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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

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Abstract: A large number of green infrastructure (GI) projects have recently been proposed, planned and implemented in European cities following the adoption of the GI strategy by the EU Commission in 2013. Although this policy tool is closely related to biodiversity conservation targets, some doubts have arisen as regards the ability of current urban GI to provide beneficial effects not only for human societies but also for the ecological systems that host them. The aim of this work is to review the features that should be considered critical when searching for solutions that simultaneously support biodiversity and guarantee the provision of ecosystem services (ES) in urban areas. Starting from a case study in the metropolitan area of Rome, we highlight the role of urban trees and forests as proxies for overall biodiversity and as main ecosystem service providers. We look beyond the individual functional features of plant species and vegetation communities to promote the biogeographic representativity, ecological coherence and landscape connectivity of new or restored GI elements.

Keywords: biogeographic representativity; connectivity; ecological coherence; European Green Infrastructure Strategy; urban forests; urban trees

1. Introduction

The European GI Strategy defines green infrastructure (GI) 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” [1]. GI consists of “spatially or functionally connected areas which maintain ecological coherence as an essential condition for healthy ecosystems”, and contemporarily presents an added value that derives from the potential to attract investments in natural capital to strengthen the ability of ecosystems to deliver multiple goods and services that benefit human societies [2].

Since its adoption in 2013, the European GI Strategy has attracted great interest across EU Member States, stimulating the proposal, planning and implementation of a large number of GI projects at both the landscape and the local scale [3], with the latter involving above all urban and peri-urban areas [4–7]. Unlike landscape scale designs in rural settings, those conceived for local scale GI in urban contexts have been addressed mainly at enhancing the provision of ecosystem services (ES) and the cost-effectiveness of such interventions, while considering the health of ecosystems, i.e., biodiversity in its multiple aspects, just a secondary and/or approximate goal [5,8,9]. This applies to several case studies that have focused on ways of greening grey infrastructures, e.g., by means of green roofs and green walls, or on increasing the provision of green spaces without considering the environmental setting within which the cities lie [10,11].

Theoretical frameworks that effectively incorporate biodiversity conservation into GI are being promoted to overcome these restrictions. They are drawing the attention of researchers, practitioners and decision-makers to structural and functional connectivity [12], to the quality of the surrounding urban matrix [13], to native biodiversity [14], and to species, habitats and ecosystems of conservation importance [15]. The need remains, however, to build the evidence base required to ensure that GI projects are effectively biodiversity-oriented and aptly fitted to local environments [16].

In keeping with an operational perspective, the aim of this work is to provide an overview of the concrete features that should be considered when searching for solutions that simultaneously support biodiversity and guarantee the supply of ES in urban areas. In particular, the results of this overview represent the basic ecological knowledge underlying the ongoing development of pilot urban GI projects in the metropolitan area of Rome. These projects have been commissioned by the Italian Ministry for the Environment to start implementing the European GI Strategy, and consequently the related Action 6 of the EU Biodiversity Strategy, at the national level. On the one hand, we provide an overview of the literature regarding the varying performance of urban forests and trees in ES provision; on the other hand, we highlight the evidence available regarding the features that play a critical role in the conservation of urban plant diversity. Accordingly, we also identify and discuss an array of different actions that allow plant diversity values and the provision of ES to be combined. The conclusions point to the actual and expected impact of these findings at the broader national and European levels.

2. Materials and Methods

As recently proposed for the implementation of the European Biodiversity Strategy for 2020 [17], actual vegetation cover can be considered as an effective operational proxy when outlining overall ecosystem complexity [18]. Concurrently, plant communities and plant species are widely recognized as being among the main providers of ES in urban areas, especially in the form of forests though also as isolated trees [19–21]. For these reasons, we analyzed specific features of trees and forests that may, besides being able to deliver multiple ES, be critical to the quality of natural and semi-natural ecosystems in urban contexts. The city of Rome, a metropolis in Mediterranean Europe, was adopted as a case study (Figure 1). The city covers an area of 345 km² and represents the central urban sector of the municipality, which covers an area of approximately 1300 km².

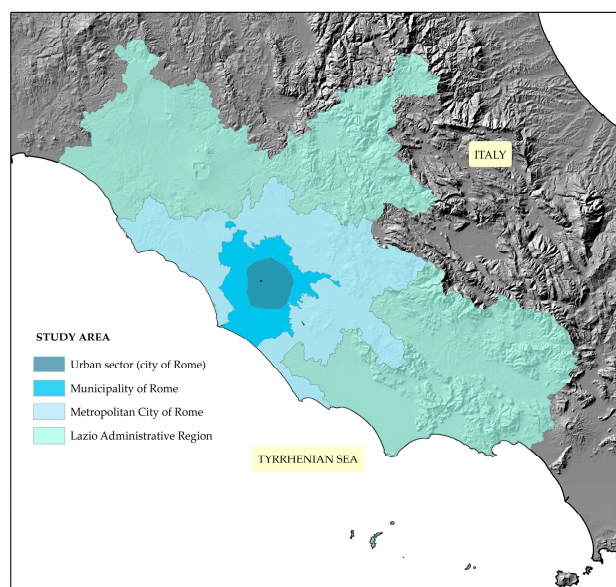


Figure 1. Study area. Location of the urban sector of Rome (central Italy) within the municipal, metropolitan and regional administrative boundaries.

