A conceptual framework for ex ante valuation of ecosystem services of brownfield greening from a systematic perspective

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ABSTRACT

Introduction: Although Brownfield greening (BG) can be a crucial solution to green space deficiency in dense urban areas, the potential benefits of different BG initiatives have rarely been quantitatively pre-evaluated. Here, the concept and main features of BG and its costs and benefits are firstly depicted. Next, a conceptual framework is presented which combines ecosystem service (ESS) valuation, economic cost-benefit analysis, and spatial pattern analysis. The framework is used to perform ex ante valuation of the ESS value of BG in Xuhui District, Shanghai.

Outcomes: The scenario comparison results show that it can spatially reflect a closer-to-reality value of ESS at the urban scale instead of a theoretical value at the site scale. The ultimate values of ESS (After economic and landscape adjustments) in the composite scenario is more than 21% higher than those in the full-eco scenario, whereas the initial values of ESS (before the adjustments) in the former was 14% lower than those in the latter. These results suggest that a considerable part of brownfield greening projects need to be implemented in the more populated and economically vibrant areas instead of solely in the ecological construction zone, thereby correspondingly providing more cultural and regulation services and forming a better urban green space network.

Conclusion: The framework provides a simple, science-based, and feasible tool for making BG decisions from a systematic perspective in dense urban areas. It can help meet the need for applying ESS knowledge to BG-based green space planning and policy making in the context of urban sustainable development.

Introduction

Primarily due to the spread and intensification of industrialization since the 18th century, humans around the world are currently living on an urbanizing planet (McPhearson et al. 2016). For China, it has experienced a rapid increase in the urbanization rate from 17.92% in 1978 to 57.35% in 2016. This urbanization rate is expected to reach 68.7% by 2030 (United Nations 2012). Although rapid urbanization provides substantial wealth to humans, it also has many adverse environmental consequences (Lu et al. 2017; McPhearson et al. 2016). Many pressing issues related to urbanization, such as excessive population density, uncontrolled urban sprawl, irrational urban planning, and industrial structure imbalances, have led to urban environmental deterioration and urban ecosystem degradation, which in turn have degraded the human living environment (Gago et al. 2013; Johnson and Munshi-South 2017; Song et al. 2017). At the same time, a series of prevailing global climatological and environmental changes, such as climate warming, natural resource shortages, and ecosystem destructions, have also posed immense challenges to the “urban sustainable development” of many cities around the world (Chapman et al. 2017; McDonald et al. 2011; Sachs 2012).

Urban ecosystem services are the direct and indirect benefits that residents derive from the functioning of ecosystems within the urban environment (Costanza et al. 1997; Gómez-Baggethun et al. 2013; Larondelle et al. 2014; MEA 2005). Urban green spaces, such as parks, urban forests, and other green infrastructures, represent fundamental components of urban ecosystems (Gómez-Baggethun et al. 2013). These green ecosystems distributed in cities can provide multiple ecosystem services to improve the urban environment, citizen health and living quality (Bolund and Hunhammar 1999; Gómez-Baggethun et al. 2013; Wolch, Byrne, and Newell 2014), therefore playing irreplaceable roles in realizing urban sustainable development (Lehmann et al. 2014; Rößler 2018; Zhang, Li, and Fu 2009). Unfortunately, with increasing urbanization...
around the world, the available lands that can be used to construct new green spaces in many cities are becoming increasingly scarce, especially in highly populated urban areas (Li et al. 2019; Bardos et al. 2016; Zhang et al. 2017). Furthermore, the land deficiency for new green spaces are especially severe for those cities that had implemented densification and compacting measures for urban sustainable development (Haaland and Konijnendijk van den Bosch 2015). As a result, many cities worldwide have started to pay much attention to the greening of “after-use” land resources (i.e., brownfields).

**Brownfields** commonly emerge in areas such as residential demolition sites, derelict land, industrial remains, and waste treatment plants in cities that have undergone socio-economic transformation (Liebmann and Kuder 2006; Mathey et al. 2015). It has been widely accepted that brownfields can be regenerated as new green spaces (which can be termed “brownfield greening”) by applying proper remediation and greening techniques (Zhang et al. 2017; De Sousa 2006; Koch et al. 2018; Bardos et al. 2016). The creation of multi-functional green spaces by regenerating brownfields is now increasingly considered a nature-based solution to restrict further urban sprawl and to optimize urban green space systems, and it plays a vital role in sustainable and resilient urban development (Nagengast, Hendrickson, and Lange 2011; Rodriguez, Ürge-Vorsatz, and Barau 2018; Mathey et al. 2015; Atkinson et al. 2014; Baing 2010; Song et al. 2019). Lots of brownfield greening attempts have been made in many developed and developing countries by governments, local communities, and private companies (Greenberg and Lewis 2000; Zhang et al. 2017; Koch et al. 2018; De Valck et al. 2019; Cundy et al. 2016). In 2017, the Chinese government published a series of official documents emphasizing the importance of brownfield regeneration for urban ecological restoration and urban organic renewal (MOHURD 2017). In Shanghai, for instance, brownfields have been now considered the core components of “challenging urban sites with greening potential” in dense urban areas (Zhang et al. 2017). Our previous investigation found that more than 80% of the planned but unconstructed green space in the central urban area of Shanghai (inside the outer-ring elevated road) could be categorized as brownfields (unpublished data).

