Identification of Ecological Sources in Urban Built-Up Areas: A Case Study of Harbin

Yuqi Chi[1], Yuanxiang Wu[2]

[1]School of Architecture, Harbin Institute of Technology; Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, Ministry of Industry and Information Technology, Harbin/China · chiyuqilant@163.com

[2]School of Architecture, Harbin Institute of Technology; Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, Ministry of Industry and Information Technology, Harbin/China

Abstract: Protecting the ecological sources of urban built-up areas is of great significance for addressing urban ecological problems. With Harbin City, Heilongjiang Province as an example, this study uses the composite performance measurement model based on the ecosystem service theory to determine the ecosystem service according to the urban ecological mixed demand, screen the ecological source of urban built-up areas through ecological performance, and propose protection strategies. The results show that this screening method is suitable for urban built-up areas, suggesting guiding strategies to optimize the protection of ecological sources and strengthen the ecological construction of ecological pedal space. This study proposes a method of using the composite performance model to identify the ecological source of urban built-up areas, which provides a reference for their determination and support for enterprises and governments to manage ecological space and create mixed hybrid landscapes.

Keywords: Geodesign, composite performance measurement model, source identification, hybrid landscape

1 Introduction

The use of ecological networks to solve urban ecological problems has been studied extensively (YUANJING et al. 2015). Ecological sources and corridors are both important components of ecological networks (SHILIANG et al. 2017). The corridors of the urban ecological network are carriers of the flow of ecosystem services, while ecological sources are important ecological spaces that can maintain sustainable urban development (SHILIANG et al. 2017) and are responsible for the transport of matter and energy (SWAN et al. 2021). In the past, researchers have focused on optimizing the pattern of corridor and urban ecological network connectivity (YUANJING et al. 2015), addressing both structural and service functional aspects. In the extraction of ecological source regions from urban ecological networks, however, only the pattern has been considered. This method is suitable for regional ecological planning, but it lacks consideration of the ecological needs of urban built-up areas. For example, YUANJING (2015) directly extracted the ecological source region using spatial heterogeneity and patch area, while ignoring the service functional focus, which led to the extraction method for urban ecological source areas being defective. Ecosystem services theory is a suitable theory to quantify function (SHEN et al. 2021).

This study describes how to quantify the ecological sources of cities that can provide hybrid ecosystem services. In this study, we propose a novel method for the extraction of urban ecological sources based on a composite performance measurement model. This study enriches the existing research on urban ecological networks and promotes the study of urban

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ecological network characteristics from a service functional perspective rather than from a structural perspective.

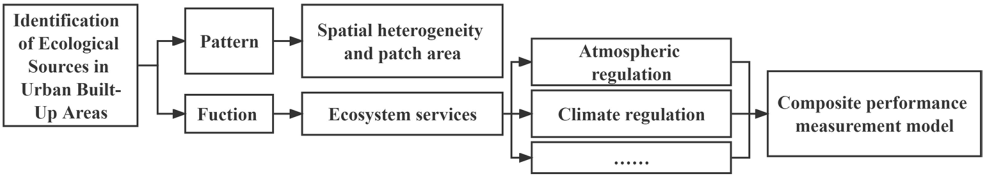

Fig. 1: Identifying of ecological sources in urban built-up areas

2 Research Method: Composite Performance Measurement Model

2.1 Ecosystem Services Theory

The products and functions of ecosystems are collectively referred to as ecosystem services. Ecosystem services are substances produced by the habitat, species, biological state, nature, and ecological processes of natural ecosystems, and they directly benefit mankind by maintaining a good living environment (ARYAL et al. 2021). In recent years, the application of quantitative measurements to ecosystem services has yielded fruitful results. Ecosystem service theory and its quantification can be efficiently used to measure ecological space from a service functional perspective, such as through the valuation of ecological assets (BATEMAN et al. 2013).

