Article

Not peer-reviewed version

Study on the Spatiotemporal Evolution of the "Contraction-Expansion" Change of the Boundary between Two Green Belts in Beijing Based on a Multi-index System

Zhan Fangzhi and Liu Zhicheng *

Posted Date: 10 July 2023

doi: 10.20944/preprints202307.0610.v1

Keywords: Urban green; Green Belt; Multi-index System; Boundary effects

Article

Study on the Spatiotemporal Evolution of the "Contraction-Expansion" Change of the Boundary between Two Green Belts in Beijing Based on a Multi-Index System

Zhan Fangzhi and Liu Zhicheng *

Aff
* grace19971205@gmail.com

Abstract: As an important means of controlling the spread of cities, large-scale urban green belts have been widely used in the planning and construction of green space systems in various mega-size cities around the world. In previous studies, there has been more research on the overall isolation effect of green belts, while there has been less research on changes in their internal structure. There have been more perspectives on the land-use change (LUC) caused by urban expansion, and less systematic research on the dual driving factors of LUC. In this paper, we constructed a multi-dimensional index system to measure the "contraction-expansion" mechanism of land use in the overlapping vegetation areas of large green belts under the dual influence of urban expansion and urban greening, from the perspectives of quantity, space, and connectivity during different construction periods. Taking the boundary of two green belts in Beijing as an example, we hope to provide scientific support for the construction and ecological protection of Beijing's green belts.

Keywords: Urban green; Green Belt; Multi-index System; Boundary effects

---

1. Introduction

Urban green belts serve as a significant means to control urban expansion. This concept was first proposed by Ebenezer Howard in his book "Garden Cities of To-morrow" to control urban areas. Today, it is a common practice in major cities around the world from the "Greater London Plan" in 1944 to the urban plans of major international cities such as Paris, Berlin, and Moscow and so on. Although criticisms of the effectiveness and difficulty of implementing green belts have never stopped, it must be admitted that in some developing and emerging countries, the main contradiction in urban development is still the instability of construction scale and the irreversible damage to the urban ecosystem caused by the spread of construction land under population growth. these issues about the higher leapfrog development costs for the surrounding residents and the resulting land allocation and a series of other issues as local conflicts (Ramesh and Nijagunappa, 2014；Immergluck and Balan, 2018) can be resolved through government regulation.

On the other hand, due to the difficulty of controlling urban sprawl under the current situation(Li et al, 2022), it is more necessary to implement strong urban green planning policies. The relationship between the two is a balance of adaptation. Much evidence(Zhou and Wang, 2011； Liu et al., 2021；Wu et al., 2019)has shown that as urban areas continue to grow, the implementation of urban green planning has been reflected in changes in land use patterns and is beneficial in improving the urban living environment. From this perspective, the advantages of urban green belts outweigh their disadvantages.

As the capital and mega-city of China, Beijing's urban sprawl is still the main issue in its urban development. Since the 1950s, Beijing has proposed plans for the first and second green belts to control the construction scale of the central urban area. Today, the first green belt has been completed at the end of 2019, and the second green belt is still under construction. Based on the construction

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 July 2023 doi:10.20944/preprints202307.0610.v1

experience of the first green belt, the municipal government has adopted stricter planning goals and construction measures for the second green belt. The "Beijing Land and Space Ecological Restoration Plan (2021-2035)" and "Beijing Land and Space Short-term Plan (2021-2035)" published after 2020 emphasize the importance of Beijing's green belt areas in the overall macro strategic level, and propose a series of construction measures for the construction of green space structure of the belt area – including green wedges, green corridors, and shaping the functionality of country parks. Based on them, the "Beijing Second Green Belt Area Reduction and Improvement Plan (2021-2035)" draft was released in 2023, which provides more precise and strict indicators for forest coverage, ecological protection red line area, number of country parks, and green ways, green wedge areas in the green belt area.