The overall approach adopted in the present work is shown in Figure 2.

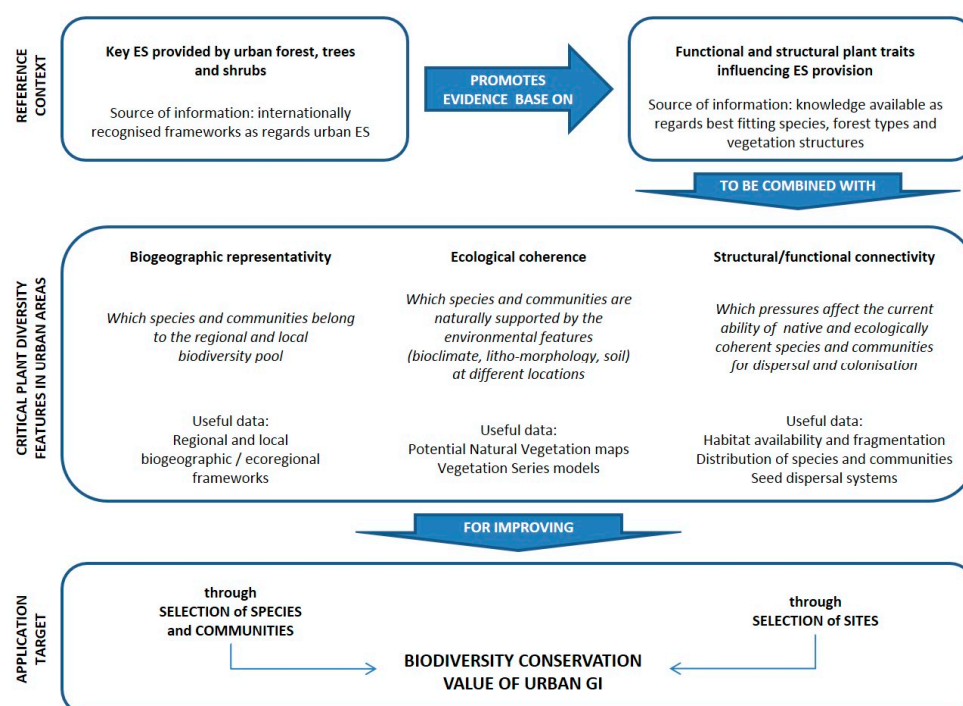


Figure 2. Overall approach adopted for the identification of biodiversity values that should be integrated into GI projects.

We first identified the ES framework of the research, and then searched for evidence of the functional and structural traits of urban trees and forest remnants that influence the provision of such ES in the scientific literature. As a reference framework for the key ES that are provided by urban forests and trees, we adopted the summary recently published for the mapping and assessment of urban ecosystems in Europe [4] (Table 1).

Table 1. Key ES totally or partially provided by woody vegetation in urban contexts (simplified from Maes et al. [4]). Sections and class types of ES refer to the international CICES (Common International Classification of Ecosystem Services) hierarchical classification system [22]. Providing units that are relevant to the present work are in bold.

ES Section	Urban ES Class Type	Service Providing Unit
Regulating	Regulation of air quality	Forest, trees, shrubs
	Climate regulation through reduction of CO ₂	Vegetation , soil
	Urban temperature regulation	Forest, trees, shrubs , herbs, lawns , wetlands, water bodies
	Noise mitigation	Forest, trees, shrubs, vegetated surfaces
	Water flow regulation and run-off mitigation	Trees, shrubs, vegetated and permeable surfaces
Cultural	Nature based recreation	Parks, gardens, forest, trees , agricultural areas in the commuting zone, wetlands, water bodies, waterways, Natura 2000 sites
	Nature based education	

For each of the key ES listed in Table 1, we then performed an exploratory review of the scientific literature in order to find estimates of the capacity of different tree species and forest types to provide ES that may be relevant to our case study (Table 2). Specifically, references in Table 2 focus on

studies that mainly considered woody species and forest types belonging to the flora and to the natural vegetation types of the city of Rome [23,24], and/or that geographically involve the study area (Figure 1). The nomenclature of the species follows Conti et al. [25] for the native flora and Celesti-Grapow et al. [26] for the non-native flora.

Table 2. Information on the capacity of different woody species and forest types to provide ES and corresponding spatial level of the estimates.

Capacity to Provide ES	Spatial Level and Geographic Location of the Estimates Available
Air pollutant removal by different physiognomic—structural vegetation categories	Local level estimates for the administrative region and the metropolitan area of Rome [27–29]
Carbon mitigation by different forest types and tree species	(a) National level estimates [30,31] and (b) Local level estimates for the city of Rome [32,33]
Cooling effect by different tree species frequently planted in cities	(a) Local level estimates for various European cities [34–36] and (b) Local level estimates for the city of Rome [32]
Ability of different vegetation structures and hedgerow species to reduce noise levels	(a) Local level estimates for North American cities [37,38] and (b) Local level estimates for the city of Rome [39]
Influence on stormwater run-off and its rate of discharge by different vegetation/tree canopy cover types	Local level estimates for North American cities [40]
Development of people’s identity, attachment to natural environments, and increasing commitment toward nature protection by different conservation/development urban zones	Local level indications for the Municipality of Rome [41–43]

In a second stage (Figure 2), we collected and integrated the wide range of information available on plant diversity for our case study, i.e., the urban sector of the city of Rome [4,44]. This information includes recent and updated inventories and distribution maps of plant species [23,44,45], forest ecosystems and habitats of conservation interest [43,46], and potential natural vegetation types [24]. On the basis of the scientific literature [13,47,48] and of the knowledge available on drivers of biodiversity loss at the local level [49,50], we then selected features that are critical to the enhancement and conservation of urban trees and forests.

