



Methods for identifying green infrastructure

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Abstract

Nature forms interdependent networks in a landscape, which is key to the survival of species and the maintenance of genetic diversity. Nature provides crucial socio-economic benefits to people, but they are typically undervalued in political decisions. This has led to the concept of Green Infrastructure (GI), which defines an interlinked network of (semi-) natural areas with high ecological values for wildlife and people, to be conserved and managed in priority to preserve biodiversity and ecosystem services. This relatively new concept has been used in different contexts, but with widely diverging interpretations. There is no apparent consensus in the scientific literature on the methodology to map and implement GI. This paper serves as an informed primer for researchers that are new to GI mapping understand the key principles and terminology for the needs of their own case-study, and as a framework for more advance researchers willing to contribute to the formalization of the concept. Through a literature review of articles on creating GI networks, we summarized and evaluated commonly used methods to identify and map GI. We provided key insights for the assessment of diversity, ecosystem services and landscape connectivity, the three 'pillars' on which GI identification is based according to its definition. Based on this literature review, we propose 5 theoretical levels toward a more complex, reliable and integrative approach to identify GI networks. We then discuss the applications and limits of such method and point out future challenges for GI identification and implementation.

Keywords Green infrastructure · Spatial conservation prioritization · Biodiversity · Ecosystem services · Connectivity

1 Introduction

1.1 Context

Climate change and biodiversity loss are two of the most urgent challenges of our time [71, 73, 74, 153]. Biodiversity at all levels is declining worldwide at an unprecedented rate, due mainly to land and sea use changes, direct exploitation of organisms, climate change, pollution and invasive alien species, and are expected to continue declining if no concrete actions are taken [73, 111, 158]. Ecosystems are losing their resilience to maintain their functions, which will ultimately jeopardize our food and water security,

deteriorate our health and threaten our social-economic well-being [39, 103, 135].

It has been estimated that 68% of the world's growing population will live in urban areas by 2050 [154], which will inevitably increase the pressure to develop the "grey" infrastructure for housing, mobility and economic use. Along with other human activities, urbanization continues to have serious consequences for biodiversity and the provision of ecosystem benefits to people. Growing demand for new residential areas is a major policy driver in urban land use planning and management, and road constructions also represent a global threat to biodiversity [107]. Despite numerous efforts devoted to nature conservation

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and the expansion of protected areas, we are failing to meet the Aichi Targets for 2020 set by the UN Convention on Biological Diversity [73, 151]. We now face the urgent need for a credible agenda and well-defined action plan to safeguard the survival of species and restore the ecosystems on which we depend [97].

1.2 The concept of green infrastructure

Nature conservation schemes traditionally focused on preserving species and intact wilderness, but have recently evolved to adopt a more holistic “people and nature” approach [95], where the landscape is managed to support biodiversity and humanity on the long term [79]. This new paradigm takes into consideration the numerous interactions between people and nature and analyzes social, economic and ecological systems as a whole. This novel framing illustrates our dependence upon ecosystems and emphasizes that people are part of nature, not apart from it [96].

As land degradation is one of the major threats to natural habitats and biodiversity [6, 14, 72, 73], the importance of our natural capital in decision-making must be better emphasized to improve the sustainability of landscape management [22]. This recognition has led to the concept of ‘Green Infrastructure’ (GI) [20] to help preserve a functional ecosystem network through land-use planning. GI describes an interconnected network of natural and semi-natural areas designed and managed to deliver a wide range of ecological, social and economic benefits [20, 52].

GI are increasingly being considered as a nature-based solution [33] or natural and cost-effective alternative to grey infrastructure to help mitigate environmental impacts, adapt to climate change and build resilient societies. Considering environmental resources as infrastructure allows us to recognize their role in our livelihoods, and also to point out that ecosystem services (ES) also require maintenance to sustain their capacity to provide clean water and air, aesthetic benefits, physical and mental health, wildlife conservation and other community values. GI has gained credibility among land planners and policy makers as a strategic tool to promote sustainable development and to assess synergies and trade-offs between conservation goals and other conflicting land-use interests [86]. It has been integrated into national, regional and continental environmental agenda [42, 51, 53].

One of the main assets of GI is its focus on landscape multifunctionality, i.e., promoting spatial areas that can serve more than one purpose, such as biodiversity conservation, climate change mitigation, the creation of recreational green spaces and supplying employment opportunities [52]. While grey infrastructure is often designed for a single function (e.g., habitation, transport or economy),

GI addresses multiple demands and contributes to finding solutions for a range of environmental, social and economic pressures [110]. Da Silva and Wheeler [38] have traced the history of the concept of ecosystems as an infrastructure and synthesized the concept of GI as a network of natural, semi-natural areas that are designed and managed at different spatial scales for the preservation of biodiversity and a wide range of ecosystem services, to ensure resilient ecosystems and societies.

To implement a conservation action, planners must know where the most urgent needs are and where actions will deliver optimal results. For this, it is necessary to identify areas where the landscape ensures ecological resilience and habitat quality, helps people and species adapt to climate change and enhances people’s physical and mental health. Visualizing priority conservation areas will support decision-makers to optimally allocate limited resources for ecosystems preservation. Having such priority areas mapped out in advance also saves time by avoiding conflicts when a key resource or environmental concern is brought up after a development project has been initiated [56].

However, there is no consensus, neither on its components nor on the method to identify and map GI [160]. Consequently, the concept of GI has been formulated and interpreted in divergent ways, and various concepts and names have emerged to refer to the same idea (e.g., greenprints, natural asset maps, ecological networks, green, blue, brown, black corridors) [56]. Inconsistent definitions can lead to misunderstandings among stakeholders and hinder efforts to mainstream GI into sustainable development actions and policy agendas. Operational definitions of GI vary both in the type of habitat they include, but also the biological value-sets that are incorporated. A typology of GI could help provide an overview of this variation.

Some have used the GI concept as a strictly urban greening method or architectural element that can also be considered as nature-based solutions [69, 75, 76, 98]. Others limit the GI to a network of natural and semi-natural core areas for preserving biodiversity and the supply of ES, with links between these areas to ensure ecological connectivity [45, 84, 92, 144].

GI that focus only on biodiversity indicators may not fully capture societal values that may resonate with a larger fraction of the population. In fact, while the supply of ES implies a minimal level of biodiversity, spatial synergies among different ES or between ES and biodiversity may be weak [32]. In some specific eco-regions, areas with high species diversity provide more ES than areas with low levels of diversity [99], but this is not always the case [100]. In addition, implementing conservation actions based only on habitats or abiotic surrogates may lack coverage of rare or functionally important species, since similar

habitats can be biologically different [157]. As ES locations may differ from where they are supplied to where they are consumed, their integration in GI requires special care on the type of connectivity involved in their treatment [82]. Therefore, priority areas for ES supply and biodiversity distribution should be analyzed separately, as they are not appropriate surrogates for each other.

In this paper, we explore how a multidimensional GI, which integrates both numerous biodiversity and ES indicators, could be implemented. Snäll et al. [144] and the European Environment Agency [52] among others have argued that a functional GI network will require the integration of three main aspects, which we will call 'pillars': (1) the diversity of species and habitats (commonly referred to as "biodiversity"), (2) ecosystem services (also referred to as nature's contributions to people) [46] and (3) the structural and functional connectivity of the landscape. Biodiversity is the variability of living organisms at various scales from genes, to species and landscapes [30]. ES are nature's benefits and contributions to our society and our well-being [35, 106]. Functional connectivity measures the relative ease of mobility between landscape patches for selected species [148, 163], whereas structural connectivity (also named "connectedness") refers to the structural links or topological distance between landscape features [150].

1.3 Objectives

This paper serves as an informed primer for researchers that are new to GI mapping understand the key principles and terminology for the needs of their own case-study, and as a framework for more advance researchers willing to contribute to the formalization of the concept. We provide a structured catalogue (typology) of existing GI methods, and a guide toward possible tool choices for the needs of their own case-study. We viewed the different GI identification approaches used in case-studies that have the same GI definition as mentioned above. Following the foundations and recommendations of GI identification by Snäll et al. [144], we analyzed if and how the case-studies included the three pillars (diversity, ES and connectivity), and how the areas were selected to be integrated in the GI network. We then evaluated the methods used to assess the three pillars and the identification of GI itself. We summarized these approaches in levels according to their representativeness and reliability in order to help future researchers identify the appropriate method for their own work. We also discussed some hypotheses explaining the observed tendencies in the method's choice, as well as future challenges for GI identification and mapping.