This theory was used for the following reasons: 1) it was found to be consistent with the aim of the study because this theory is based on service functions and the ability to categorize services functionally (WENHUA et al. 2009); 2) it conforms to the characteristics of the research object. Accordingly, the ecosystem services theory covers a wide range of parameters, including the city size required for this study.

2.2 Composite Performance Measurement Model

Based on the theory of ecosystem services, the compound performance measurement model quantifies the service functions of urban ecological spaces and extracts the model of urban ecological sources. This model mainly refers to the quantitative measurement model of ecosystem services first applied by SHEN (2021) in the Sujiahu area and adjusts SHEN's model according to the needs of the city. To better analyze the complex ecological problems of the city, the service functions of the urban ecological space were quantitatively measured using this model.

This method was used for three reasons: 1) to identify the ecological source of urban built-up areas from the perspective of ecosystem service function, which meets urban ecological needs; 2) it has a simple calculation and low data requirements; and 3) it can quantify the ecological performance of ecological sources and help create a mixed landscape.

2.3 Steps of Composite Performance Measurement Model

(1) Assessment of Individual Ecosystem Service Capacity in Eco-Space

According to Chinese government documents, the General Offices of the Central Committee of the Communist Party of China and State Council have issued "several opinions on delimiting and strictly observing the red line of ecological protection." They define ecological space as a land space with natural attributes and the main service functions of providing ecological services or ecological products, including forests, grasslands, wetlands, rivers, lakes, beaches, coastlines, oceans, wastelands, deserts, glaciers, alpine tundra, and uninhabited islands. The primary objective of the first step of the model was to determine the spatial capacity of individual ecosystem services to facilitate quantification of the spatial hybrid ecosystem service capacity for subsequent purposes. We selected ecosystem services according to the following three criteria: 1) derived from the ecosystem service framework modified by GAODI (2015), which is suitable for China; 2) aimed at the core ecological problems and contradictions in the relationship between the environment and human supply and demand within the context of map city development in Harbin; and 3) has available data.

We used GAODI's (2015) classification of ecosystem services, which divides ecosystem services into four tier 1 types: supporting services, regulating services, provisioning services, and cultural services, and 11 secondary types of subordinates. The selection of key urban ecosystem services was based on the regional profile of the study. After comparing and selecting existing research methods, the equivalent factor method (GAODI et al. 2015), which is based on the service functional units, was used to calculate the ecosystem services per unit area. After revising the equivalent factors according to the actual scenario, the ecological space service capacity of a single ecosystem was calculated, and the results were graded as very low, low, medium, high, or very high. Finally, a spatial status map was prepared using ArcGIS software.

(2) Multiple Ecosystem Service Capacity Indices for Ecological Spaces

The second step of the analysis was to determine the multiple ecosystem service capacities of the ecological space and quantify the capacity of the hybrid ecosystem services in multiple spaces based on the first step. There was synergy among ecosystem services in the urban ecological sources. Based on previous studies (SHEN et al. 2021), we assumed that the value of hybrid ecosystem services provided by a unit eco-space included not only ecosystem services, but also the complex ecosystem service capacity generated by the synergy between ecosystem services and the hybrid ecosystem service capacity that the two can provide for the ecological space. To calculate the multi-ecosystem service capacity index for each ecological space, the following equation was used:

$$f(x^1, x^2, x^3, x^4, x^5) = \gamma(\sum_{i=1}^{N} \frac{1}{(N+2)N} x_i + \frac{N+1}{N+2} \prod_{i=1}^{N} x_i^{\frac{1}{N}}) ,$$

where N is the number of ecosystem services provided by the ecological space, i is the ecosystem service number, x is the score of an ecosystem service provided by the ecological space (0-5 points), $\frac{1}{(N+2)N}$ is the contribution weight of an individual ecosystem service, $\frac{1}{(N+2)N} x_i$ is the contribution of a single ecosystem service to the multi-ecosystem service capacity index, and $\frac{N+1}{N+2}$ is the index of the composite ecosystem service capacity under synergy. The common enhancement trend obtained by the synergy of multi-ecosystem services was assumed to be greater than that of single ecosystem services. The sum of all weights was 1. The final aim was to generate a spatial situation map using ArcGIS.