Lastly, we provided original practical suggestions on how to integrate these biodiversity values into urban green infrastructure elements in the study area.

3. Results

3.1. Ranking of the Performance of Urban Forests and Trees in ES Provision

The estimates of the capacity of urban trees and forests to provide key ES that are listed in Table 2 display varying degrees of impact on the selection of species and sites that are deemed suited to GI interventions in the case study (Table 3).

As regards the cultural services, i.e., nature-based recreation and education (Table 3, item A), the literature only provides a coarse definition of the sectors of the city that should contemporarily: (i) develop pro-environmental concern, awareness and commitment for “nature” and biodiversity at the local and global level; (ii) promote the sense of continuity between urban and rural areas; and (iii) promote a collaboration between natural and social-behavioral sciences for a better urban and architectural planning of the city and increase people’s positive relationship with urban green areas [43].

As regards the regulating services, evidence on noise mitigation (Table 3, item B1) was early collected both for the sites of intervention, which need to be as close as possible to the source of disturbance, and for vegetation structure, which should ideally consist of wide belts of tall, dense trees, or combinations of trees, shrubs and grasses, which are even more effective [37]. Moreover, evergreen species were deemed to perform better on account of their year-round noise screening qualities [37]. More in particular, an experimental study on the evergreen shrubs traditionally used for hedges in the city of Rome (Table 3, item B2) showed that, owing to their denser foliage and branches and higher leaf mass per unit of leaf area, species such as *Pittosporum tobira* and *Laurus nobilis* perform better than *Pyracantha coccinea* and *Nerium oleander* [39]. *Laurus nobilis* and *Pyracantha coccinea* are representative of the natural forest types of the study area, while *Nerium oleander* is typical of the islands and southernmost regions of Italy and *Pittosporum tobira* is a non-native species.

Table 3. Ranking of ES provision according to site and/or species and communities performance (+++, ++, +: relatively high, medium and low performance).

ES Type	Ranking According to SITE Performance		
	+++	++	+
A. Nature-based recreation/education	Sectors with a core function for the combined conservation of natural, agricultural and human capital	Sectors with a connection function between natural and urban systems	Sectors suitable for innovative and sustainable management strategies
ES Type	Ranking According to SPECIES and COMMUNITIES Structure and/or Physiognomy Performance		
	+++	++	+
B1. Noise mitigation	Wide, tall and multi-stratified vegetation belts with evergreen species		Narrow, short and mono-stratified vegetation belts with deciduous species
B2. Noise mitigation	Evergreen hedges with denser foliage and branches and higher leaf mass per unit of leaf area (<i>Pittosporum tobira</i> and <i>Laurus nobilis</i>)		Evergreen hedges with less dense foliage and branches and lower leaf mass per unit of leaf area (<i>Pyracantha coccinea</i> and <i>Nerium oleander</i>)
C. Water flow regulation and run-off mitigation	High canopy coverage		Low canopy coverage
D1. Urban temperature regulation	Trees with smaller leaves (e.g., <i>Robinia pseudoacacia</i> , <i>Pinus sylvestris</i>) in parks		Trees with larger leaves (e.g., <i>Acer platanoides</i> , <i>Aesculus hippocastanum</i> , <i>Platanus hispanica</i>) along streets
D2. Urban temperature regulation	Trees with larger crown volume (<i>Quercus pubescens</i>)		Trees with narrower crown volume (<i>Quercus ilex</i>)
E1. Climate regulation through reduction of CO ₂	<i>Quercus ilex</i> forests Exotic conifer forests Deciduous oak forests <i>Fagus sylvatica</i> forests White fir/Norway spruce forests	<i>Castanea sativa</i> forests Hygrophilous broadleaved forests Mediterranean pine forests Mountain pine forests Exotic broadleaved forests	Bushlands Mediterranean broadleaved deciduous forests
E2. Climate regulation through reduction of CO ₂	<i>Quercus pubescens</i> and <i>Q. ilex</i>	<i>Platanus hispanica</i>	
F1. Regulation of air quality (particulate matter removal)	Conifer forests High Mediterranean maquis Mediterranean evergreen oak forests	<i>Castanea sativa</i> forests	Deciduous oak forests <i>Fagus sylvatica</i> forests
F2. Regulation of air quality (ozone removal without extreme summer aridity)	Conifer forests (mainly with <i>Pinus pinea</i>)	Deciduous forests (mainly with oaks and exotic broadleaves)	Evergreen forests (mainly with <i>Quercus ilex</i> and <i>Q. suber</i>)

The estimates for water flow regulation and run-off mitigation (Table 3, item C) only provide indications about the efficiency of different vegetation cover structures, regardless of their composition. The general recommendation is to increase canopy cover of the land surface [40].