It is worth noting that these planning and construction documents emphasize the overall ecological benefits and value of the entire green space in the first and second green belt areas to the overall ecological security of Beijing. At the same time, the importance of the “quality” of green space is emphasized over the “quantity”. However, in previous research and practices, researchers and planners often focused more on the green space within the first or second green belt, neglecting how the two green belts can better connect with the urban and ecological structures to better realize the value of the entire green space. In addition, when facing the classic issue of urban sprawl, research on changes in construction land use trends is often more detailed, while descriptions and research on green space are often based on changes in construction land use, which does not reflect the fairness, independence, and initiative of various land use types, especially green space, in value bearing and supply functions. There are also problems with the singularity of evaluation indicators and the differentiation of evaluation standards among different indicators when evaluating urban green space.

On the other hand, although a large number of researches have been performed on the distribution of administrative boundaries in China based on different targets(Jayasinghe et al, 2021). In fact, China's administrative boundaries are the product of a national hierarchical management system in which planning targets and development resources are distributed downward through a rigid hierarchical system of spatial administration(Ma, 2005). Therefore, this boundary management system exists not only between provinces and cities, but also between smaller scale levels, such as between urban areas, ecological land areas, etc. The advantage of this boundary management system is that it can have clear ownership from planning control, which provides convenience and standardization for the implementation of planning at all levels. However, when different areas of the city have common economic, cultural, and ecological aspirations, it turns linear constraints into restrictions rather than facilitation. In recent years, the Chinese government has also realized the problem and proposed various types of development strategies for regional integration. The issue of eco-regional integration is often overlooked, as in the case of the first green belt and the second green belt. The two belts are influenced by their different construction era, background, scale and goals with relatively clear planning boundaries. The clear planning boundary brings the effects of cut-off urban construction, and the multiple landscape structures of greenways, green networks and green belts in the areas are affected by administrative jurisdiction, and part of the current situation is contrary to the original planning objectives. Focusing on their interface properties rather than linear properties is of significant importance to alleviate this phenomenon. Based on the above research gaps, this article considers the planning and construction of the entire green space from a macroscopic scale (including the first and second green belts). Taking the boundary in Beijing as the research object, the specific scope and conceptual definition of the area are clarified, and the basic connotation of the "contraction-expansion" mechanism of green space is proposed. Based on the diverse problems of ecological status, this article constructs diverse evaluation indicators from three aspects: quantity, space, and connectivity. Moreover, it improves the content and description objects of the indicators, analyzes the land use change pattern of the boundary between two green belts in Beijing from 2005 to 2020, and provides a scientific basis for the planning and construction of green space in Beijing.

2. Concept of "Contraction-Expansion" Evolution

The concept of space evolution type originated from patch evolution type, which is a spatial description used in forestry research to describe the evolution of small patch topology and morphology. Based on this, Qiong Wang (Wang et al., 2021)introduced the research category from forest research to urban green space and classified the evolution types of urban green space patches in the research of urban green space patch evolution. The increase in the area of urban green space patches is defined as the "expansion" evolution type, and the decrease in the area of urban green space patches is defined as the "contraction" evolution type, in order to express the evolution states that exist in the process of urban green space evolution. Based on previous research, this article defines the "contraction-expansion" evolution type of green space as the transformation of land use types of urban green space patches caused by urbanization, leading to dynamic phenomena of area increase or decrease in geographical and quantitative change levels. In previous studies (Ren et al., 2018, Li et al., 2022, Chu et al., 2022), a large number of literature has been devoted to the study of the contraction of urban green space, such as the fragmentation of urban green space, the driving factors of the reduction of urban green space, and other ecological problems caused by the reduction. The advantage of these studies is that they can analyze the dynamic relationship between urban expansion and green space reduction more accurately, so as to grasp the patterns. The disadvantage is that the perspective is relatively single, and the dynamic nature of urban green space change is not well understood, and the important impact of urban policies is also ignored accordingly. The change of urban green space is often complex and comprehensive, so focusing on its dynamic characteristics can better understand the changing mechanism of urban green space and comprehensively evaluate the impact of urbanization process on urban green space, which is conducive to more effective future urban planning.