In recent years, studies on the quantification and mapping of the benefits (many are in terms of ecosystem services) of brownfield greening projects emerged to reflect their roles in improving the urban environment and human wellbeing. From site scale to city scale, assessments based on literature reviews, mathematical modeling, and various surveys showed that green areas built on brownfields delivered quantifiable ecosystem services (Mathey et al. 2015; De Valck et al. 2019; Pueffel, Haase, and Priess 2018; De Sousa 2006). The ecosystem services provided by brownfield greening are dependent on location, area, shape, remediation methods, greening mode, vegetation coverage, community configuration, and among other factors (Lehmann et al. 2014; Mathey et al. 2015). It is widely thought that the knowledge of potential ecosystem services can support planning and policy-making in the comparison and selection of alternative scenarios for sustainable goals in urban contexts (Kain et al. 2016; Elmqvist et al. 2010). However, compared to the well-conducted ex post evaluation studies that show results of ecosystem services delivery, the potential ecosystem services of different brownfield greening scenarios have rarely been quantitatively pre-evaluated. Cortinovis and Geneletti (2018) explored the spatial supply-demand match of two ecosystem services to assess future brownfield regeneration scenarios in Trento, Italy, which is one the very few ex ante assessment cases for brownfield greening strategies that we have ever seen. Besides, it is also worth noting that, for a real-life brownfield greening projects, not only ecosystem services value, but also financial cost-effectiveness should be considered for an overall valuation of the broader benefits (Mathey et al. 2015; Bardos et al. 2016; O’Brien, Foot, and Doick 2007). Furthermore, for the integrated green space system at the urban scale, ideal strategies of brownfield greening can also help support a higher connected wildlife habitat network and providing more easily-accessed recreational areas (Mathey et al. 2015; Harrison and Davies 2002). Given the above review, to provide practical supports for planning and policy-making of brownfield greening in a specific urban area, an urgent and realistic demand is to quantitatively know the overall value of different scenarios by integrating ecosystem services with economic outcomes from a systematic perspective.

The current paper aims to propose and test the procedure for the close-to-reality ex ante valuation of ecosystem services of different brownfield greening strategies at the urban scale. In the following sections, the definition and main features of brownfield greening and its benefits to urban sustainable development are first depicted (section 2). Then, we propose a conceptual framework to conduct ex ante valuation of the ecosystem services of different brownfield greening scenarios in dense urban areas from the systematic perspective (section 3). After that, the applicability of the conceptual framework is tested, taking Xuhui District in Shanghai as a case study (section 4). We then discuss the contribution of this conceptual framework to practical planning and policy-making of brownfields greening as well as the possible pathways of better applying it in other urban areas (section 5). Section 6 is the conclusions of this work. This type of framework can become a promising decision-support tool for urban brownfield regeneration.
Theoretical ground

Brownfield greening

The concept of brownfields was first proposed in the UK in the 1980s. Since then, the term has evolved to include numerous legal, formal, and colloquial meanings in different countries (MOE 2007; U.S. EPA 2009; Ferber et al. 2006; Zhang et al. 2017). The most commonly used definition of brownfields to date is derived from the United States Environmental Protection Agency (EPA)’s Brownfields Economic Redevelopment Initiative. It describes a brownfield as “a property, expansion, redevelopment, or reuse that may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant” (U.S. EPA 2009). When referring to a specific brownfield regeneration project, other definitions and terms (i.e., urban wastelands, previously used land, and abandoned or derelict land) have also been adopted depending on the analytical and planning contexts. Nevertheless, there is a consensus that brownfields are previously developed urban lands that are now abandoned or used with low efficiency (Atkinson et al. 2014).

In the context of urban densification and compact city development, the principle of “internal before external development” is followed by many cities around the world. From this perspective, brownfields are extremely useful “after-use” land resources that can be used for urban regeneration, thereby helping meet the goals of land saving and resource recycling (Baing 2010; De Sousa 2006; Lange and McNeil 2004; Nagengast, Hendrickson, and Lange 2011). Urban administrators have recognized that, once they are revitalized or regenerated, brownfields have great potential for supporting sustainable urban development (De Sousa 2006; Schilling and Logan 2008).

In the past, people preferred to convert brownfields into industrial and commercial lands or housing estates (Doick et al. 2009a). In recent years, it was realized that brownfield regeneration should incorporate economic, ecological, and social goals instead of merely economic goals, especially in the dense urban areas (Haaland and Konijnendijk van den Bosch 2015; De Valck et al. 2019). Therefore, brownfields greening becomes a central part of the brownfield regeneration (Moffat and Hutchings 2007; Ruiz-Jaen and Aide 2005). In this study, we offer the following definition for brownfield greening: “It refers to the restoration or reestablishment of vegetation in brownfields through either artificial or semi-artificial measures.” Brownfield greening can offer an effective solution for tackling urban challenges by reusing polluted or abandoned lands to provide more vigorous and healthier living environments (Doick et al. 2009b; Siikamaki and Wernstedt 2008).