2 Methods

2.1 Articles selection

We focused our articles on search results from Web of Science (searched on the 24.03.2020) using the following topic keywords: "ecosystem service*" AND "biodiversity" AND ("corridor*" or "connect*") AND "green infrastructure*". We then filtered out articles defining GI as strictly urban greening methods or architectural elements and used those that interpret GI as a strategically planned network of interlinked natural and semi-natural areas to preserve biodiversity and ES, to compare different GI identification approaches. We then looked at how many case-studies explicitly performed a separate assessment of each of the three pillars for their GI design: (1) biological diversity (habitats, species occurrences, species distributions), (2) ES (relations between vegetation types and services, modeling of ES), and connectivity (functional connectivity with species dispersion and resistance maps, landscape structure). The full dataset of references is available in the additional resources ("Appendix 1").

2.2 Evaluation methods

We focused our analysis of different GI identification approaches on our review of the literature ("Appendix 1"). The methodological review consisted in analyzing for each pillar the type of data used as input, the software and methods used, the quality and quantity of items calculated, modeled or mapped, the choice of surrogates, the conceptual approach, the representativity and reliability of the results in the context of nature conservation. Following the foundations and recommendations of GI identification by Snäll et al. [144] and our review of the literature ("Appendix 1"—articles with similar GI definition), we then classified GI identification approaches into 5 levels, according to the complexity of their methods. The lower level methods would represent a GI identification considering one or two pillars, a few surrogates and simplified analysis, and higher-level methods would consider all pillars, many surrogates, and a complex methodology to identify GI. We discussed these complexity levels and their relevance in the discussion.

Having a common baseline to identify and map GI is necessary, since there are as many methods as articles in the literature. The aim of this work is not to evaluate the quality of GI identification method for each article, but to point out general, theoretical, conceptual and methodological directions to assess each pillar to reach a more reliable, functional and efficient GI network.

3 Results

3.1 Bibliographic search

The topic keywords search in Web of Science resulted in 67 articles (“Appendix 1”). Those defining GI as strictly urban greening methods or architectural elements were filtered out, leaving 32 articles that interpret GI as a strategically planned network of interlinked natural and semi-natural areas to preserve biodiversity and ES. We excluded reviews and conceptual papers, even if they considered the importance of the three pillars, to only keep case-studies for the evaluation of GI mapping methods. Among them, only 7 case-studies explicitly took all three pillars into account—biological diversity, ES, and connectivity—for their GI design (Table 1).

Once the three pillars are calculated, they must be compiled to perform a spatial selection of most ecologically valuable areas in order to build a GI network. This kind of map highlights priority ecological areas where habitats should be conserved and land development avoided, and identifies areas where land changes would have minimal impact on the ecosystem. Although many use conventional overlay analyses by combining GIS data, [144] argue that priority areas could be optimized with a spatial conservation prioritization (SCP) method. Despite SCP tools being appropriate for GI network mapping, case-studies applying them to solve the challenges of spatial planning remain scarce. In fact, among the 7 selected case-studies that identified GI based on all three pillars, only 4 used a prioritization method to identify their GI, including 2 using the SCP tool Marxan.

There is a research gap in the literature of studies using SCP methods for GI identification: even when including conceptual GI papers, only 9 papers used or mentioned “spatial prioritization” (Fig. 1). However, among the 27 papers that have used all keywords except the term “green infrastructure”, some have similar approaches while using other terms such as “protected area(s) network” [3, 12, 90] instead.

3.2 Box 1: Spatial conservation prioritization and its benefits

Methods commonly used for mapping GI include overlay analyses with Geographic Information Systems (GIS), morphological spatial pattern analysis, minimum path model and landscape-functional units [112]. Yet, these are not well suited for maximizing synergies and minimizing trade-offs between ES and biodiversity, which is the aim of efficient conservation planning [31].

SCP is widely used in systematic conservation planning by conservation biologists who are also confronted with finding optimal areas to allocate protected areas or restoration actions [81, 108]. The main advantage of SCP tools is their capacity to account for trade-offs and synergies among multiple components in a landscape, and to present alternative solutions to spatial planning, which is not straightforward with other methods such as overlay analyses using Geographic Information Systems (GIS) [21, 48, 128, 144].

SCP software use computational methods to optimize the selection of priority areas in a landscape for a given target. Weights can be attributed to some features to influence the outcome in order to account for factors such as species rarity and ecological connectivity. In addition, opportunity costs, opposing land use interests, land ownership and other restrictions can be considered in the analysis in order to create more realistic solutions. As weights accorded to input data may significantly influence the prioritization result, expert knowledge and stakeholders’ consultation are strongly advised.

The most widely used prioritization software include Marxan [13] and Zonation [108]. Marxan was created to identify a set of planning units to meet conservation targets for selected biodiversity features while minimizing the total cost. The tool’s optimization algorithm is based on simulated annealing for a fast and relatively simple way to solve minimum set problems of different types and sizes, and find the best fit among multiple alternative solutions [13]. Marxan can be used to analyze trade-offs between biodiversity features, boundary length, area and costs by varying the representational targets in the input files [127]. The tool takes into consideration connectivity between selected planning units, but cannot include species-specific connectivity requirements. It can account for ecological processes, site condition or socio-political influences (private parcels or culturally important sites).

Zonation was created to address the maximum utility problem, i.e., maximize the conservation value for the selected species or biodiversity features within limited resources [108]. The main output is a hierarchical map of ranked conservation priority. It does not require setting a specific target and can be used to evaluate the adequacy of proposed protected areas or to specify where to expand conservation or restoration areas [108]. Zonation uses information on different types of features such as species presence/absence, abundance, probabilities of occurrence and costs/constraints to prioritize sites according to their representativeness and persistence. The tool’s cell removal rules are based on core-area zonation for emphasizing rare features, additive benefit function for selecting richer areas, or target-based planning for specifying specific conservation targets for each feature. The algorithm

Table 1 Approaches used in the 7 case-studies identifying GI with all three pillars

Article	Hermoso et al. [67]	Capotorti et al. [27]	Lanzas et al. [86]	Capotorti et al. [28]	Hu et al. [68]	Cannas et al. [25]	Liquete et al. [92]
<i>Information on the study</i>							
Scale	Continental/national	Local	Regional	Local (city)	Regional	Regional	Continental
Resolution	10 km ²	2 km ²	1 km ²	1.5 km ²	30 m ²	25 m ²	1 km ²
Method for final GI network identification	Prioritization	Prioritization	Prioritization	Overlap analysis	Prioritization with overlay	Prioritization	Maximum value of pixels for the pillars
<i>Species and habitat diversity pillar</i>							
Type of data	Species occurrences, vegetation map	Occurrences (trees, shrubs), species distribution maps, natura2000 protected sites, LULC map	Species distribution maps, LULC map	Vegetation map	Habitat map	Habitat map	Habitats (for large mammals)
Surrogates	767 vertebrate species, 229 habitats	Species richness and conservation concerns of vascular plants, mammals, birds, Amphibians and reptiles	Birds of interest, habitats of interest	Vegetation types	Habitat types	Habitat types	Large mammals
Software/methods	Compilation of existing data	Compilation of existing data	Compilation of existing data	Vegetation species recognized for their performance in provision of air purification service	INVEST's "habitat quality" tool	Conservation value based on a regional report, natural value including ecological integrity with INVEST's "habitat quality" tool	Compilation of existing data
<i>ES pillar</i>							
Type of data	Raster maps	LULC habitats map	CORINE LULC and Remote Sensing maps	Vegetation map	Habitat map	LULC, habitat types, threats raster map, sources of degradation	Maps of indicators
ES types considered	5 ES supplies of cultural, supporting and regulating services	Supply of cultural, supporting and regulating services	10 ES supplies of regulating, cultural and provisioning services	Air purification service (supply and demand)	"biodiversity service equivalent" including recreation and agriculture	Cultural services (recreation, anthropic heritage)	8 ES supplies of regulating, supporting services
Software/methods	None, used the maps directly as inputs for Marxan	ES supplies of each vegetation type (biophysical table method)	None, used the maps directly as inputs for Marxan	Overlap between recognized critical ecosystems, population density and the particulate matter mean annual concentrations	China ecosystem services evaluation indicator based on surveys	Conservation value and natural value including levels of ecosystem functions and capacity to provide ES (INVEST's "habitat quality" tool)	Proxy measures