This article focuses on the "contraction-expansion" change pattern in three ways: firstly, to summarize the specific types of the "contraction-expansion" change pattern under urban development and planning regulations; secondly, to simulate the "contraction-expansion" change state through expansion; thirdly, to describe and explain the land use change patterns of the current situation.

3. Data Source and Processing

The data used in this article includes 10-meter land use data for 2005, 2015, and 2020. The data for 2005 and 2015 were provided by the project team and have an overall accuracy of 92.4719% and a kappa coefficient of 0.9045 for the city of Beijing. The 2020 land use data comes from the European Space Agency's 10-meter global land use data (https://viewer.esa-worldcover.org/worldcover).

4. Research Area

The research area is located between the first and second green belts within the central urban area of Beijing (excluding non-plain areas). As shown in Figure 1, the total area is 696.75 km^2, with coordinates of 39°45′–40°9′ north latitude and 116°4′-116°38′ east longitude. The average altitude is 42m, accounting for approximately 4.25% of the total area of Beijing. The current green space area is 128.73 km^2, while the planned green space area is 230.38 km^2. The entire area spans four administrative districts: Haidian, Chaoyang, Fengtai, and Shijingshan, forming a central surrounding pattern. According to the "Beijing Central Urban Area Municipal-level Greenway System Plan", the inner boundary is the outside the urban park ring in the city center (the first green belt), and the outer boundary is the boundary between the urban near suburbs and far suburbs (inside the second green belt). The average width of the interlaced zone is about 10.5 km, and the specific location and scope of the area.

 doi:10.20944/preprints202307.0610.v1

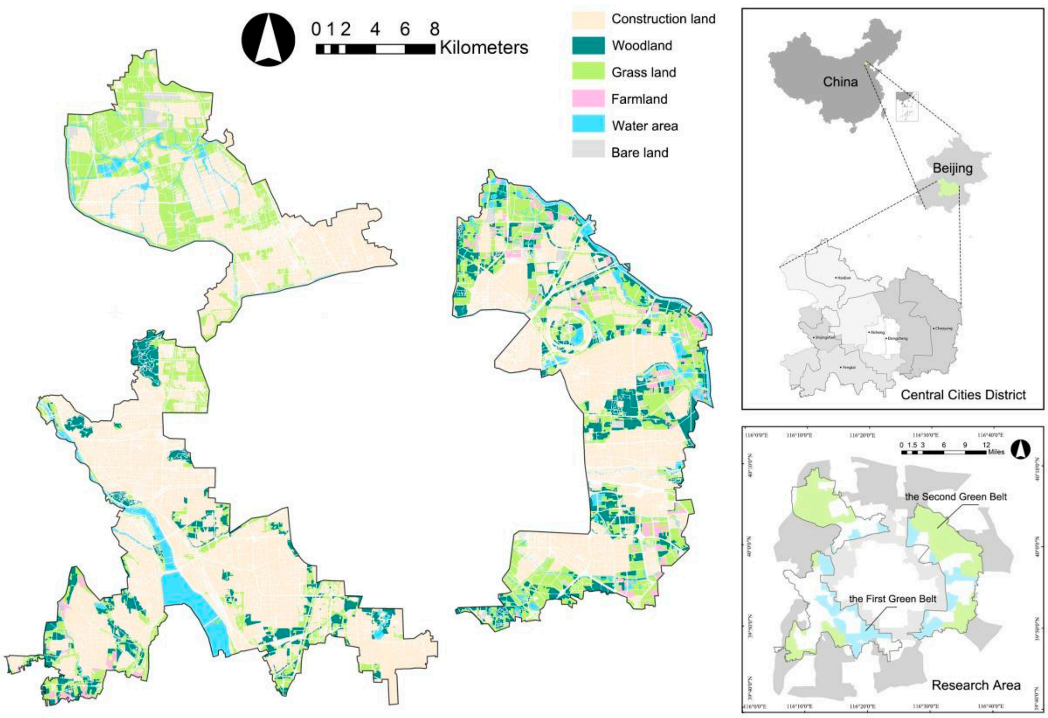

Figure 1. Study area.