As for the cooling effect related to the peculiar features of a site, a review of the available empirical evidence highlighted the positive role of size for urban parks [51]. With regard to species performance, Leuzinger et al. [34] showed that, at least in central European cities (Table 3, item D1), the crown temperatures of trees with smaller leaves, including conifers, tend to be lower than those of trees with larger leaves and, generally, that trees in parks are more efficient than trees surrounded by sealed

ground. Only three of the species considered by the authors of that work, all of which displayed a medium or low performance, are native and naturally distributed in the administrative region that includes the city of Rome (*Acer platanoides*, *Tilia cordata*, *Tilia platyphyllos*), while one (*Pinus sylvestris*), whose performance is good, is a native species but has a biogeographic distribution that is restricted to the Alpine regions of the country, which lie far from the study area. All the others are non-native species that belong (*Aesculus hippocastanum*, *Gleditsia triacanthos*, *Platanus hispanica*, and *Robinia pseudoacacia*) or do not belong (*Acer saccharinum*, and *Tilia tomentosa*) to the flora of the city of Rome. Evidence regarding the performance of additional tree species that partly belong to the flora of the city of Rome also emerged from other European cities in the strictly Mediterranean or sub-Mediterranean climatic zone [35,36]. Specifically, the best performing species among those analysed in Thessaloniki [35] include a non-native species (*Morus alba*), a native species (*Celtis australis*) and a complex of species whose status is not unique to Rome (*Platanus* spp.). As the species set measured in that work does not fully represent the tree and forest diversity of Rome and no general consideration is provided regarding plant traits that mainly influence the thermal effect of different species, this ranking is not included in Table 3. At a more local level (Table 3, item D2), further indications related to two oak species that are native to the study area (Table 3, item D3) emerged for the city of Rome [32], with experimental evidence showing that in summer the deciduous oak *Quercus pubescens* performs better than the evergreen oak *Q. ilex* owing to its larger crown volume.

As regards both carbon mitigation and air pollutant removal, the indications that are available take into account the functionality of the different physiognomic types found in the case study and are consequently more specific.

The data available at the national level on carbon net primary productivity (Table 3, item E1) were considered as a proxy for carbon mitigation [30]. The ranking of physiognomic types that are characteristic of the urban sector of Rome points to a slightly better performance of evergreen oaks over exotic conifers and deciduous oaks, a medium performance of chestnut, hygrophilous broadleaves, Mediterranean pines and exotic broadleaves, and a minor potential contribution of bushlands and other Mediterranean deciduous broadleaves. Local estimates available at the tree species level (Table 3, item E2) for the native evergreen oak *Quercus ilex*, for the native deciduous oak *Q. pubescens* and for the introduced hybrid (native x non-native) broadleaved *Platanus hispanica* confirm the aforementioned ranking of the respective physiognomic types [33].

Lastly, local estimates for particulate matter removal (Table 3, item F1) indicate that conifer forests, Mediterranean maquis and evergreen oak forests perform better, per unit of forest cover, than chestnut, deciduous oaks and beech forests [29]. By contrast, deciduous species were found to contribute to tropospheric O₃ removal per unit of forest cover to a greater extent than evergreen species (Table 3, item F2), though to a lesser extent than conifers [28].

3.2. Critical Features for the Conservation of Urban Trees and Forests

3.2.1. Biogeographic Representativity and Ecological Coherence

Since non-native species expand as urbanization increases and often represent an important component of urban ecosystems [52–54], we use the term “biogeographic representativity” to refer above all to the native status of species and communities.

Moreover, “locally contextualized biodiversity” is becoming increasingly important in approaches aimed at improving urban sustainability [15,55,56]. In this respect, the concept of biogeographic representativity may be applied up to the point at which the species that belong to the natural pool of the strict metropolitan area are distinguished from the overall group of native species.

At fine scales, biogeographic representativity further merges with the physical features of the environment in determining the species composition of natural communities. Therefore, we consider ecological coherence as species suitability for specific combinations of climatic, litho-morphological and edaphic conditions, i.e., coherence with the potential natural vegetation and related natural substitution

communities [57,58]. As the natural bio-physical setting is never totally hidden by urbanization, even in the very center of cities [59,60], and as native and ecologically coherent forests and trees grow well with little or no management [61,62], both biogeographic representativity and ecological coherence should be targeted for the conservation of biodiversity in urban regions [63].

In the area considered in this study, the baselines for biogeographic representativity and ecological coherence were ranked in multiple tiers by means of the incremental filtering of forest and tree pools from the regional to the city scale. As regards forest communities, a reference framework available for the Roman Area ecoregion includes 6 prevalent physiognomic types, 2 differential physiognomic types and 1 exclusive physiognomic type of vegetation potential belonging to the western Mediterranean, Italo-Tyrrhenian biogeographic province [64,65]. The prevalent and exclusive vegetation potential types consist of mixed communities dominated by deciduous oaks and of riparian woods, while the differential vegetation potential type consists of thermophilous beech forests that are typical of volcanic substrata in the ecoregion. In particular, the municipal area of Rome is characterized by 13 types of forest communities, nine of which occur in the restricted urban sector [44]; the urban forest communities include four types of deciduous and semi-deciduous oak woods that are characterized by a mixture of western and eastern Mediterranean and coastal Tyrrhenian and mountain Apennine biogeographic influences, four types of evergreen Mediterranean oak woods and five types of riparian and plain woods.