Table 1 (continued)

Article	Hermoso et al. [67]	Capotorti et al. [27]	Lanzas et al. [86]	Capotorti et al. [28]	Hu et al. [68]	Cannas et al. [25]	Liquete et al. [92]
<i>Structure and connectivity pillar</i>							
Type of data	Species, ES supplies and habitat maps	LULC	Results from biodiversity and ES assessments	Vegetation map	Habitat map	Habitat suitability map based on literature, resistance map based on the inverse of habitat suitability	Habitats quality
Structural/functional	Structural	Structural and functional	Structural	Structural and functional	Structural	Functional->corridors (and structural)	Functional
Software/methods	Marxan Zones	Structural connectivity with FRAGSTAT's Euclidean Nearest Neighbor Distance index, and functional connectivity with plant dispersal and plant-animal interactions	Marxan zones	Vegetation species composition and planting patterns, biogeographic representativity, dispersal potential. Use of Mean Nearest Neighbor Distance and Proximity Index with FRAGSTAT	Conefor Sensinode	Expert opinion, resistance map, least-cost path with ArcGIS Linkage Mapper Cost-Weighted distance-based	Habitats quality ranking

The table lists the scale of the study, the resolution of the resulting maps, the approach used to compile the pillars into a final GI map, the type of data and methods used for the assessment of each pillar, as well as the surrogates used

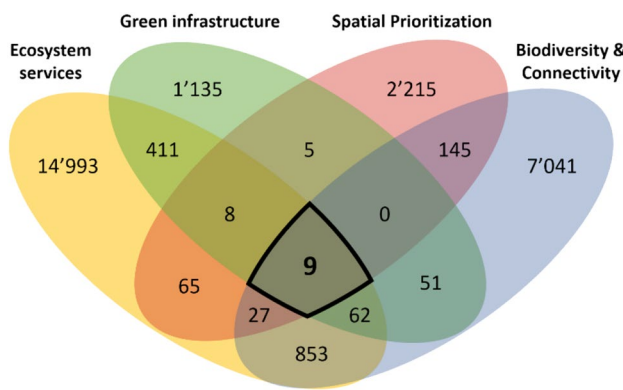


Fig. 1 Research gaps in GI studies using SCP. Numbers represent the quantity of results obtained in Web of Science using the corresponding combination of keywords. See "Appendix 2" for the exact query

uses accelerated stepwise heuristic, which starts from the whole landscape and iteratively removes cells with the smallest marginal loss over the total conservation value [108]. Zonation can also account for corridors using an additive penalty method in spatial priority ranking. This method does not rely on habitat patches, resistance coefficients or species targets, and uses two key parameters—penalty strength and corridor width—to control trade-offs between connectivity and other factors in conservation planning [123].

Other softwares include C-Plan and ConsNet Portal, which are used to solve the minimum area problem (representing all biodiversity surrogates with minimum area) and the maximum representation problem (representing the maximum number of surrogates in a constrained area) [108]. The choice of prioritization tools will depend on the objectives of the project as well as available data for inputs. However, several studies have indicated that different tools could lead to similar results and that the most important factor in SCP assessments is the quality of the input data [41].

3.3 Approaches to GI mapping

3.3.1 Pillars assessment methods and dimensions of a holistic GI

The complexity and precision of the evaluation of each GI pillar will depend on the objectives of each case-study, the needs of the map's end-users, as well as the allocated time and resources. The precision of each pillar will be determined by the source and quality of data (up to date and adequate resolution), the approach and a sufficient number of surrogates representing the pillar (for instance, supply and demand of various ES, separate consideration

of red list species, use of species distribution models together with complementary indices including specific richness/hotspots, naturalness, etc.). This section presents different assessment approaches for each pillar to help find the optimal balance between the required information and the resources necessary to acquire it.

3.3.2 Species and habitat diversity

Using perimeters of existing protected areas or (semi-) natural areas in a broad sense (such as forests) is sometimes used to map biodiversity, but this remains a rough estimation of how diversity is distributed in the study area. Considering a broad range of biodiversity surrogates would enable to integrate multiple aspects of biodiversity. Using species distribution models of multiple groups of fauna and flora species, precise habitat maps, and diversity indices such as specific richness, Shannon index, and Simpson index [58, 137, 142] would increase the representativity of the pillar.

Species distribution modeling is a powerful method to model species' realized ecological niches in a landscape and to extrapolate corresponding geographic distributions (Fig. 2) [65, 118, 136, 144, 165]. This method has several advantages, since the distribution of all species cannot be monitored exhaustively in space and time. A precise and updated data sample of species' locations or observation points are needed for these analyses.

A large number of methods exist to model species distribution. The MaxEnt software [121] based on the maximum entropy approach has become very popular because of its ease of use. The R software packages [126] have proven to be an efficient environment for statistical modeling and prediction of species distribution with regression methods such as: Generalized Linear Models (GLMs) fitting linear responses of predictors for different distributions of responses (e.g., presence-absence, abundance, richness, biomass); Generalized Additive Models (GAMs) are extending GLMs by fitting nonlinear response shapes based on smooth functions; Multivariate Adaptive Regression Splines (MARS) are further extending GAMs by allowing multiple responses and fitting more easily interactions between predictors; Boosted Regression Trees (BRT) and Random Forest (RF) [10, 50, 65] are addressing the problem of small datasets by using shrinkage techniques to fit a series of small models and integrate them at the end without violating the available degrees of freedom. Finally, ensemble forecasting are combining all the above methods to explore the uncertainty associated to the choice of modeling techniques and input variables [5, 149].

Species distribution maps can be aggregated in order to map species richness (alpha diversity) and identify "hotspots", i.e., areas where many species live relative to

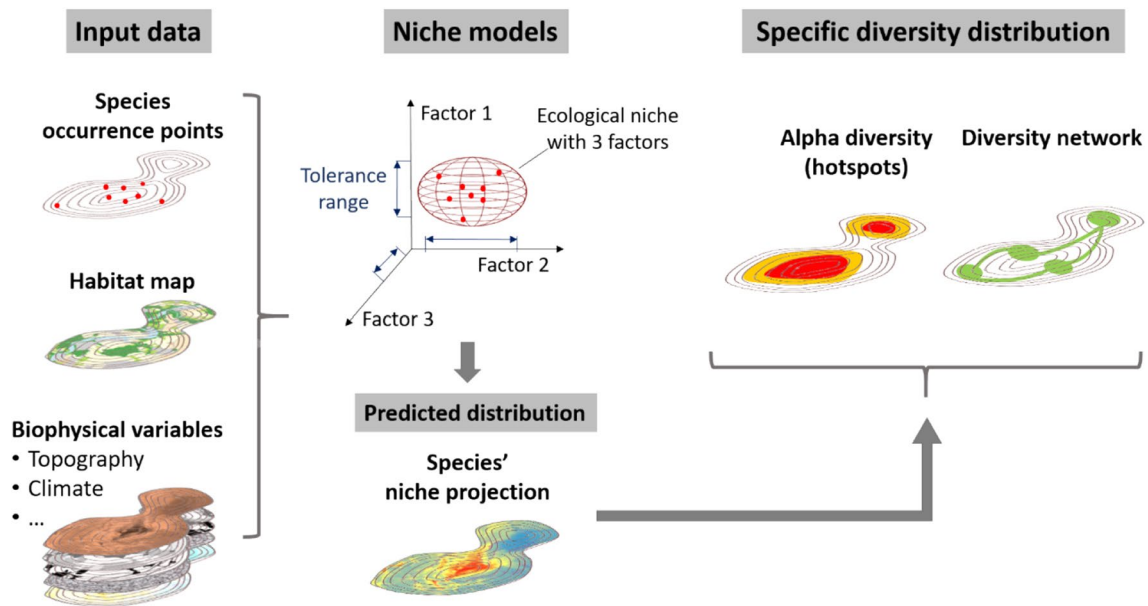


Fig. 2 Example of a SDM workflow for the species diversity pillar

the study area [88, 136]. However, considering only alpha diversity might lead to rare, specialist, endangered or isolated species being overlooked and could miss most of the global diversity in computer simulations [93]. A specific modeling and assessment of such species could be beneficial. Although relatively uncommon in conservation planning [104], beta diversity, the change of diversity between areas, could also be calculated and mapped [145].