(3) Identification and Extraction of Urban Ecological Sources

The third step was to identify and extract the city's ecological sources. The multi-ecosystem services capacity index of all ecological spaces was classified into six levels according to their average values. These levels correspond to important ecological protection land, ecological protection land, ecological core, stepping-stone patch, ecological space unit, and scattered ecological space, in decreasing order. The ecological space of the first three average values of the multi-ecosystem services capacity index was extracted as the urban ecological source.

3 Research Results Based on Composite Performance Measurement Model

3.1 Study Area Profile and Data Sources

The study area (125°42'-130°10' E, 44°04'-46°40' N) was located in the south-central part of Heilongjiang, China, in the capital city, Harbin. The total study area was 368.40 km^2. The built-up area of Harbin has strong ecological demand and rich plant resources, which can provide high-quality mixed ecosystem services for urban residents. Harbin is a typical urban built-up area that is suitable for use as an experimental case. The data in this study were obtained from pre-processing vector data (https://www.resdc.cn/) using the ArcGIS platform, and the database of the research area was established after the data were calibrated, rasterized, extracted according to the border of the main urban area of Harbin, and reclassified based on the objects. For research purposes, datasets were extracted to create six types of eco-spatial land: forest, grassland, shrubland, wetlands, water bodies, and unused land.

3.2 Results of Ecological Source Identification in the Study Area

Individual ecosystem service capacities of the study area were identified and evaluated. According to the current situation in the study area, five services were selected: atmospheric regulation, climate regulation, environmental purification, hydrological regulation, and landscape aesthetics. According to the equivalent factor table of GAODI (2015), this value was adjusted based on the actual scenario in Harbin, and was found to be more than 1. In addition, the relationship between each ecological space and the key ecosystem services was determined (Table 1).

The supply space for a single ecosystem service was then determined (Figure 2). The ecosystem space in the study area provided high services for atmospheric and climate regulation.

Table 1: Correlation between key ecosystem services and ecological space in the study area

Ecological Space	Key Ecosystem Services and Numbering				
	1-Atmospheric Regulation	2-Climate Regulation	3-Environmental Purification	4-Hydrological Regulation	5-Landscape Aesthetics
Forest	√2.35	√7.03	√1.99	√3.51	√1.14
Grassland	×0.51	√1.34	×0.44	×0.98	×0.25
Shrub land	√1.97	√5.21	√1.72	√3.82	×0.96
Wetland	×0.51	√3.60	√3.60	√24.23	√4.73
Water body	×0.77	√2.29	√5.55	√102.24	√1.89
Unused land	×0.00	×0.10	√1.11	×0.00	×0.01