As regards woody species, 230 native *taxa* belong to the regional pool of the Lazio administrative region [66], which extends in longitude from the central Apennine chain to the central Tyrrhenian coast, ranges in altitude from sea level up to 2458 m, and includes a large hilly sector. Seventy-nine species in this regional pool are representative of the vegetation potential of the municipal area of Rome, with 62 of these species occurring in the urban sector [44]. The woody species that do not reach the inner city are either restricted to the Mediterranean coastal sector of the municipality (e.g., *Erica scoparia* and *Juniperus oxycedrus* subsp. *macrocarpa*) or to the more mesophilous zones near the Apennine sector (e.g., *Acer obtusatum* and *Sorbus torminalis*). Interestingly, all the species of the genus *Quercus* that are characteristic of the most common types of potential natural vegetation in the whole municipality also occur in the urban sector. These species include: (i) evergreen oaks (*Quercus ilex*, and *Q. suber*), which have adapted to local arid conditions and draining substrata that are found in areas other than the coastal sector; (ii) thermophilous and hygrophilous deciduous oaks (*Q. cerris*, *Q. frainetto*, and *Q. robur*), which are typical of the macroscopic conditions of the area; and (iii) semi-deciduous oaks (*Q. virgiliana*, and *Q. x pseudosuber*), which are characteristics of the Transitional zone between the Mediterranean and the Temperate bioclimatic regions [67,68].

According to these baselines, we were able to highlight the following critical features of urban forest and tree diversity: (i) which forest and tree types found in the city are coherent with the natural potential at the different geographic levels; and (ii) the sites in which non-native trees and forests prevalently or exclusively represent the actual woody plant diversity, characterize the spontaneous recovery of woody vegetation, or hinder nature conservation in protected areas. Some examples of this evidence base are shown in Figure 3.