3.3.3 ES supply and demand

Ecosystem services (ES) represent the benefits people obtain from nature [35, 106], and their value corresponds to the relative contribution of ecosystems to a community's goal [152]. In other words, ES refer to benefits to human well-being produced by natural capital combined with built capital and/or human and social capital [35]. The 'cascade model' from Haines-Young and Potschin [66] is often used to describe the flow of ES from the environment to people. It is important, however, to consider the socio-ecological system as a whole (Fig. 3) including the stock-flow (supply–demand) relationships for a better management of natural resources [96].

ES are sometimes included solely as potential co-benefits of identified high-ecological areas, without separate assessment of specific services. Yet, this may result in overlooking areas providing important ecosystem functions, as the distribution of ES and biodiversity are not appropriate surrogates for each other [100]. To have a better representation of ES provided by a territory, multiple services of both regulating and supporting ES should be assessed,

as well as their spatial flow from where the service is supplied to where it is consumed [82]. The choice of services included in the GI design will be influenced by the type of landscape (coastal, mountainous, urban, etc.), and the most relevant services to communicate to the targeted users or audience. Cultural and provisioning ES should, however, be integrated with caution as they may be in opposition with biodiversity and connectivity conservation [144]. Conserving biodiversity and connectivity may benefit cultural and provisioning services indirectly and/or in the long-term but including them for the GI design may lead to too many trade-offs or contradictory messages.

ES mapping approaches can roughly be categorized into five types [101]: (1) the "lookup tables" method links land-cover classes with values derived from the literature to estimate ES supply (natural capital) or ES demand; (2) the "expert knowledge" method relies on specialists to rank land cover classes based on their potential to provide services; (3) the "causal relationships" method incorporates statistics and existing knowledge from the literature to create spatial proxies of ES; (4) the "extrapolation of primary data" method associates weighted field data with land cover and other cartographical data; (5) the "regression models" method combines biophysical information from field data and the literature into a quantitative ecological system model.

Modeling is widely applied for ES assessment. In addition to the methods described above, process-based models are typically used to evaluate key environmental systems such as air, water (Soil and Water Assessment Tool—SWAT; swat.tamu.edu) or soil (Revised Universal

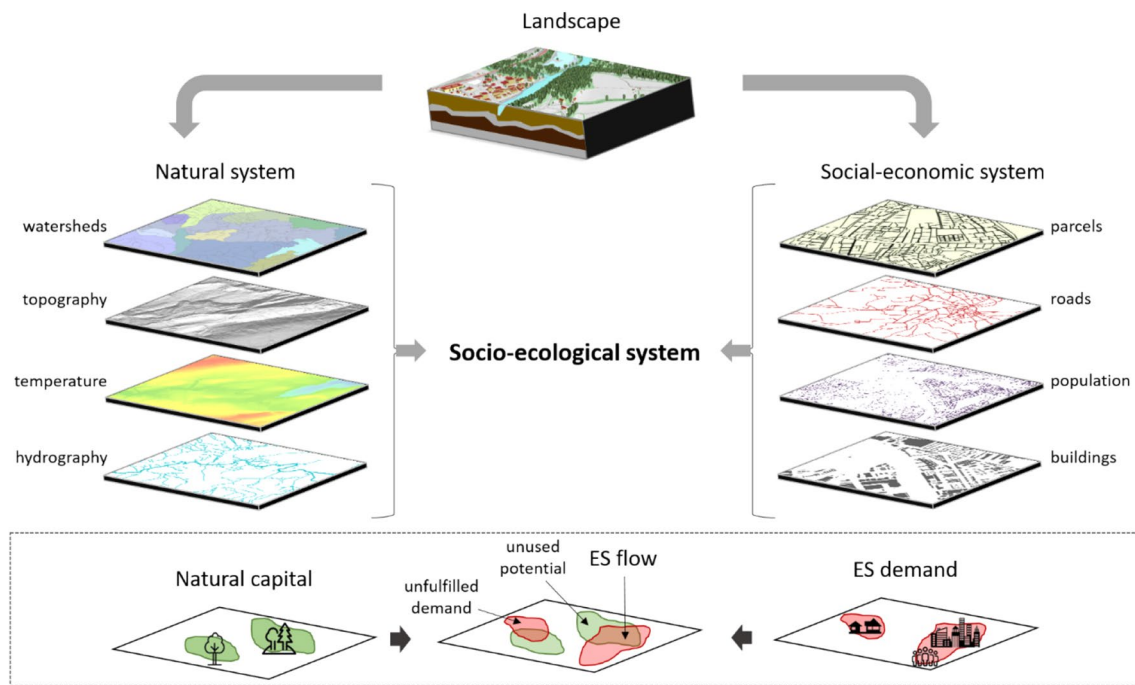


Fig. 3 Illustration of socio-ecological systems. People benefit from the interactions between natural systems and socio-economic systems that co-function within the same landscape

Soil Loss Equation—RUSLE). Many models have specifically been developed to analyze ES. For instance, IMAGE, EcoPath and ARIES [156] can project future changes in ES; InVEST and TESSA are two static models which describe the state of ES at points in time [70]; and NAIS and Ecosystem Valuation Toolkit are designed for monetary valuation of ES [11]. Grêt-Regamey et al. [64] have proposed a three tiered-approach for assessing ES in function of policy needs.

3.3.4 Structural and functional landscape connectivity

Ensuring species movement through a connected landscape helps increase the genetic diversity in a metapopulation, which raises the chances of species' survival by improving their resilience against climate change and other perturbations [117]. Species use the landscape's structure in different ways according to their specific ecological niches, lifestyles and dispersion abilities. GI builds on these principles to account for habitat shapes and sizes, as well as edge areas surrounding a habitat serving as a buffer.

Spatial structure refers to the topological distance between landscape features [150] and the spatial arrangement of landscape elements and determines the mosaic of contiguous land cover types [20]. Functional connectivity refers to the relative ease of mobility between landscape patches for a specific species [148, 163]. For instance,

spatially unconnected landscape elements (e.g., low connectedness) may represent strong constraints for species with low vagility [37], but may not necessarily reduce connectivity for flying species [17]. Corridors structurally connecting two patches may also be too narrow to have any functional connectivity values for some species. Considering only one or the other in a broad sense risks overlooking important corridors, and the pillar would lack representativity of ecological processes and functions. Analyzing landscape connectivity for multiple species groups (mammals, insects, birds, etc.) helps identify corridors that are more frequently used, to ensure connections between natural patches of habitats, and allow gene exchanges among populations.

Tracking animals can be difficult and costly but remains the best method to collect data on the actual use of the landscape. Modeling species connectivity is a suitable alternative (or complement) to animal radio tracking. Information regarding reproduction, habitat preference and dispersion ability is collected to identify suitable habitats for each species. Results from species distribution models can also be used to help identify habitat preferences. A resistance map can be created based on identified core areas, a land use—land cover (LULC) map and expert knowledge. This resistance map attributes a score to each LULC class representing the difficulty of the selected species to travel across it (Fig. 4). Appropriate parameters and thresholds for modeling corridors and connectivity

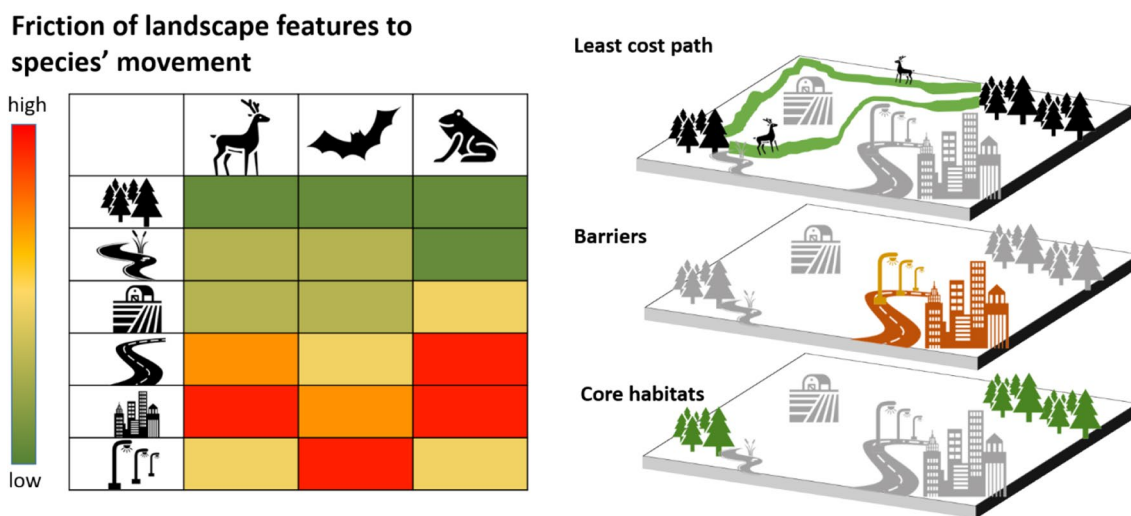


Fig. 4 Representation of species' least cost path between core habitat patches estimated with the friction of landscape features to species' movement

must be selected with care, because the resistance level of a LULC class varies among species, since an ecological barrier for a species can be physical (e.g. roads, lakes) or non-physical (e.g. noise, light and chemical pollution) [16].