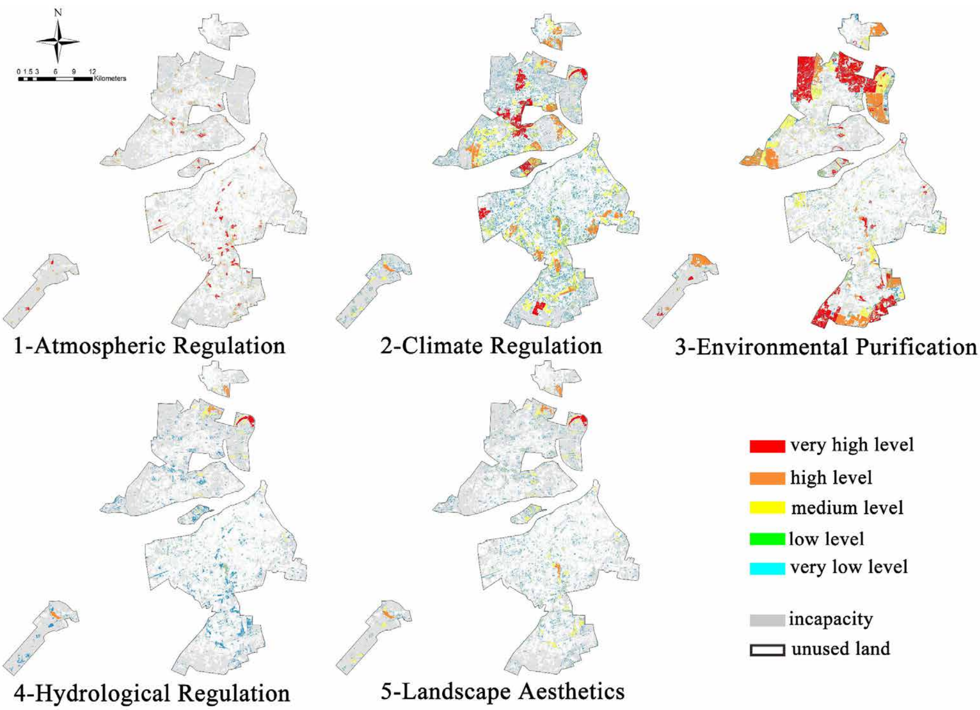

Fig. 2: Spatial status map of ecosystem service supply in the study area

The multi-ecosystem services capacity index of the ecological space in the study area was evaluated and analyzed (Figure 3). Forest and water bodies had the two highest overall levels of ecosystem service supply in the study area, and their multiple ecosystem service capacity index values ranged from 1.00-2.66 and 0.80-4.00, respectively. The supply level of shrubs and wetlands was medium, and their indices of multi-ecosystem services capacity were 0.80-

1.00 and 0.80-1.28, respectively. The supply levels of grassland and unused land were low, and the index of multi-ecosystem service capacity was similar (0.20-1.00).

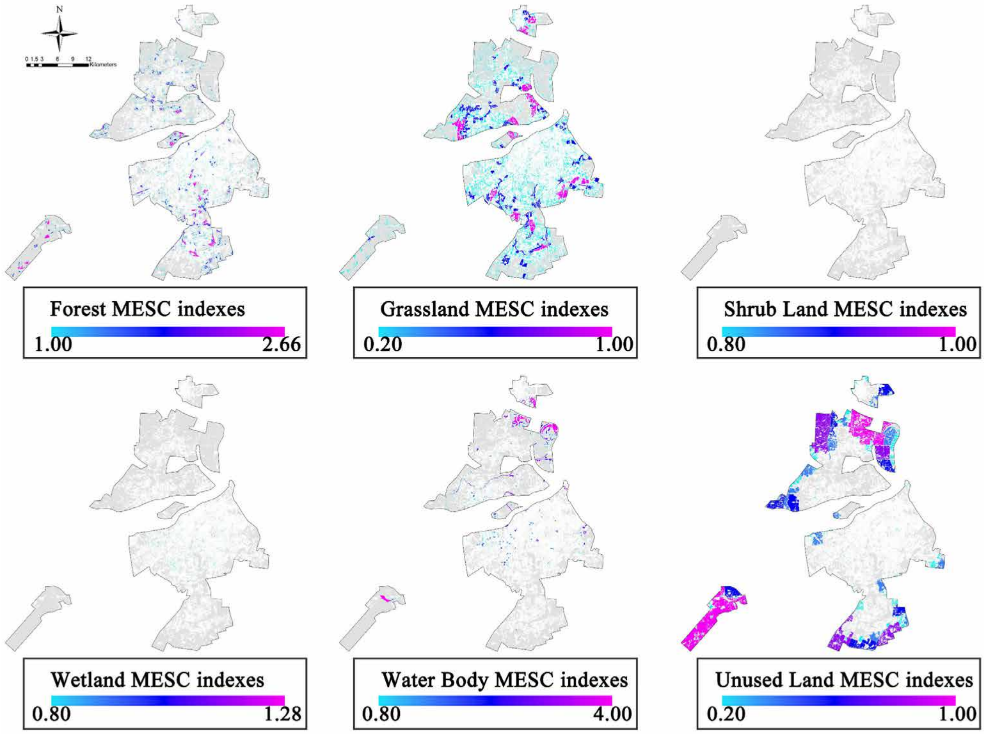

Fig. 3: Spatial distribution of multi-ecosystem service capacity (MESC) index in the study area