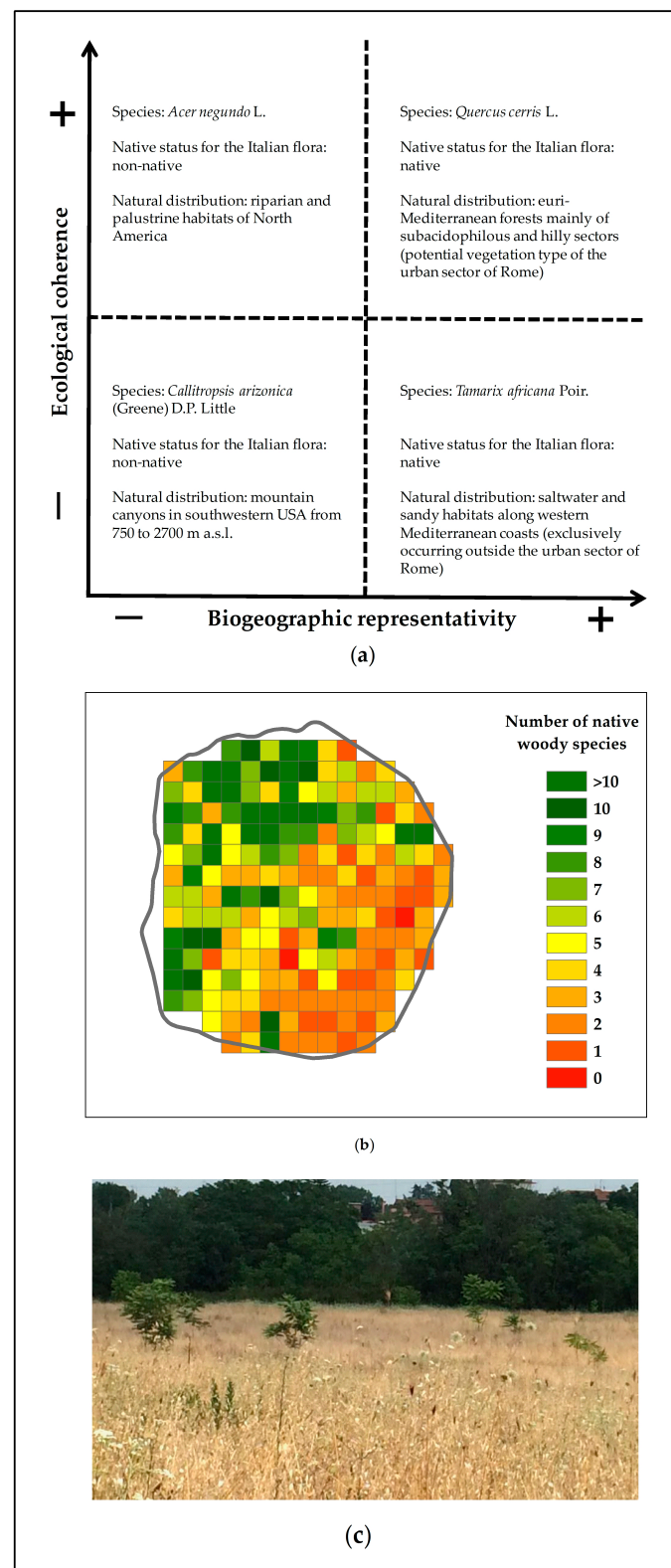


Figure 3. Examples of critical features of urban forest and tree diversity in the urban sector of Rome: (a) different biogeographic representativity and ecological coherence values for tree species that belong to the flora of the city [23,26,69–72]; (b) number of native woody species in the various sites according to the Atlas and to the inventory of the flora of Rome (cell size: 1.2 km × 1.4 km) [23,45]; and (c) non-native trees (*Ailanthus altissima*) that spontaneously recover an abandoned agricultural area in the Valle dell’Aniene Natural Reserve (central-eastern part of the city) (photo by Veridiana Barucci).

3.2.2. Structural and Functional Connectivity

One of the main concerns regarding the persistence of urban biodiversity is the reduction, fragmentation and isolation of natural habitats and communities [73–75]. The effects of such pressure are usually recognized through structural connectivity measures that consider the spatial arrangement of remaining natural ecosystems in a transformed landscape mosaic [76,77]. Apart from the spatial proximity between natural patches, the level of connectivity between plants also depends on functional traits related to pollen and seed dispersal systems [78–80], which means the capacity to disperse over a prevalently artificial matrix is particularly important for plant diversity conservation in urban contexts.

Structural connectivity indicators for the overall municipal area of Rome revealed that evergreen and deciduous forests have become less isolated in recent decades [50]. This contrasts with the increasing isolation affecting other types of natural ecosystems, such as inland wetlands and beaches, dunes and sand plains [50]. However, compaction of artificial surfaces within the urban sector of Rome has severely impaired the functional connectivity of woody plants, particularly that of barochores (species dispersed by gravity) and of zoochore (species dispersed by animals), such as oaks.

Therefore, if combined with the lack of animal dispersal vectors that affect some of the urban sites [81], existing gaps in the distribution of species that are representative of the more widespread vegetation potentials have become a priority concern for biodiversity conservation (Figure 4).

3.3. Suggested Actions for Integrating Biodiversity Values into Urban GI in the City of Rome

The analysis of the tree and forest features that proved to be critical to the city of Rome led to the identification of a set of actions aimed at effectively integrating the conservation and/or restoration of biodiversity within multi-functional urban GI projects:

- (1) Proactive conservation [82] of the native and spontaneous trees and forest remnants, focusing on those types that are most representative of the local potential natural vegetation. Although this action is markedly oriented toward biodiversity conservation, it always provides an expectedly positive balance between the delivery of maintenance, regulatory and cultural ES, and guarantees the long-term survival and low maintenance costs of the related GI components.
- (2) Facilitation of the spontaneous natural dynamics, also defined as passive restoration [78], for the recovery of natural forest types in the various environmental units of the city. This GI intervention should generally be faster and less costly than active restoration measures and is expected to yield the same, well-balanced, multiple benefits as proactive conservation, without the risks involved in the planting of trees that do not fit in with the environmental conditions of the site. Moreover, if the size and the landscape context of the site permit it, a wider coverage area of ecologically coherent species and communities may enhance the GI-based delivery of regulating ES (as in the case of particulate matter removal) to a greater extent than a more limited number of trees that may perform better but that are ecologically incoherent (as in the case of evergreen oaks outside strictly Mediterranean-like environments).
- (3) Control of the spread of non-native trees and replacement of exotic forests at specific sites, such as areas in which biogeographically representative and ecologically coherent woody plant diversity is poor, areas with a progressive vegetation dynamic that is prevalently based on non-native species, and protected areas. In such sites of the study area, the effort to recover native trees and forests should prevail over any other expected value of non-native species and communities related to the functional behavior and cost-effective introduction of the latter [47]. Therefore, this indication places some constraints on the open adoption of the best performing species and communities that are listed in Section 3.1 for the improvement of ES provision to desired levels.
- (4) Active restoration of seed sources and enhancement of functional connectivity for biogeographically representative and ecologically coherent trees with critical gaps in their present distribution and short-distance dispersal. This action is particularly important in sites with poor native species diversity and a dense artificial matrix. In such markedly artificial environments,

in which the focus is placed on GI elements that perform most effectively in elements such as noise abatement and/or air pollution removal, regardless of the type of ES providers, at least part of the areas being restored should be dedicated to the enhancement of functional connectivity between these woody species.

