Thermi to the two dams.

Finally, the scattered transition points are important man-made or natural attractors to the network. Their role is to serve as entry points to the network, so appropriate infrastructure is required to achieve this function. The structure of the proposed GI network is shown in Fig. 2.

Conclusions

Until recently, GI development was perceived as a solution-oriented and cross-sectoral approach to spatial planning, due to the fact that it was associated with ecological resilience and focused mainly on preservation. Today, GI has been reinvented as a framework or even a strategy that identifies interventions which can help tackle major environmental and socioeconomic needs and capitalize on opportunities. The key concept in this approach is the capacity of the natural environment to carry out several functions, meaning that it can supply a variety of ecosystem services and fulfill a wide range of policy objectives.

Despite the undoubted benefits of treating GI as an infrastructural resource and an integral component of spatial policies, recent studies of the integration of GI into spatial planning have reported limited acknowledgement of the ecosystem services that GI can offer and a lack of a territorial perspective. More specifically, a review of the Greek spatial planning framework indicated that there is no national or comprehensive GI policy that can provide a strategic vision for embedding GI into territorial policies, and it highlighted the fragmented integration of GI into the spatial planning system. Furthermore, the review found that there is only a limited understanding of the basic GI aspects of connectivity and multifunctionality, and there is a general ignorance of the potential they have to provide ecosystem services and nature-based solutions.

To this end, the proposed methodology aims to facilitate a territorial approach to GI planning at the metropolitan scale. Apart from categorizing GI elements into the structural components of such networks (i.e., hubs, corridors, and transition points), the functional classification and assessment of these elements is crucial to the development of the network. The proposed functional assessment, which is based on the ecosystem services provided by the GI elements as well as the corresponding policy objectives, was shown to facilitate the prioritization of competing planning priorities and to promote planning objectives and a territorial perspective.

The proposed methodology can clearly be improved in many ways. For instance, the incorporation of priority weights into the policy objectives would enable objectives to be weighted according to how important they are to each policy priority. Another improvement could be the incorporation of other objectives derived from policy areas such as climate change, sustainable agriculture, and disaster risk reduction. Last but not least, a better understanding of the links between functions and ecosystem services would enhance the effectiveness of the prioritization procedure and the design process in general.

To conclude, it is essential to integrate GI into spatial planning at all spatial scales. GI must be treated as a fundamental infrastructural resource that is necessary to achieve balanced spatial development, since it promotes the goals of an ecosystem-service-based approach and supports sustainable land management, which are essential for resilient territorial development.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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