Benefits and costs of brownfield greening

In the urban context, a real-life brownfield greening project always embraces a complex set of social, environmental, and economic factors and an integration of different stakeholders’ interests to achieve the ongoing delivery of site aims and objectives (Doick et al. 2009b). As illustrated by (O’Brien, Foot, and Doick 2007), both monetary and non-monetary benefits and costs may directly or indirectly occur in the lifetime of brownfield greening projects, which have to be taken into account for an overall valuation (Table 1).

Benefits derived from ecological structure and processes of urban brownfield greening are urban ecosystem services. Generally, the ecosystem services of brownfield greening include but are not limited to regulating services, cultural services, and supporting services. Once the brownfields are successfully transformed into green spaces, they can help adapt cities to the adverse effects of rising temperatures and changing precipitation patterns (Bowlar et al. 2010; Gill et al. 2007). They can also absorb atmospheric gaseous and particulate pollutants, fix and store CO₂, and reduce noise, etc. (Derkzen, van Teeffelen, and Verburg 2015; Kain et al. 2016). Besides, brownfield greening will provide new, pleasing landscapes for the nearby residents to recreate, relax and retreat (Puefeil, Haase, and Priess 2018; Matthey et al. 2015), which might be the most significant benefits (Beames et al. 2018; De Valck et al. 2019). Brownfield greening can also produce vital habitats for endangered wildlife in urban areas (Gilbert 1991; Schadek et al. 2009; Kowarik 2013). Moreover, the existing green space networks can be optimized by building necessary patches or corridors on brownfields (Bonthoux et al. 2014; Matthey et al. 2015). These services are highly valuable to cope with the urban environment and living quality problems that the existing green spaces cannot adequately address (Matthey and Rink 2010), especially in dense urban areas with lower green coverage (Andersson et al. 2015).

As for the economic outcomes of brownfield greening, on the one hand, some consequential economic benefits are also achievable from urban greening, which are deemed out of the scope of ordinary ecosystem services. These benefits include increased surrounding property valuation and regenerated local economy (Kaufman and Cloutier 2006; Noh 2019). On the other hand, much higher economic costs may also occur to tackle the challenging planting sites and health and safety issues in the brownfields. These costs include massive investments in soil remediation and pollutant removal, as well as the ever-increasing budget for construction and maintenance of new green spaces (Costanza et al. 1997; Pediaditi, Doick, and Moffat 2010; Cortinovis and Geneletti 2018; O’Brien, Foot, and Doick 2007). Therefore, it is highly recommended that both the consequential
economic benefits and the considerable economic costs are taken into consideration during the overall valuation of brownfield greening project (Atkinson et al. 2014; Blokhuis et al. 2012; O’Brien, Foot, and Doick 2007). Given that, to maximize the broader benefits (including both the ecosystem services value and the consequential economic benefits) of utilizing these idle urban lands at the lowest expenses, it is necessary to develop decision support systems for brownfield greening planning and policymaking.

**Conceptual framework for ex ante valuation of ecosystem service**

Here, we propose a conceptual framework that combines ecosystem service valuation, economic cost-benefit analysis, and spatial pattern analysis to quantify the potential shifts in the value of ecosystem services under different brownfield greening scenarios at the urban scale (Figure 1). Under this framework, an overall valuation of ecosystem services derived from brownfields greening taking the economic outcomes and the systematic impacts into account can be conducted and mapped for the decision making use (Cortinovis and Geneletti 2018). Moreover, the attributes from the current land use map can also be assigned to the brownfield patches in the given urban area such that ecosystem service knowledge for optimizing brownfield greening can be easily applied in land use planning decisions (Lehmann et al. 2014).

**Spatial database of BGPs**

To analyze the potential ecosystem services of brownfield greening, the first step is to construct a spatial database of brownfields with greening potential (BGPs) in a given urban area. Data on the different types of BGPs need to be obtained, classified and input into the database. During this process, multiple related thematic spatial data and materials are needed, such as remote sensing (RS) images, land use maps, green space system planning maps, administrative investigation data, site-specific historical data, and field survey and laboratory data.

Usually, high-resolution, up-to-date RS images should be prepared first. The RS images, land use map and green space system planning map can be overlaid on a GIS platform to extract and identify potential patches of BGPs. Following desk work, field verification is needed to adjust the BGP maps to a more realistic map, while the detailed attributes of

Table 1. Potential benefits and costs of converting urban brownfields into green spaces (adopted from O’Brien, Foot, and Doick 2007).

| Benefits | Costs | Non-Monetary Benefits | Costs |
|----------|-------|------------------------|-------|
| Direct | Indirect | Direct | Indirect |
| Monetary | Benefits | Costs | | |
| Recreation | Investigation | Restricted access | Reduced business/project/personal risk and liability |
| Timber | Remediation | Site hazard | Doing nothing |
| Parking fees | Establishment | Health | Opportunity cost |
| | Maintenance | Health and safety issues | Social deprivation |
| | Funding (e.g., woodland grant) | Environmental damage | Perceived risks and liabilities |
| | Finance (capital investment) | | |
| Non-Monetary | Benefits | | |
| Preservation/ improvement | Wider social, economic, political, environmental and technical value and benefit (e.g., pollution control; social and human capital; crime reduction; inclusion; ownership; empowerment; innovation; involvement in local decision-making). |
| Heritage (historic, cultural and landscape) | | |
| Archeology | | |
| Ecology (biodiversity) | | |
| Environment (e.g., carbon sequestration) | | |
| Community engagement | | |
| Education | | |
| Amenity | | |
| Health | | |
| | | |
| Potential 
| benefits | | |
| and costs | | |
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each BGP patch can also be collected and assigned. After that, the distribution map of BGP s can be created for the object urban area at a specific temporal point. However, not all urban brownfields are suitable for or need to be regenerated as green spaces. The local demands for commercial and residential land use, together with the lands reserved for future use, should also be considered when identifying the BGP s.