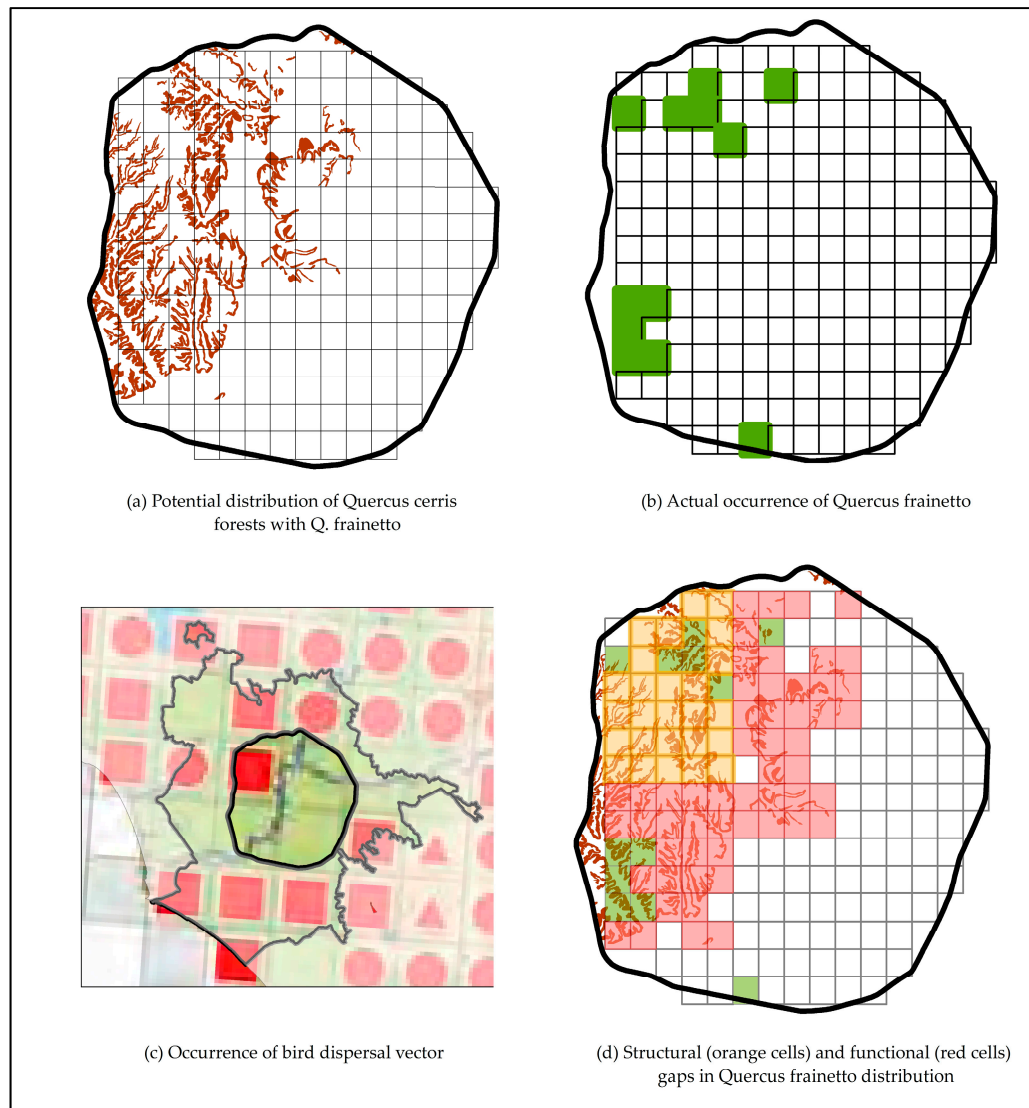


Figure 4. Identification of critical gaps in the distribution of a tree species (*Quercus frainetto*) that is representative of a vegetation natural potential type of the city of Rome (*Quercus cerris* and *Q. frainetto* forests on sandy hills slopes): (a) potential distribution of the species according to the natural environmental setting (data source: Map of the potential natural vegetation of Rome Municipality [24]); (b) actual distribution of the species in 1.2 km × 1.4 km grid cells (data sources: Atlas and inventory of the flora of Rome [23,45]); (c) occurrence of a key bird dispersal vector for the species (*Garrulus glandaria*) in 10 km × 10 km grid cells (data source: Atlas of the nesting birds of Lazio Region [81]; red squares = confirmed breeding; red circles = probable breeding; red triangles = possible breeding; empty cells = not found); and (d) identification of critical distribution gaps across the sites that may potentially host the species (cells with structural gaps = absence of the tree species despite favorable vegetation potential of the site; cells with functional gaps = absence of both the tree species and the key bird dispersal vector despite favorable vegetation potential of the site).

4. Discussion and Conclusions

The results of the present work provide a body of evidence that supports the inclusion of biodiversity issues in GI planning processes even within an urban context.

First, the approach adopted to select the estimates of the capacity of urban trees and forests to deliver key ES focuses on the geographic context of the research and on the components of biodiversity currently present in the study site.

On the one hand, the selection of estimates that prevalently refer to the regional, metropolitan, municipal or strictly urban area of the case study allows the widely acknowledged limitations of information transfer from different climatic, socio-economic and biogeographic contexts to be overcome [83–85]. This approach is in keeping with the urban ecology principle that is based on an integrated vision of cities and surrounding landscapes [86].