5. Construction of a Multidimensional Indicator System

Ecological planning is usually analyzed and interpreted from multiple perspectives. As more indicators are integrated into quantitative analysis of ecological planning, research should also adhere to the basic direction of multi-objective planning and form a diversified quantitative system. It is necessary to scientifically and clearly interpret the problems that exist in the urban ecological status during the urban development process. this article will measure the land use change characteristics of the green ecotone zone from three aspects: quantity change, spatial characteristics, and connectivity.

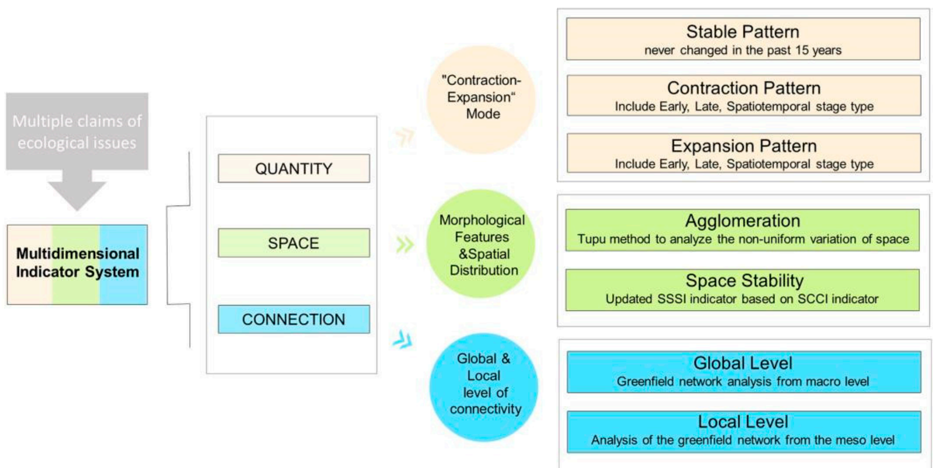

Figure 2. Framework of Multi-index System.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 July 2023 doi:10.20944/preprints202307.0610.v1

5.1. Change in Quantity Level - Area Change under "Contraction-Expansion" Mode

Quantity change is a way of measuring urban land use area change characteristics from a statistical perspective. Inductively analyzing the land use change between different land types in the green belt ecotone zone from the dimension of temporal evolution can provide a clearer understanding and analysis of changes in urban green space area. Meanwhile, with the help of the Land Use Patterns Tupu (PLT) method, a detailed interpretation of the "map unit" within the green belt ecotone zone can be carried out at the micro-scale level. The PLT method was first proposed by Chen Shupeng, an academician of the Chinese Academy of Sciences. It can more accurately quantify the change of various types of land, and can be well coupled with the "contraction-expansion" change pattern to explain its mechanism and characteristics, demonstrating certain advantages, but has been rarely applied in land use change research.

Area changes in the "Contraction-Expansion" mode mainly include area changes in the contraction mode, stable mode, expansion mode, and sub-mode changes under each category. All three calculations are based on the graph method and then classified to calculate their area values. The formula is as follows:

$$P = \sum_{E=1}^{N} Q_E 10^{N-E} \quad (N \geq 1)$$

where P represents the land use of several continuous expansion intensities in the analyzed area to the attribute values of the new map unit grid; N represents the number of consecutive periods studied; E represents the period sequence number; Q_E represents the attribute value of the land use grid of the Eth period in the study area. The results obtained are normalized to (0,1].