Scenario setting of brownfield greening options

Once the spatial database of BGP s in the object urban area is constructed, the next step is to set several comparable and close-to-reality brownfield greening scenarios. Scenario-based ex ante ecosystem service assessment has great potential to support decision-makers to resolve conflicts between limited land resources and greening demands in urban areas. Furthermore, the results of scenario analysis can also be reviewed by other stakeholders who want to know the possible benefits of different decisions of brownfield greening (Alcamo and Henrichs 2008).

A series of preparations are needed to set possible scenarios of brownfield greening. First, an in-depth analysis of the pros and cons of the existing green space system should be conducted. Second, the relevant plans (such as master plans and green space system plans), laws and policies should be collected and analyzed. Third, site assessments, analyzes of greening feasibility and function demands in the involved BGP s are highly recommended. Then, the potential benefits and costs involved in brownfield greening should be documented and summarized through a broad investigation of different stakeholders, for example, via questionnaire surveys and focus groups. After these preparations, the targeted BGP patches, greening modes, vegetation coverage, and community configuration can be predeter-

Valuation of ecosystem services of brownfield greening

The next step is to establish an applicable indicator system encompassing multiple categories of ecosystem services (La Notte et al. 2017; De Valck et al. 2019). A mostly commonly known indicator system for ecosystem service assessment was proposed in Millennium Ecosystem Assessment (MEA) (MEA 2005). The MEA categorization was adopted with modifications in the Economics of Ecosystems and Biodiversity project (Elmqvist et al. 2010) and the Common International Classification for Ecosystem Services (CICES) (Potschin and Haines-Young 2016) and constitutes the core of most other recent classifications (Costanza et al. 2017).

Following the above prevailing classification systems, a library of alternative indicators for the ecosystem services valuation of brownfield greening can firstly be built based on literature review, expert consultations and questionnaires. Then, a series of qualitative (such as frequency analysis and the Delphi method) and quantitative (such as correlation analysis and principal component analysis [PCA]) methods can be used to screen the required indicators. Finally, if necessary, the weight of each indicator can be determined using methods such as PCA, or fuzzy synthetic evaluation. De Valck et al. (2019) recently summarized
and compared 29 multiple urban ecosystem service studies, which could be referred to for indicator system construction of brownfield greening evaluation.

Once an indicator system is constructed, the corresponding quantitative methods of the included indicators should be chosen subsequently. Among these methods, the valuation of ecosystem services in monetary units is an essential tool for raising awareness and conveying the (relative) importance of ecosystems and biodiversity to policymakers (De Groot et al. 2012; De Valck et al. 2019; Costanza et al. 2017). Currently, mainstream economic valuation approaches for ecosystem services are based mainly on market theory. For example, the “value transfer” or “benefit transfer” method based on literature reviews or expert knowledge can be used to estimate the unit area value of multiple services and goods of different ecosystems/land cover types (Costanza et al. 1997; Xie et al. 2008; De Groot et al. 2012). Another widely used method is to calculate the physical flows of ecosystem services through field observations, RS inversions, GIS spatial analyzes, and integrated models. Then, corresponding market theory methods are applied to calculate the monetary values of different services and goods using necessary local socioeconomic parameters (Nelson et al. 2009; Turner et al. 2016; Costanza et al. 2017).

**Adjustments of the ecosystem service value of brownfield greening**

Under each possible scenario, we can use the above valuation methods to estimate the initial value of ecosystem services for each BGP patch. Moreover, we include both the appreciation of economic benefits and the increased economic cost of brownfield greening projects in the framework to integrate economic outcomes into ecosystem service valuation. Through two economic adjustment procedures at the patch scale, the initial value of the ecosystem services of each BGP included in the specific brownfield greening scenario can be adjusted to reflect an objective monetary value of ecosystem services.

Moreover, at the urban scale, future brownfield greening projects are likely to change the landscape pattern of the existing urban green space system and directly or indirectly affect the provision of ecosystem services (Li et al. 2012; Hao et al. 2017). For this reason, we also include the potential systematic impacts of brownfield greening on the spatial pattern and, consequently, the ecosystem services in the framework. Landscape indices can be calculated to determine the changes in the spatial structure of the green space system under different scenarios. Subsequently, the economically adjusted value of ecosystem services at the patch scale can be systematically integrated by area and type to produce the ultimate value of the ecosystem services at the urban scale, which will be meaningful and informative for decision-makers and also other stakeholders.