Finally, we identified the ecological sources of the city. Based on the analysis of the multi-ecosystem service capacity index, the ecological space of the main urban area was divided into six levels (Figure 4).

The first three eco-spaces of the average multi-ecosystem services capacity index were extracted as urban eco-sources (Figure 5). After identification, the urban ecological source area was divided into three levels. The average values of the multi-ecosystem service capacity index of the urban ecological source area were 3.01 for the first level, 2.17 for the second level, and 1.63 for the third level.

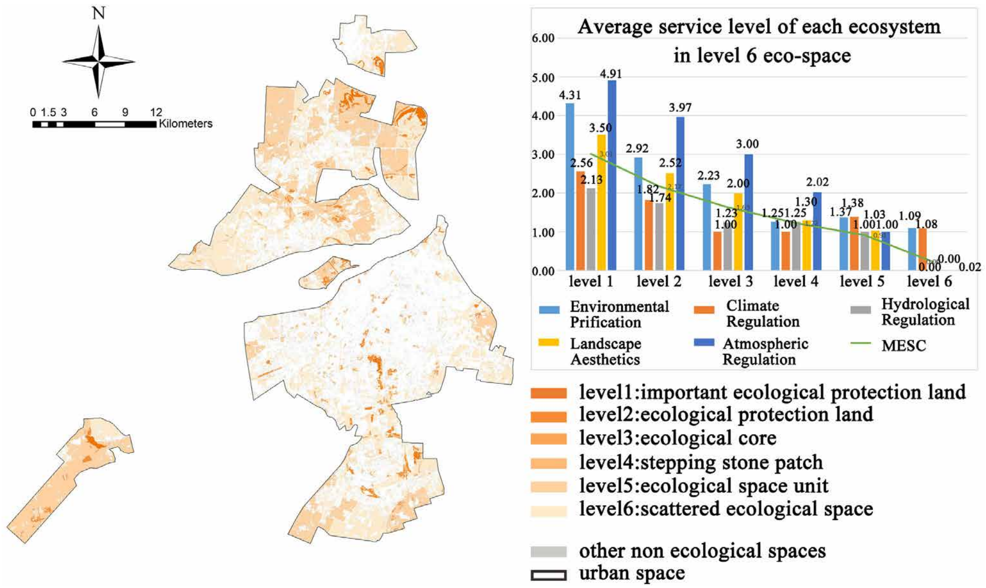

Fig. 4: Urban ecological source in the study area & average service level of each ecosystem in the six level of ecological space