On the other hand, the explicit reference to the most comprehensive knowledge available on the spontaneous flora and natural vegetation of the city offers an effective tool for an informed selection of the species and communities to be planted, restored and/or conserved within an urban GI. In this regard, technical guidelines for the choice of sites and species in sustainable forestry have recently been outlined for the Municipality of Rome [87], and the present overview provides a set of reasoned scientific references that support these choices, including pivotal works, such as that on noise mitigation [37], more recent advances, such as that on urban temperature regulation [36], and local knowledge, such as that on air quality regulation [28]. Moreover, the synthesis of the estimates, as shown in Table 3, is also a useful tool for investigating inherent potential synergies and trade-offs (e.g., between evergreen and deciduous species/communities) according to approaches that have been developed to assess the multi-functional role of urban trees and forests (e.g., [88]). At the same time, it highlights which ES provision capacities are not strictly determined by species and community types, as in the case of water flow regulation and run-off mitigation. Moreover, it identifies the items for which further scientific evidence needs to be collected, as in the case of the delivery of cultural services, which are currently ranked merely according to different sites rather than to specific components of biodiversity. This overview cannot, however, be considered exhaustive, particularly in view of the lack of a thorough assessment of trade-offs, otherwise defined as ecosystem disservices or costs [89–91]. Such trade-offs were not considered in this work because: (i) they usually require a finer, site-specific approach, as in the case of damage to infrastructures and monuments [92,93]; (ii) they rarely depend on the specific composition of the ecosystems, as in the case of negative attitudes displayed by inhabitants toward urban green areas [42]; and (iii) they are still controversial, as in the case of the balance between ozone removal and emission of volatile organic compounds by trees, which might increase ozone concentrations in the urban atmosphere [28].

Second, the analysis of features that are critical to biodiversity is based on a multi-scaled framework designed to assess the representativeness of the native vegetation. In addition, it fits into the combined structural and functional approach adopted to assess the role of connectivity in the persistence and resilience of biodiversity as well as in the subsequent capacity to provide ecosystem services [94,95].

The framework provides a tiered definition of vegetation potential and a baseline for the assessment of actual vegetation status that was previously used, in part, to select the priority sites and vegetation types for the municipal forestation program [96]. We now provide additional data that may help to enhance the synergies between ES provision and biodiversity conservation/restoration within a more comprehensive context of “biodiversity-led” [15] GI planning. With regard to the ultimate aim of GI projects and the desired ES provision, a different degree of consistency in terms of biogeographic representativeness and ecological coherence should, however, be expected [97]. Therefore, the various tiers allow the interventions to be assessed on a scale that ranges from markedly to weakly consistent (e.g., in terms of native status and degree of representativeness from the local to the regional scale), and may be defined as critical when inconsistent species and communities are expected to have strong negative impacts [98] on the layout of urban biodiversity (as in the cases shown in Figure 3).

As regards connectivity, the evidence that emerges from the present work may be considered to be an initial step in improving the urban GI planning process in the city of Rome. This evidence provides some hints on which basic knowledge should be collected and combined to perform a comprehensive analysis of the issue, including the need to: (i) measure and monitor landscape connectivity in space and time [99], clearly distinguishing between the dynamics that affect the inner city from those that affect the suburban sectors [50]; (ii) recognize the functional traits of focal species [79]; and (iii) assess the spatial representation of both actual/potential distribution of plants and dispersal vectors. This information provides reliable information on the GI pilots in the study case, though its utility and applicability needs to be carefully investigated before it can be applied on a wider scale to other geographic contexts and cities of varying sizes that are characterized by different ecosystem pressures, conditions and spatial arrangements.

Third, the actions proposed here to integrate biodiversity values into urban GI in the city of Rome contribute to the field of research that addresses sustainability and resilience in urban GI design [100,101]. As a preparatory phase for follow-up projects, the suggestions follow a qualitative rather than a quantitative approach. Moreover, they prevalently concern patchy and linear components of GI (i.e., hubs and links sensu Benedict and McMahon [102]). The role of punctual features, such as green roofs and green walls, which are attracting an increasing amount of attention as potential tools for urban biodiversity conservation [103,104], has not yet been considered. Notwithstanding these limitations, the evidence that emerges from our case study highlight elements that critically contribute to win-win and resilient solutions as regards biodiversity and ES provision (especially actions 1 and 2) and provide original indications that may be used to better define the ecological dimension of non-native plant management in cities (especially actions 3 and 4) [105,106].

In conclusion, we believe that the estimates of the capacities of urban trees and forests to provide key ES may help to select the most suitable species and communities for forestation programs and GI projects in cities. However, we do recognize that this selection often places excessive emphasis on ES delivery efficiency to the detriment of other features that are critical to the conservation and improvement of biodiversity values [20], thereby exposing biodiversity to certain risks, such as those identified by Garmendia et al. [8].

The present work represents a first step toward combining these two aspects through the provision of a set of evidence-based data for the effective, sustainable and resilient GI planning in the city of Rome. Although this evidence focuses on the urban trees and forests, and their respective features, found to be critical in the study area, it may be traced for any ecosystem components of urban GI as well as for other cities throughout the world.

The recommended actions that emerge from this study have been applied to pilot projects whose aim is to implement the GI strategy at the national level [18] and have been proposed at the European level within the context of the MAES Urban Pilot of the EU Commission [4]. Future research efforts will be made to fill the aforementioned existing gaps in knowledge, such as the need for a better definition of potential synergies and trade-offs between alternative urban forestry choices, a more comprehensive assessment of the complex cultural value of urban trees and forests, and a more in-depth investigation of the issue of ecological connectivity in urban contexts. Furthermore, a concerted effort to harmonize the proposed framework and the other findings that have emerged from numerous projects on GI planning and nature-based solution in Italian and European cities (e.g., [15,16,107,108]) will also be made in the near future.

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