**A case study of applying the framework in Xuhui district, Shanghai**

According to its latest urban master plan released in January 2018, the area of public green space per capita in Shanghai will increase from 8.5 m²-person⁻¹ in 2020 to 13 m²-person⁻¹ in 2035. A supply of nearly 250 km² of new green spaces is needed to meet the goal. However, by 2035, only approximately 15 km² of urban construction area can be newly supplied across the whole city, while industrial and logistical spaces (which fit the scope of brownfields) will be reduced by more than 500 km². Therefore, brownfields undoubtedly constitute the major land resources available for new green space construction in Shanghai.

Xuhui District is located in the southwestern part of the central urban area in Shanghai, covers an area of 54.93 km² and has a population of over 1 million. It is a sub-center of Shanghai city that is famous for its industrial, commercial and service industries. In such a densely populated and well-developed urban area, there are substantial demands of creating new green spaces to prevent or counteract potential social, economic and environmental problems. Brownfield greening is believed as the only choice for new green space construction in this district in the next decades. Various types of brownfields with different greening potentials are scattered across the city, and opinions of different stakeholders (from local government, urban residents, to investors and constructors) have to be taken into account in the future brownfields regeneration plan. Since it is not realistic to convert all the brownfields to green spaces in the next few years, this case study was aimed at supporting the planning and policy making of near future brownfield greening initiatives in Xuhui district by applying the conceptual framework proposed above.

**Database of BGPs in Xuhui District**

The specific technical procedures for the identification, location, and classification of BGPs in Xuhui District are illustrated in Figure 2. First, the planned but unconstructed green spaces were screened from all planned green spaces based on the green lines that were officially delineated in 2016. Second, the map of the planned but unconstructed green spaces was overlaid with the latest (August 2017) high-resolution RS image (Gaofen-2 satellite) to identify, locate and classify all the BGPs in Xuhui District. Finally, the distribution of BGP patches with their respective attributes was produced in a polygon shapefile format on a GIS platform. After
a comprehensive analysis of the land use, urban development plan, historical information, site investigation, and greening feasibility, the BGP patches were classified into three main types: potentially contaminated land, special end-use land, and existing green space. In further, based on their current land use attributes, potentially contaminated lands were sub-classified into three subtypes (industrial, transportation, and residential/commercial use), and special end-use lands were sub-classified into two subtypes (logistical warehouse use and temporarily empty land).

Scenario setting for brownfield greening options in Xuhui District

To establish feasible scenarios, the targeted BGP patches, and possible greening modes were firstly predetermined. The distribution of BGPs was overlaid onto the map of the strategic guidance of Xuhui District planned for 2035 (Figure 3). Then, the entire district was divided into three major functional zones: the economic development zone (EDZ), living and leisure zone (LLZ) and ecological construction zone (ECZ). Corresponding to these zones, we defined three modes of brownfield greening: composite functional green space (CFG), life recreational green space (LRG) and natural ecological green space (NEG). For each mode, the proportions of different types of cover (trees, shrubs, herbs, impervious surfaces, and water bodies) were stipulated (Table 2). Then, the attributes of greening mode, vegetation coverage, and vegetation composition were assigned to each BGP patch on the GIS platform.

Assuming that approximately 55% of all the BGPs in Xuhui District will be regenerated into green spaces in the near future, we defined three brownfield greening scenarios. In scenario 1 (the full-eco scenario), all the targeted BGPs were selected from the ECZ (55.65% of the total area). In scenario 2 (the eco-lei scenario), 27.28 and 28.39% of the targeted BGPs were selected from the ECZ and the LLZ, respectively (55.67% of the total area). In scenario 3 (the composite scenario), 11.33, 28.39 and 15.96% of the targeted BGPs were selected from the ECZ, LLZ, and EDZ, respectively (55.68% of the total area) (Table 3). Under the three scenarios, the potential monetary values of ecosystem service of turning urban brownfields into green spaces in Xuhui District at the urban scale were calculated and compared.

Valuation of ecosystem services of brownfield greening in Xuhui District

To conduct monetary valuation of ecosystem services under different brownfield greening scenarios in Xuhui District, the value transfer method was adopted to define the value per unit area (i.e., value coefficient) of different ecosystem services for different types of green space cover (Bateman et al. 2009; De Groot et al. 2012). The value transfer method resulted in estimates that can be thought of as the theoretical value (namely, initial value) of ecosystem services of specific green space cover.

First, five types of cover in green spaces were classified: woodland, shrub, grassland, water, and impervious surface. For each cover type, eight ecosystem services that are closely related to human wellbeing...
in urban areas were selected: cooling, air purification, carbon sequestration, flood regulation, water purification, habitat provision, leisure and recreation, and surface soil preservation (Table 4). Second, the existing valuation information from case studies of green spaces in Shanghai was collected and used in the
value transfer. However, due to the limited studies in Shanghai, the valuation information from similar case studies of green spaces in dense urban areas in other similar megacities worldwide was also explored, adjusted to fit the social-economic contexts of Shanghai and adopted. Consequently, value data points in the eight most similar pieces of literature were aggregated for the valuation of ecosystem services of the green spaces regenerated from brownfields in Xuhui District. Then, to make the valuation information from all studies comparable, the collected values were converted to value coefficients based on purchasing power parity (PPP) in 2017, namely, CNY·m⁻²·a⁻¹. The value coefficients for all the cover types were then applied to estimate the initial value of ecosystem services for each BGP patch.