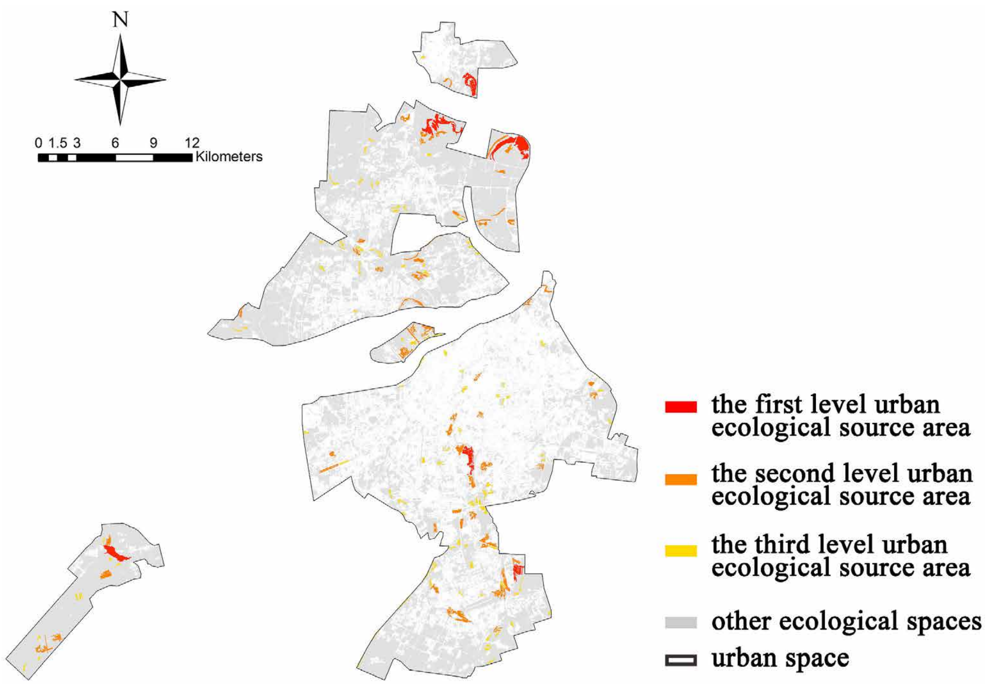

Fig. 5: Urban ecological source in the study area

3.3 Optimization Strategy of Ecological Source Region Patterns in the Study Areas

The primary aims of this study were to determine the location of the ecological sources of the city of Harbin in the ecological space and to determine whether these have important hybrid service functions in the ecological space providing appropriate size. To ensure that these critical urban ecological sources do not disappear in the process of urbanization, we need to put forward strategies to protect them. The results of this study suggest that the service capacity of the first-class city ecological source is the strongest, and protective facilities are added near the first-class ecological source to control the number and frequency of visitors (Figure 3). The service capacity of secondary urban ecological sources was weaker than that of primary urban ecological sources, and stronger than that of other sources. The service capacity of the third-level ecological source area was the weakest among the ecological source areas, but stronger than that of other ecological spaces in the city, strengthening the ecological construction of the ecological space of Treadstone among the three ecological sources.

4 Conclusion and Recommendations

The population density of urban built-up areas is high, and there is an urgent demand for ecosystem services provided by ecological sources. This paper discusses a method for identifying urban ecological origins from the perspective of ecosystem service function, and the conclusions are as follows:

1) Based on the ecosystem service theory and compound performance model, this study proposes a method to identify the urban ecological source.

2) Through the Harbin case study, the composite performance measurement model was found to be able to screen the ecological sources of three levels of urban built-up areas, and the average ecosystem service capacity indexes were 3.01, 2.17, and 1.63 for the first, second, and third levels, respectively. Our screening method is suitable for urban built-up areas and proposes guiding strategies for optimizing the protection of ecological sources and strengthening the ecological construction of ecological pedal space.

The innovation of this study lies in extracting the ecological source of urban built-up areas from the perspective of service functions. Existing methods identify and extract urban ecological sources from the perspective of pattern or only from the perspective of a single factor service function. In contrast, our method considers urban ecological demand and quantifies the service function of urban ecological source areas, which is more suitable for use at the urban scale.

At the same time, this study has some limitations: trade-offs and synergies between ecosystems are complex (ARYAL et al. 2021) and are not discussed in detail in this article. The equivalent factor method can only measure the supply of ecosystem services numerically and cannot reflect its influence on the entire spatial pattern. These deficiencies are expected to improve through follow-up research.

The identification and protection of ecological sources in urban built-up areas is unique. This study can serve as a reference for the identification of ecological network sources in urban built-up areas and provide support for enterprises and governments to manage urban green spaces and create mixed landscapes.

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