Commonly used metrics for modeling functional connectivity include Euclidean distance (centrality analysis), least-cost path length and cost (an extension of graph theory), and circuit theory's resistance [105]. Popular corridor modeling tools include Linkage Mapper Connectivity Analysis Software (www.circuitscape.org/linkagemapper) [19], GuidosToolbox (forest.jrc.ec.europa.eu/download/software/guidos/), Corridor Design (<http://corridordesign.org>), Circuitscape [24], Conefor [134] and Graphab [57]. FRAGSTAT [102] is also a widely used spatial pattern analysis program to calculate various landscape pattern indices.

FRAGSTAT [102] is also a widely used spatial pattern analysis program to calculate various landscape pattern indices.

3.3.5 Overall GI identification approaches

Based on the literature review and the precision of each pillar's assessment, we identified 5 broad levels of GI identification (Fig. 5). Case-studies corresponding to levels 1 and 2 without separate analysis of the pillars or with only one or two pillars are often more biocentric-focused,

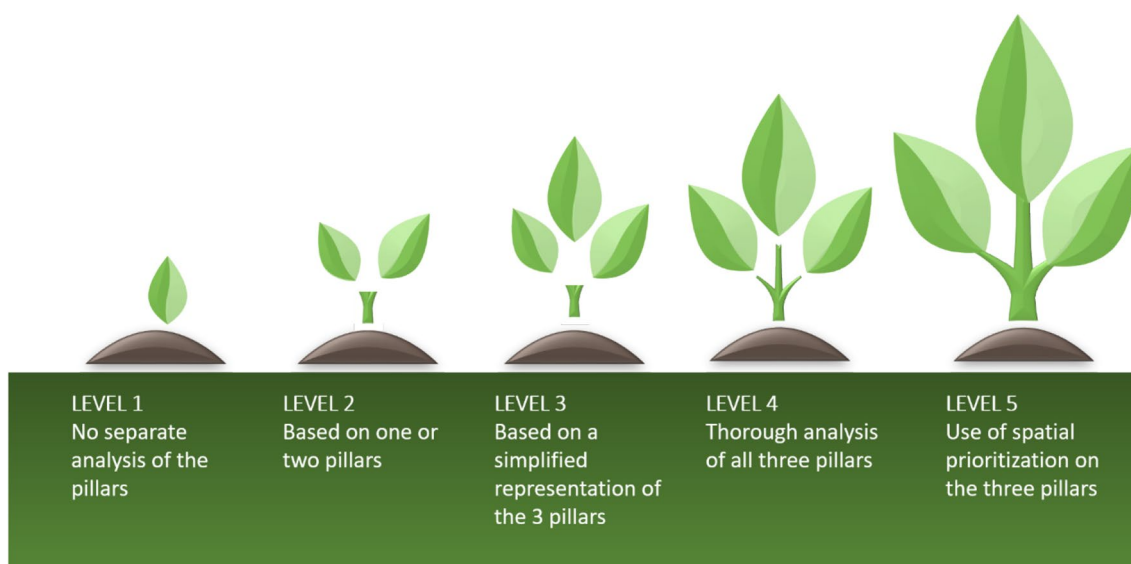


Fig. 5 Representation of levels in GI identification approaches

whereas case-studies including all three pillars are more polycentric.

Level 1 No separate analysis of the pillars. The GI is identified with existing protected areas and natural spaces, or based on a matrix of qualitative values for each land cover type estimated with expert opinions and the literature. This approach may be quick and simple to compute but lacks representativity and reliability to distinguish key areas to protect biodiversity, ES and connectivity.

Level 2 Based on one or two pillars. GI is identified using one or two of the three pillars while mentioning the co-benefit for the remaining one(s), such as habitat distribution and species corridors, or species distributions and ES. Some high-quality areas could be missed if the three pillars are not assessed equally and separately, and the resulting GI network may not effectively preserve resilient natural processes.

Level 3 Based on a simplified representation of the three pillars. GI is identified through the separate assessment of all three pillars, but without using a broad range of surrogates. For example, using existing reserves to identify biodiversity-rich areas, or a limited number of ES. This type of GI risks missing important corridors, buffer zones around core areas, or interesting (semi-)natural areas for ES supply or biological diversity (rare species

distribution or habitats), especially for large-scale studies (see discussion).

Level 4 Thorough analysis of all three pillars. GI is identified on the separate assessment of all three pillars, using a broad range of surrogates. Consideration of many representative natural habitats and species groups (birds, mammals, insects, amphibians, flowering plants, pteridophytes, coniferous, etc.), several ES, and the evaluation of structural and functional landscape connectivity. The results from the pillars are sufficiently representative of Nature’s multi-aspects, but no prioritization method is used to select area to include in the final GI network.

Level 5 In addition to the conditions of level 4, use of spatial prioritization on the three pillars instead of an overlap analysis, in order to rank each pixel of the map according to their multifunctional quality (see Box 1). The resulting map would theoretically represent the most valuable areas to optimize the conservation of natural entities, processes and functions. Below is an illustration of a framework that would correspond to this type of GI identification (Fig. 6).

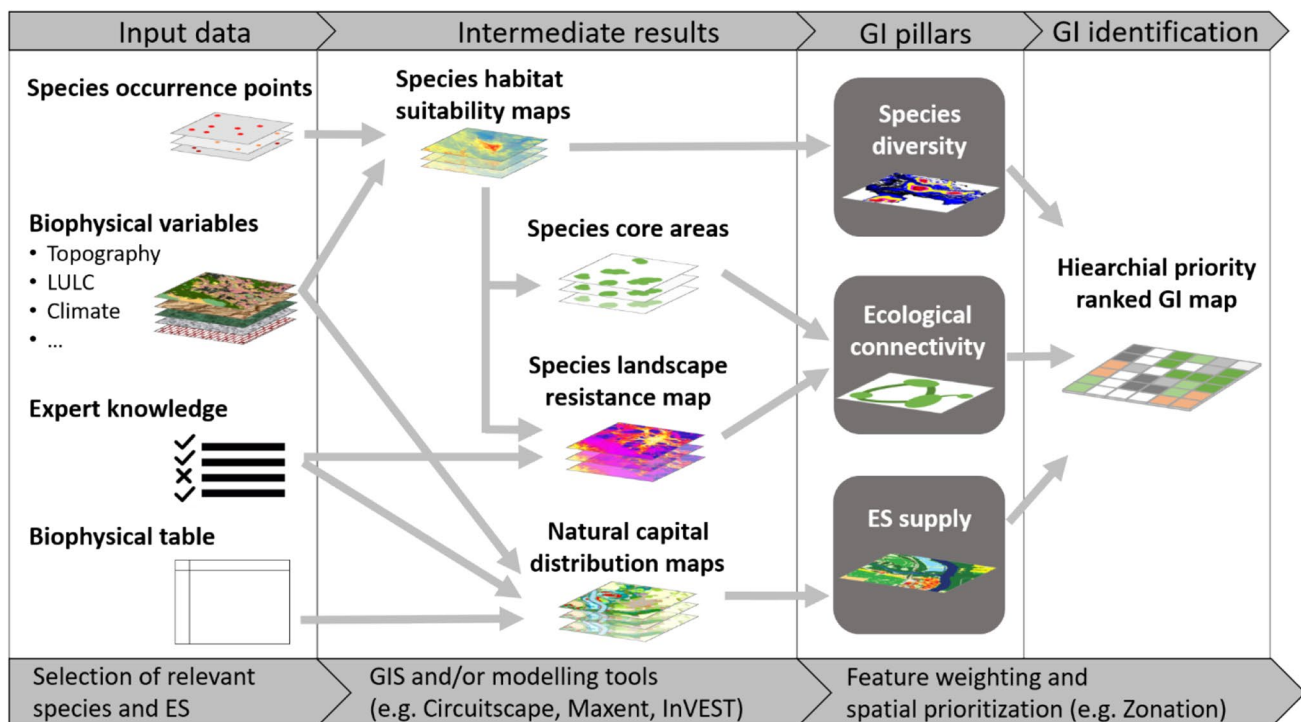


Fig. 6 Example of a framework for a case-study requiring precise and detailed GI map, corresponding to a level 5 GI identification approach described above