Notably, most real ecosystems have internal heterogeneity, and the beneficiaries of different services may vary greatly. Meanwhile, there are still considerable difficulties about how to practically value some intangible ecosystem services, such as esthetics and cultural heritage (Vejre, Jensen, and Thorsen 2010). Therefore, the value transfer method has some uncertainty, although it requires minimal time and effort by utilizing previously completed ecosystem service valuations (De Groot et al. 2012). For this reason, the value coefficients proposed in this case study apply only to ex ante scenario comparisons of ecosystem service values under different brownfield greening strategies in Xuhui District.

### Adjustments of the ecosystem service value in Xuhui District

At the patch scale, two economic adjustment coefficients were introduced. The economic benefit appreciation coefficients were determined based on the functional zones where the BGPs were located (Table 3). The economic cost deduction coefficients were determined based on the types of BGP patches and the greening modes (Table 5). In this case study, the two coefficients were determined mainly by expert knowledge. An interview was conducted to a focus group of local experts including policy makers, designers, engineers, and researchers to summarize these two economic adjustment coefficients. First, for different functional zones, expert opinions regarding the effects of the brownfield greening projects on the economic revitalization of the surrounding areas were collected. Then, the corresponding cost coefficients for site remediation, construction, and maintenance of brownfield greening projects were assigned by the same group of experts. Using the above two economic adjustment coefficients, the initial monetary value of ecosystem services in each patch was adjusted to be the intermediate monetary value (economic adjustment).

At the urban scale, we integrated the new green spaces regenerated from brownfields with all the existing green spaces to generate a map of potential green space systems under each scenario (Figure 4). Then, the landscape pattern analysis software FRAGSTATS 4.2 (McGarigal and Marks 1995) was adopted to evaluate the connectivity of the integrated green space system using the map. A connectance index (CONNECT) at the class level was selected to reflect the associations between the spatial structure and ecosystem services in the green space system. 600 m was set as the threshold distance between two green spaces primarily considering people living within a 300 m radius circle from the new green spaces were considered as the main beneficiaries (Stessens et al. 2017). The CONNECT of the existing green space system was set as the benchmark reference. Based on this

### Table 4. Indicator system and value coefficients for the valuation of the ecosystem services provided by brownfield greening scenarios in Xuhui District, Shanghai.

| Ecosystem services                          | Woodland | Shrub | Herbaceous | Water | Impervious surface |
|--------------------------------------------|----------|-------|------------|-------|--------------------|
| Cooling                                    | 5.63     | 4.21  | 2.10       | -     | -                  |
| Air purification                           | 2.00     | 1.89  | 0.20       | -     | -                  |
| Carbon absorption                          | 2.24     | 0.50  | 0.01       | -     | -                  |
| Flood regulation                           | 4.02     | 2.21  | 2.00       | 4.80  | -                  |
| Biodiversity conservation                  | 2.00     | 1.00  | 0.50       | 2.21  | -                  |
| Recreation                                 | 20.00    | 15.00 | 30.00      | 23.3  | -                  |
| Noise reduction                            | 0.45     | 0.40  | 0.15       | -     | -                  |
| Soil conservation                          | 0.39     | 0.40  | 0.20       | -     | -                  |

* Sources of ecosystem service valuation: ¹ (SALASP 2017), ² (Derkzen, van Teeffelen, and Verburg 2015), ³ (Davies et al. 2011), ⁴ (Wang, Zheng, and Guo 2008), ⁵ (Fang and Ling 2003), ⁶ (Song 2018), ⁷ (Ji and Wen 2013), ⁸ (Grafius et al. 2016)

### Table 5. Economic cost deduction coefficients of the different types of BGP patches in Xuhui District, Shanghai.

| BGP types                              | The economic cost deduction coefficients(-) |
|----------------------------------------|---------------------------------------------|
| Existing green space                   | 0.9                                         |
| Temporarily empty land                 | 0.8                                         |
| Residential/commercial use land        | 0.7                                         |
| Logistic-warehouse use land            | 0.6                                         |
| Transportation use land                | 0.6                                         |
| Industrial use land                    | 0.5                                         |
index, the landscape adjustment parameters were calculated and applied to all the BGP patches to produce the ultimate monetary value of ecosystem services (landscape adjustment). Then, the ultimate ecosystem service value at an urban scale under each scenario was systematically estimated by integrating the value of every BGP patch by type and area (Table 6).
**Results of the scenario simulation**

At the patch scale, the intermediate value of ecosystem services (after economic adjustment) of each BGP can be spatially calculated and inter-compared for the planner and policy-maker to assess their necessity and priority for future greening initiatives. Figure 5 shows the intermediate total and unit value of ecosystem services for the top 20 area BGPs in Xuhui District. BGP 15 could provide the largest total value (5209.71 × 10^3 CNY·a⁻¹) and a relatively higher unit value (30.49 CNY·m⁻²·a⁻¹), followed by BGP 13, while the lowest total ecosystem service value might occur in BGP 6. Furthermore, the composition and ranks of multiple ecosystem service values could also be useful for their trade-offs in detail planning and design at specific sites. As is shown in Figure 5, for most of the BGP patches, more than half of the values of brownfields greening might come from cultural services through the increased supply of recreation and amenities, followed by urban cooling and flood regulation services, while the carbon sequestration service might possess the smallest overall contribution to the total value.

More importantly, at the urban scale, the integrated ultimate value of ecosystem services of all the included BGPs can be highly helpful in choosing the best scenario of optimizing the green space system via reasonable brownfield greening initiatives. In specific, as listed in Table 6, compared with the full-eco scenario, which included only BGPs in the ECZ, the composite scenario, in which the targeted BGPs were selected from all three zones, exhibited an approximately 10% lower initial total value and unit value of ecosystem services. However, after economic adjustments at the patch scale, the total and unit values of ecosystem services in the composite scenario were 13.8% and 13.7% greater than those in the full-eco scenario. Furthermore, after landscape adjustments at the urban scale, the ultimate total value and unit value of ecosystem services in the composite scenario were 21.8% and 21.7% greater than those in the full-eco scenario. Similar although smaller variations were observed when comparing the full-eco scenario with the eco-lei scenario. These results suggested that among the three alternative scenarios, the composite scenario might be the best one to enhance the ecosystem service value of the entire urban green space system via massive brownfield greening in the next few years.

**Discussion**

**Valuation of brownfield greening by expanding ecosystem service knowledge**

Multiple long-term ecosystem services can be achieved with short-term efforts by creating green spaces in brownfields (Atkinson et al. 2014; Rall and Haase 2011). Although ecosystem services valuation can provide a quantified insight into the benefits of brownfield greening to a wide array of stakeholders (Atkinson et al. 2014; Doick et al. 2009b; De Valck et al. 2019; Cortinovis and Geneletti 2018), it may not enough to fully reflect the overall value of the artificial green spaces regenerated from brownfields in dense urban areas. From this perspective, although there are difficulties in attaching monetary values to some of the broader benefits (O’Brien, Foot, and Doick 2007; Vejre, Jensen, and Thorsen 2010). the ecosystem service knowledge needs to be expanded to include economic cost-effectiveness to provide more objective and widely accepted valuations in the urban context (Bardos et al. 2016; Song et al. 2019).

To date, several sustainable assessment frameworks of brownfield remediation have been proposed. Pediaditi et al. (2005) proposed a Redevelopment Assessment Framework (RAF) to holistically address the sustainability of greenspace establishment by assessing the environmental, social, economic, and physical impacts throughout a site’s life cycle of land use. Bardos et al. (2016) described a value-based approach (Brownfield Opportunity Matrix (BOM)) to identify and optimize services provided by the restoration of brownfields to soft reuses. Li et al. (2019) recently developed a conceptual site model of sustainability based on sustainability assessment criteria produced by the UK Sustainable Remediation Forum (SuRF-UK). Although these sustainability assessment frameworks could be applicable to a wide range of brownfield greening projects, they were mostly site-specific, comparatively, subjective, and only showed qualitative results (Bardos et al. 2016). In this case, these frameworks could not objectively and quantitatively reflect the overall value of massive brownfield greening initiatives at the urban scale.

For the first time, our framework can help improve brownfield greening decisions at the urban scale by combining ecosystem service valuation, economic cost-benefit analysis, and spatial pattern analysis. As is shown in the case study, the results of scenario analysis could spatially reflect the relative closer-to-reality value of ecosystem services at the urban scale instead of a theoretical value at the site scale. These quantitative and comparable results were believed to be useful to support planning, policy-making and even project detailed design for massive brownfield greening initiatives in the targeted urban area. For instance, the following questions can find the clues: Which groups of BGPS should be converted to a new green space with priority? What kind of brownfield greening scenario should be adopted? What kind of brownfield greening mode should be chosen in a specific functional zone? We believe that such a framework can also be applied to other dense urban areas in the world where brownfields are the main future available lands to develop green spaces, although several indicators and parameters need to be reset according to the local context.
Optimization of the urban green space network by brownfield greening

In recent years, apart from multi-functionality, connectivity and accessibility have also been considered central concerns in planning and designing green spaces systems in urban areas. Therefore, the primary focus of current green space development has shifted from scattered, individual green spaces to integrated urban green space networks (Madureira, Andresen, and Monteiro 2011; Zhang et al. 2019). To date, many brownfield greening practices have been implemented in cities across, for example, Asia, Europe, America, and Australia to meet the demands for constructing integrated and multifunctional urban green space networks (De Sousa 2006; Zhang 2007; Kabisch 2019; Koch et al. 2018; Newton and Glackin 2018).

From the viewpoint of system theory, regardless of the scale, brownfield greening will entail perturbation of the existing green space system. Consequently, it is believed that the structure, functions, and benefits of the existing green space system will interact with and be impacted by the new green spaces constructed from brownfields (Mathey et al. 2015). Given the potential impacts of different brownfield greening strategies on the whole green space system, it is necessary to assess the extent to which each brownfield greening option meets both of the requirements for multi-functionality, higher connectivity, as well as better accessibility in urban areas. However, the systematic impacts of brownfield greening options in terms of connectivity or accessibility were rarely considered in the existing ex ante assessment of ecosystem services for urban planning and policy-making (Cortinovis and Geneletti 2018).