4 Discussion and conclusion

Views about the relationships between people and nature have evolved throughout the years, moving from a discourse simply about nature conservation to focusing on sustainable use of the environment [114]. The ideal of 'Nature for itself' and 'Nature despite people' has carried on to this day [96], but as the pressure on ecosystems continues to increase, there are multiple advantages of integrating nature's benefits for people into conservation planning. In fact, the concept of ES brings together all the values and benefits people attribute to their landscape [59]. Stakeholders in landscape planning may regard GI as irrelevant to them, if the concept is primarily associated with restrictive nature reserves and legally binding measures. By identifying shared values and opportunities, introducing nature's benefits for people can better communicate how landscape changes affect individual or collective well-being, and better align actors with different interests [159]. This improves acceptance of local policy decisions and favors collaboration and collective actions, which are vital for successful sustainable landscape management [87].

Mapping GI networks is an important step toward actual operationalization, because spatially explicit approaches are essential to support spatial planners' decisions. The involvement of stakeholders in a participatory process, the use of scientifically sound methods and quality data will also increase acceptance and the likelihood of effective implementation [15, 89]. As this methodology moves away from pure biodiversity conservation through protected areas toward the selection of multi-functional landscapes, many more stakeholders will be involved, typically in the selection and weighting of input data.

The different definitions of GI in the scientific literature have led to highly variable assessment methods and results. GI are sometimes interpreted as interlinkages between core areas for species [67, 86], and in other cases it is applied to identify areas of interest for specific groups of organisms such as pollinators [130]. The GI concept is adaptable and can be used from local scales and urban contexts [27, 28] to a regional/continental scales and in mosaic landscapes [67, 78, 92]. Yet, such analyses and purpose widely differ from one another, making it difficult to compare their methods and the identified networks.

To identify GI networks, most studies have relied on a few selected ecosystem functions or services, sometimes including habitats in a broad sense, without considering a wider range of ES and species [160]. Used in this way, GI is suited to address specific environmental concerns such as storm water management or coastal erosion control. GI based solely on habitat and species richness would not

necessarily integrate ecosystem functions, and ecological processes that generate and maintain biodiversity, such as meta-populations dynamics and large effective population sizes. If the concept of GI seeks to support a conservation plan for enhancing the sustainability of a landscape, it is important to search for synergies and trade-offs when setting priority areas for conservation.

Several hypotheses may help explain the scarcity of articles relying on a separated assessment of the three pillars, a wide range of surrogates and spatial prioritization. (1) The restricted availability and accessibility of qualitative data (species occurrences, LULC map etc.) is often a major obstacle to fulfill the numerous inputs required to run a complete analysis (levels 3 to 5) of the proposed methodologies. In fact, compiling data from flora and fauna monitoring or atlas and creating a precise LULC map with several natural habitat categories are the first and fundamental steps in GI identification (Fig. 3). (2) Cooperation among many scientific fields is necessary to cover the wide knowledge and skills set required to use the complex methods and software, such as Geographic Information Systems (GIS), species distribution and ES models, as well as field data acquisition (for cultural ES, species occurrences, etc.). Thus, the identification and implementation of GI networks is a transdisciplinary approach that would greatly benefit from creating and maintaining a solid collaboration between stakeholders, landscape planners, technicians and scientists from various fields. (3) Pre-processing data and running models are time-consuming and require a specific skill set that may not be readily available in a team. (4) The use of spatial prioritization methods has a steeper learning curve than overlay methods and may not be as widespread outside conservation biologists.

The levels proposed in this paper represent steps toward methodological complexity and an integrative approach. The more complex the method, the more inputs and data must be integrated, the more processing time and skills are required to run the analyses, and the more multidisciplinary collaboration is necessary for the implementation of the resulting GI network. There is a tradeoff between complexity, representativeness, quantity and quality of inputs and surrogates on the one hand, and the accessibility, feasibility and comprehensibility of the methods and results on the other hand. The choice, complexity and precision of GI identification methods will ultimately depend on the needs of the end-users, as well as the allocated time and financial resources. In fact, a policy-maker may have tight deadlines and only need to have an approximate idea of the distribution of natural capital in a territory, whereas a conservation practitioner may wish to retrace which species and ecosystem functions are behind certain priority conservation areas identified in the GI map.

Overly complex models that are too difficult to explain to decision-makers may not be desirable or suitable for a 'real-world' application [132]. Yet nature is complex and includes genetic, species, habitat diversity as well as interactions between organisms, ecosystem functions, individual mobility and functional traits. An overly simplified model will not capture enough facets of the natural world. For example, Kujala et al. [80] showed that considering many different species increase the stability of modeled conservation areas in spatial prioritization models. But even when many species are considered, the addition of a few randomized rare species in the models could still greatly alter the final result. It is therefore recommended to add as much pertinent information and data as available in the GI identification process, if they fit the global aim of the study [60].

Future challenges of GI identification and mapping include: (1) Approving on a common baseline and definition of GI to move from a theoretical framework to an applicable and testable approach. GI as urban nature-based solutions and architectural elements and GI following the definition presented in this paper should be differentiated in particular to avoid potential confusions. (2) A closer collaboration among scientific fields and between research and policy, in order to share skills and knowledge among researchers, conservation practitioners, landscape planners, decision-makers and other stakeholders. Since biodiversity loss is a global problem and a threat to the resilience of our societies, nature's conservation cannot be efficient without an integrative and transdisciplinary approach. (3) A better accessibility to software and updated data to integrate as many aspects of diversity, ES and connectivity in GI identification and mapping for landscape planners as possible. Improving data sharing between countries and institutions, and ensuring the availability of spatially and temporally relevant data would also be beneficial to expand this effort. (4) Creating a common set of variables to improve the comparability of different studies and their inputs that can have various data sources. This can be done by identifying essential variables for GI as an intermediate value between environmental policy indicators and their data sources [129]. This has been done to prioritize the monitoring of Earth systems, namely climate [23], biodiversity [120] and oceans [34].

Finally, a GI map should not be static solution, as ecosystems and socio-ecological systems are dynamic. In fact, implementation of GI should aim at preserving biodiversity and ES in the long run. Future urbanization plans can be used to predict the evolution of a GI network and potential threats. Considering future climatic scenarios and predicting species migrations will also enable adapting the design of current GI to efficiently protect ecological values under future conditions.

We believe this work would clarify conceptual aspects of GI identification and serve as a primer for researchers and practitioners that are new to GI mapping, and as a framework for more advanced researchers willing to contribute to the formalization of the concept. It provides an overview of different approaches to guide practitioners toward the most appropriate tool choices for the needs of their own case-study.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Appendix 1

The articles are sorted by their GI definition then by year of publication. We analyzed whether the authors considered each pillar in a broad sense, even if they do not specifically assess the pillar in the study. We verified if the authors were interpreting GI as an architectural element or a nature-based solution tool for urban greening, or if they were using the same GI definition than the one presented in this paper. We also categorized each type of article (review, case study or conceptual paper).

See Table 2.