To tackle the above concerns, our framework proposes a promising pathway of optimizing the urban green space network by proper brownfield greening strategies. The case study of Xuhui District shows that under the same total area of greening, implementing all brownfield greening projects solely in the ECZ may not be the best choice. In contrast, a considerable part of brownfield greening projects should also be implemented in the LLZ and the EDZ, where are more populated and economically vibrant. Among the three alternative brownfield greening scenarios in Xuhui, the composite scenario is likely to produce the highest ultimate value of ecosystem services at the urban scale, which is probably realized by better providing cultural and regulation services that urban residents desperately need and can easily acquire, as well as by forming a better spatial pattern for the urban green space network.

Further work for better application of the conceptual framework

The case study of Xuhui district reported in this paper showed the merit to quantitatively demonstrate the potential provisions of ecosystem services derived from brownfield greening in an urban context. However, we want to point out that several aspects can be improved for better applying the conceptual framework in Xuhui district and other similar urban areas. These aspects mainly include indicator selections, alternative scenario setting, valuation methods, parameter selection, and among others (De Valck et al. 2019; O’Brien, Foot, and Doick 2007; Mathey et al. 2015; Cortinovis and Geneletti 2018). Although all of these aspects seem to be common for any deliberate ecosystem service assessment, we suggest that any potential users of the conceptual framework keep these aspects in mind to get even better decision-making supports.

First, for any real brownfield greening initiatives, the appropriate indicators for measuring the expected benefits of brownfield greening in terms of changes in ecosystem service must be specifically identified and reasonably integrated, according to the ultimate objectives, the expected beneficiaries, the local context, et al. (Ruckelshaus et al. 2015). Besides, the possible trade-offs among different services, the possibility of reasonable valuation, the risk of double-counting, and the availability of the needed data should also be considered in setting the indicators system of ecosystem service valuation (De Valck et al. 2019; Kain et al. 2016).

Second, if it is possible, besides the city master plan and the general green lines, the detailed regulatory plan, and green space design guidelines in the targeted area should also be collected and referred to in setting alternative scenarios (Li, Sutton, and Nouri 2018). Besides, as mentioned in Section 4.2, a series of field investigations, practitioner interviews, and questionnaires can also be conducted to figure out the more refined and practical scenarios of brownfield greening initiatives. These alternative scenarios are deemed to better guide the optimization of the urban green space system based on brownfield regeneration (Alcamo 2008; Cortinovis and Geneletti 2018).

Third, our valuations of ecosystem service are highly dependent upon the value coefficient. Despite possible uncertainty in choosing different value sets, considering constraints on time and budget in the case study, we deemed the chosen value coefficient is acceptable for testing the applicability of the proposed framework (De Groot et al. 2012). As a matter of fact, there is no consensus on the most reasonable value coefficient or the most appropriate valuation methods on a specific ecosystem service (De Valck et al. 2019). These statements also apply to the determination of the landscape indices. The potential users can try to select the most appropriate valuation methods or landscape indices according to the specific projects.

Fourth, As for the determination of economic adjustment coefficients, apart from expert knowledge adopted in the case study, a hedonic pricing model can
also be used to investigate the responsiveness of residential property values to brownfield greening in similar urban areas (Kaufman and Cloutier 2006). Besides, as mentioned earlier, some key standing factors in the brownfields that can determine or restrict plant growth (such as soil texture, fertility, and pollutants) can be determined through systematic field sampling and laboratory testing. These site attributes are critical for determining the costs of brownfield greening projects.

Conclusion

Under the pressure of urban densification and global changes, brownfield greening can be a crucial solution to green space deficiency by providing a range of ecosystem services to address specific environmental and human living issues in dense urban areas. In this study, to provide practical supports for brownfield greening initiatives at the urban scale, a conceptual framework that combines ecosystem service valuation, economic cost-benefit analysis, and spatial pattern analysis was proposed to pre-assess the shifts in the potential ecosystem service value under different brownfield greening scenarios.

The case study of Xuhui district conducted in this paper showed that the framework could spatially reflect the relative closer-to-reality value of ecosystem services at the urban scale instead of a theoretical value at the site scale. Before economic and landscape adjustments using the framework, the initial value of ecosystem service in the composite scenario was approximately 14% lower than that in the full-eco scenario. However, after the two adjustments, the ultimate value of ecosystem service in the composite scenario was more than 21% higher than that in the full-eco scenario. Therefore, we believe that when the same greening requirements of the total area are complied with, implementing all brownfield greening projects solely in the ECZ may not be the best choice. In contrast, a considerable part of brownfield greening projects should also be implemented in more populated and economically vibrant areas to provide cultural and regulation services that local residents eagerly need and to form a better urban green space network.

Despite the limitations mentioned above about the case study, it proved that the conceptual framework proposed in this work provides a simple, science-based, and feasible decision-making tool for applying ecosystem service knowledge to brownfield greening in dense urban areas from a systematic perspective. This decision-support tool could be included in future brownfield regeneration schemes for the overall valuation of their broader benefits at the urban scale. We believe that it is necessary to apply ecosystem service knowledge appropriately to brownfield-based green space planning and policy-making in the context of urban sustainable development.

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