Table 2 67 articles found using the following keywords in Web of Science on the 24.03.2020: "TOPIC: ("ecosystem service*") AND TOPIC: ("biodiversity") AND TOPIC: ("corridor*" or "connect*") AND TOPIC: ("green infrastructure*") Timespan: All years"

Article	Year	Title	Pillars consideration			Similar GI definition	Article type		
			ES	Diversity	Connectivity		Review	Case study	Conceptual
Hermoso et al. [67]	2020	Designing a network of green infrastructure for the EU	Yes	Yes	Yes	Yes	No	Yes	(Yes)
Wanghe et al. [162]	2019	Assessment of Urban Green Space Based on Bio-Energy Landscape Connectivity: A Case Study on Tongzhou District in Beijing, China	Yes	Yes	Yes	Yes	No	Yes	No
Cunha et al. [36]	2019	Methodology for mapping the national ecological network to mainland Portugal: A planning tool toward a green infrastructure	Yes	Yes	No	Yes	No	Yes	No
Capotorti et al. [27]	2019	Local scale prioritization of green infrastructure for enhancing biodiversity in peri-urban agroecosystems: a multi-step process applied in the metropolitan City of Rome (Italy)	Yes	Yes	Yes	Yes	No	Yes	No
Gocheva et al. [62]	2019	Ecosystem restoration in Europe: Can analogies to Traditional Chinese Medicine facilitate the cross-policy harmonization on managing socioecological systems?	Yes	No	No	Yes	No	No	Yes
Lanzas et al. [86]	2019	Designing a network of green infrastructure to enhance the conservation value of protected areas and maintain ecosystem services	Yes	Yes	Yes	Yes	No	Yes	No
Carlier and Moran [29]	2019	Landscape typology and ecological connectivity assessment to inform Greenway design	No	No	Yes	Yes	No	Yes	No
Svensson et al. [147]	2019	Landscape trajectory of natural boreal forest loss as an impediment to green infrastructure	Yes	Yes	Yes	Yes	No	Yes	No
Capotorti et al. [28]	2019	Biodiversity and ecosystem services in urban green infrastructure planning: a case study from the metropolitan area of Rome (Italy)	Yes	Yes	No	Yes	No	Yes	No
Hu et al. [68]	2018	Integrated methods for determining restoration priorities of coal mining subsidence areas based on green infrastructure: A case study in the Xuzhou urban area, of China	Yes	Yes	Yes	Yes	No	Yes	No
Vasiljević et al. [155]	2018	The concept of green infrastructure and urban landscape planning: a challenge for urban forestry planning in Belgrade, Serbia	Yes	Yes	Yes	Yes	No	Yes	No

Table 2 (continued)

Article	Year	Title	Pillars consideration			Similar GI definition	Article type		
			ES	Diversity	Connectivity		Review	Case study	Conceptual
de la Fuente et al. [40]	2018	Natura 2000 sites, public forests and riparian corridors: The connectivity backbone of forest green infrastructure	No	Yes	Yes	Yes	No	Yes	No
Cannas et al. [25]	2018	Green infrastructure and ecological corridors: a regional study concerning Sardinia	Yes	Yes	Yes	Yes	No	Yes	No
Albert et al. [1]	2017	Applying network theory to prioritize multispecies habitat networks that are robust to climate and land-use change	No	Yes	Yes	Yes	No	Yes	No
Elbakidze et al. [49]	2017	A bottom-up approach to map land covers as potential green infrastructure hubs for human well-being in rural settings: a case study from Sweden	Yes	No	No	Yes	No	Yes	No
Bellamy et al. [18]	2017	A spatial framework for targeting urban planning for pollinators and people with local stakeholders: a route to healthy, blossoming communities?	Yes	Yes	Yes	Yes	No	Yes	No
Pelorosso et al. [119]	2017	PANDORA 3.0 plugin: a new biodiversity ecosystem service assessment tool for urban green infrastructure connectivity planning	Yes	Yes	Yes	Yes	No	Yes	Yes
Salomaa et al. [133]	2017	Can green infrastructure help to conserve biodiversity?	Yes	Yes	Yes	Yes	No	Yes	No
Angelstam et al. [4]	2017	Gap analysis as a basis for strategic spatial planning of green infrastructure: a case study in the Ukrainian Carpathians	Yes	Yes	Yes	Yes	No	Yes	No
Capotorti et al. [26]	2016	Combining the conservation of biodiversity with the provision of ecosystem services in urban green infrastructure planning: critical features arising from a case study in the metropolitan area of Rome	Yes	Yes	No	Yes	No	Yes	No
Kukkala and Moilanen [82]	2017	Ecosystem services and connectivity in spatial conservation prioritization	Yes	Yes	No	Yes	NO	No	Yes
Garmendia et al. [61]	2016	Biodiversity and Green Infrastructure in Europe: Boundary object or ecological trap?	Yes	Yes	Yes	Yes	No	No	Yes
Green et al. [63]	2016	Insurance Value of Green Infrastructure in and Around Cities	Yes	Yes	No	Yes	Yes	No	Yes

Table 2 (continued)

Article	Year	Title	Pillars consideration			Similar GI definition	Article type		
			ES	Diversity	Connectivity		Review	Case study	Conceptual
Lynch [94]	2016	Is It Good to Be Green? Assessing the Ecological Results of County Green Infrastructure Planning	Yes	No	Yes	Yes	Yes	No	No
Snäll et al. [144]	2016	Green infrastructure design based on spatial conservation prioritization and modeling of biodiversity features and ecosystem services	Yes	Yes	Yes	Yes	No	(Yes)	Yes
Liquete et al. [92]	2015	Mapping green infrastructure based on ecosystem services and ecological networks: a Pan-European case study	Yes	Yes	Yes	Yes	No	Yes	No
Fichera et al. [55]	2015	Application, validation and comparison in different geographical contexts of an integrated model for the design of ecological networks	No	Yes	Yes	Yes	No	Yes	No
Dupras et al. [47]	2015	Toward the Establishment of a Green Infrastructure in the Region of Montreal (Quebec, Canada)	Yes	Yes	Yes	Yes	No	Yes	Yes
Kopperoinen et al. [78]	2014	Using expert knowledge in combining green infrastructure and ecosystem services in land use planning: an insight into a new place-based methodology	Yes	Yes	No	Yes	No	Yes	No
Phillips et al. [122]	2020	Ecosystem service provision by road verges	Yes	No	No	No	Yes	No	No
Roeland et al. [130]	2019	Toward an integrative approach to evaluate the environmental ecosystem services provided by urban forest	Yes	Yes	Yes	No	Yes	No	No
Wang et al. [161]	2019	Spatial patterns of urban green infrastructure for equity: a novel exploration	No	No	Yes	No	No	Yes	No
Knapp et al. [77]	2019	Biodiversity Impact of Green Roofs and Constructed Wetlands as Progressive Eco-Technologies in Urban Areas	Yes	Yes	Yes	No	Yes	No	No
Park et al. [116]	2019	Urban food systems that involve trees in Northern America and Europe: a scoping review	Yes	No	No	No	Yes	No	No
Donaldson et al. (2019)	2019	Using green infrastructure to add value and assist place-making in public realm developments	Yes	No	No	No	No	Yes	No
Diduck et al. [44]	2020	Pathways of learning about biodiversity and sustainability in private urban gardens	No	No	No	No	No	Yes	No

Table 2 (continued)

Article	Year	Title	Pillars consideration			Similar GI definition	Article type		
			ES	Diversity	Connectivity		Review	Case study	Conceptual
Pirnat and Hladnik [124]	2019	A tale of two cities—from separation to common green connectivity for maintaining of biodiversity and well-being	Yes	Yes	No	No	No	Yes	No
Lahde et al. [85]	2019	Can we really have it all? Designing multifunctionality with sustainable urban drainage system elements	Yes	Yes	No	No	No	Yes	No
Suchocka et al. [146]	2019	Transit versus Nature. Depreciation of Environmental Values of the Road Alleys. Case Study: Gamerki-Jonkowo, Poland	Yes	Yes	No	No	No	Yes	No
Ferreira et al. [54]	2019	Impact of the urbanization process in the availability of ecosystem services in a tropical ecotone area	Yes	No	No	No	No	Yes	No
Auerswald et al. [9]	2019	HESS Opinions: Socio-economic and ecological trade-offs of flood management—benefits of a trans-disciplinary approach	Yes	No	No	No	No	Yes	No
Zhang et al. [166]	2019	Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design	No	No	Yes	No	No	Yes	No
Lin et al. [91]	2019	Establishing priorities for urban green infrastructure research in Australia	No	No	No	No	No	No	Yes
Shi and Qin [138]	2018	Research on the optimization of regional green infrastructure network	No	No	Yes	No	No	Yes	No
Dhyani et al. [43]	2018	Ecosystem based Disaster Risk Reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India	Yes	No	No	No	No	Yes	No
Rolf et al. [131]	2018	Farmland—an Elephant in the Room of Urban Green Infrastructure? Lessons learned from connectivity analysis in three German cities	No	No	Yes	No	No	Yes	No
Singh et al. [143]	2018	Simulating stream response to floodplain connectivity and revegetation from reach to watershed scales: Implications for stream management	Yes	No	No	No	No	Yes	No
Artmann and Sartison [8]	2018	The role of urban agriculture as a nature-based solution: a review for developing a systemic assessment framework	No	No	No	No	Yes	No	No

Table 2 (continued)

Article	Year	Title	Pillars consideration			Similar GI definition	Article type		
			ES	Diversity	Connectivity		Review	Case study	Conceptual
Qu et al. [125]	2018	Identifying conservation priorities and management strategies based on ecosystem services to improve urban sustainability in Harbin, China	Yes	No	No	No	No	Yes	No
Zefferman et al. [164]	2018	Knoxville's urban wilderness: moving toward sustainable multifunctional management	Yes	Yes	No	No	No	Yes	No
Schifman et al. (2017)	2017	Situating green infrastructure in context: a framework for adaptive socio-hydrology in cities	Yes	No	No	No	No	Yes	No
Angelstam et al. (2017)	2017	Green infrastructure development at European Union's eastern border: effects of road infrastructure and forest habitat loss	No	Yes	Yes	No	No	Yes	No
Brill et al. (2017)	2017	Methodological and empirical considerations when assessing freshwater ecosystem service provision in a developing city context: making the best of what we have	Yes	No	No	No	No	Yes	No
Nilon et al. (2017)	2017	Planning for the future of urban biodiversity: a global review of city-scale initiatives	Yes	Yes	Yes	No	Yes	No	No
Sikorska et al. [140]	2017	High biodiversity of green infrastructure does not contribute to recreational ecosystem services	Yes	Yes	No	No	No	Yes	No
Artmann et al. [7]	2017	Using the concepts of green infrastructure and ecosystem services to specify Leitbilder for Compact and Green Cities-The Example of the Landscape Plan of Dresden (Germany)	Yes	No	No	No	No	Yes	No
Ochoa et al. (2017)	2017	Vegetation conservation to reduce hydrometeorological risks on a border metropoli	Yes	No	No	No	No	Yes	No
Bujs et al. (2016)	2016	Active citizenship for urban green infrastructure: fostering the diversity and dynamics of citizen contributions through mosaic governance	Yes	No	No	No	No	No	Yes
Säumel et al. (2016)	2016	Toward livable and healthy urban streets: Roadside vegetation provides ecosystem services where people live and move	Yes	No	No	No	No	Yes	No

Table 2 (continued)

Article	Year	Title	Pillars consideration			Similar GI definition	Article type		
			ES	Diversity	Connectivity		Review	Case study	Conceptual
Fattorini et al. (2016)	2016	Role of urban green spaces for saproxylic beetle conservation: a case study of tenebrionids in Rome, Italy	No	Yes	No	No	No	Yes	No
Wang et al. (2016)	2016	Urban Watershed Framework Plan for Conway, Arkansas: A Reconciliation Landscape	Yes	No	No	No	No	Yes	No
Opdam et al. [113]	2015	Framing ecosystem services: affecting behavior of actors in collaborative landscape planning?	Yes	No	No	No	No	Yes	Yes
Orsini et al. [115]	2014	Exploring the production capacity of rooftop gardens (RTGs) in urban agriculture: the potential impact on food and nutrition security, biodiversity and other ecosystem services in the city of Bologna	Yes	No	No	No	No	Yes	No
Shwartz et al. [139]	2014	Outstanding challenges for urban conservation research and action	No	Yes	No	No	Yes	No	No
Kuttner et al. [83]	2014	Do landscape patterns reflect ecosystem service provision?—A comparison between protected and unprotected areas throughout the Lake Neusiedl region	Yes	No	Yes	No	No	Yes	No
Andrade et al. [2]	2013	Assembling the pieces: a framework for the integration of multi-functional ecological main structure in the emerging urban region of Bogota, Colombia	No	No	No	No	No	Yes	No
Mörtberg et al. [109]	2012	Urban ecosystems and sustainable urban development—analyzing and assessing interacting systems in the Stockholm region	Yes	No	No	No	No	Yes	Yes

Appendix 2: Number of results in Web of Science using a combination of keywords (1st of May 2020)

14'993 **TOPIC:("ecosystem service*") NOT TOPIC:("green infrastructure*") NOT TOPIC:(spatial AND prioritiz*) NOT TOPIC:(connect* OR corridor*) NOT TOPIC:(biodiversity)**

411 **TOPIC:("ecosystem service*") AND TOPIC:("green infrastructure*") NOT TOPIC:(spatial AND prioritiz*) NOT TOPIC:(connect* OR corridor*) NOT TOPIC:(biodiversity)**

145 **TOPIC:(biodiversity) NOT TOPIC:("ecosystem service*") AND TOPIC:(spatial AND prioritiz*) AND TOPIC:(connect* OR corridor*) NOT TOPIC:("green infrastructure*")**

1135 **TOPIC: ("green infrastructure*") NOT TOPIC:("ecosystem service*") NOT TOPIC:(spatial AND prioritiz*) NOT TOPIC:(connect* OR corridor*) NOT TOPIC:(biodiversity)**

51 **TOPIC: ("green infrastructure*") NOT TOPIC:("ecosystem service*") NOT TOPIC:(spatial AND prioritiz*) AND TOPIC:(connect* OR corridor*) AND TOPIC:(biodiversity)**

65 **TOPIC:("ecosystem service*") NOT TOPIC:("green infrastructure*") AND TOPIC:(spatial AND prioritiz*) NOT TOPIC:(connect* OR corridor*) NOT TOPIC:(biodiversity)**

7041 **TOPIC: (connect* OR corridor*) NOT TOPIC:("ecosystem service*") NOT TOPIC:(spatial AND prioritiz*) AND TOPIC:(biodiversity) NOT TOPIC: ("green infrastructure*")**

2215 **TOPIC: (spatial AND prioritiz*) NOT TOPIC: ("ecosystem service*") NOT TOPIC: (connect* OR corridor*) NOT TOPIC: (biodiversity) NOT TOPIC: ("green infrastructure*")**

5 **TOPIC: (spatial AND prioritiz*) NOT TOPIC: ("ecosystem service*") NOT TOPIC: (connect* OR corridor*) NOT TOPIC: (biodiversity) AND TOPIC: ("green infrastructure*")**

8 **TOPIC:("ecosystem service*") AND TOPIC:(("green infrastructure*")) AND TOPIC:(spatial AND prioritiz*) NOT TOPIC:(connect* OR corridor*) NOT TOPIC:(biodiversity)**

0 **TOPIC: ("green infrastructure*") NOT TOPIC: ("ecosystem service*") AND TOPIC: (spatial AND prioritiz*) AND TOPIC: (connect* OR corridor*) AND TOPIC: (biodiversity)**

9 **TOPIC:("ecosystem service*") AND TOPIC:(("green infrastructure*")) AND TOPIC:(spatial AND prioritiz*) AND TOPIC:(connect* OR corridor*) AND TOPIC:(biodiversity)**

27 **TOPIC:("ecosystem service*") NOT TOPIC:(green infrastructure*) AND TOPIC:(spatial AND prioritiz*) AND TOPIC:(connect* OR corridor*) AND TOPIC:(biodiversity)**

62 **TOPIC:("ecosystem service*") AND TOPIC:(green infrastructure*) NOT TOPIC:(spatial AND prioritiz*) AND TOPIC:(connect* OR corridor*) AND TOPIC:(biodiversity)**

853 **TOPIC:("ecosystem service*") NOT TOPIC:(green infrastructure*) NOT TOPIC:(spatial AND prioritiz*) AND TOPIC:(connect* OR corridor*) AND TOPIC:(biodiversity)**

16 **TOPIC:("ecosystem service*") NOT TOPIC:(green infrastructure*) AND TOPIC:(spatial AND prioritiz*) AND TOPIC:(connect* OR corridor*) AND TOPIC:(biodiversity) AND TOPIC:(("network*"))**

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