5.2. Space Characteristics Level - Morphological Features and Spatial Distribution

The morphology and pattern of urban space can reflect to some extent the state and pattern of urban ecological system, which is one of the key factors of landscape ecology applied to urban space research. The study of the morphology characteristics and spatial distribution of green corridors mainly includes two aspects: spatial aggregation and spatial stability. The spatial aggregation index is obtained by converting the land use map formula into a geographical spatial graph using ArcGIS software, and then qualitatively analyzing its aggregation characteristics. Spatial stability is analyzed through the spatial structure stability index (SSSI)(Bao et al, 2021). SSSI is calculated based on the spatial structure conflict index (SCCI), and provides a positive indication of the characteristics of green space. Its formula is:

$$SSSI = 1 - SCCI$$

The formula for SCCI is:

$$SCCI = CI + FI - SI$$

where CI refers to Conflict Index, FI refers to Fragility Index, and SI refers to Stability Index. So the expression formula for SSSI is:

$$SSSI = 1 - CI - FI + SI$$

Use the AWMPFD metric to represent CI; with the formula:

$$AWMPFD = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[\frac{2\ln(0.25P_{ij})}{\ln(a_{ij})} \left(\frac{a_{ij}}{A} \right) \right]$$

P_{ij} and a_{ij} represent the perimeter and area of patches, respectively; A is the area of each spatial unit at the landscape level; m is the total number of patches in the study area; n is the number of spatial types. The results are normalized to (0,1]. The order of landscape vulnerability of FI from

doi:10.20944/preprints202307.0610.v1

strong to weak is: 6 (construction land), 5 (unused land), 4 (farming land), 3 (forest land), 2 (grassland), 1 (water body). After assigning values to each land use category using ARCGIS software, the final result was normalized to (0,1]. The formula of SI is:

$$\mathrm{SI} = 1 - \mathrm{PD}$$

PD stands for patch density, with higher values indicating a higher degree of fragmentation and lower stability. The formula is as follows:

$$\mathrm{PD} = \frac{n_i}{A}$$

where n_i represents the number of patches in the i-th category; A represents the total area of the landscape or patches. The resulting SI is normalized to (0,1].

In order to better measure the spatial stability of the circular green belt interlacing zone, ArcGIS will be used for visual analysis from two aspects: overall stability and stability values above the median value (Above-middle-level green spaces, AGS). Combined with the standard deviation ellipse (SDE) analysis method, the distribution center, distribution direction, and distribution shape of stable or highly stable areas will be explored using the software. SDE reflects the distribution of data by measuring the mean and standard deviation using an elliptical shape. SDE can reveal the multi-faceted spatial positioning characteristics of geographic elements, including centrality, directionality, and spatial morphology. The calculation formula of SDE mainly includes:

$$C_{SDE} = \begin{pmatrix} \mathrm{var}(x) & \mathrm{cov}(x,y) \\ \mathrm{cov}(x,y) & \mathrm{var}(y) \end{pmatrix} = \frac{1}{n} \begin{pmatrix} \sum_{i=1}^{n} \tilde{x}_i^2 & \sum_{i=1}^{n} \tilde{x}_i \tilde{y}_i \\ \sum_{i=1}^{n} \tilde{x}_i \tilde{y}_i & \sum_{i=1}^{n} \tilde{y}_i^2 \end{pmatrix}$$

$$\mathrm{var}(x) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2 = \frac{1}{n}$$

$$\mathrm{cov}(x,y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) = \frac{1}{n}\sum_{i=1}^{n} \tilde{x}_i \tilde{y}_i$$

$$\mathrm{var}(y) = \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2 = \frac{1}{n}\sum_{i=1}^{n} \tilde{y}_i^2$$

where x and y are the coordinates of the i-th element, {x¯, y¯} represents the average center of the elements, and n is the total number of elements.

5.3. Connectivity Level – Global and Local Level of Connectivity

Connectivity capacity is a quantitative measurement of the ecological relationships between different patches, including global connectivity and local connectivity. Connectivity probability (PC) is used to measure overall and local connectivity, and supplementary analysis is performed using the maximum and average connectivity unit capacities (SLC and MSC). Connectivity probability (PC) is an ecological connectivity index at the landscape scale, defined as "the probability that two points randomly placed in the landscape fall into each other's reachable habitat areas". In this study, it is used to represent the connectivity between different green spaces, and the formula is as follows:

$$\mathrm{PC} = \frac{\sum_{i-1}^{n}\sum_{j-1}^{n} \alpha_i \, \alpha_j P_{ij}^{n}}{{A_L}^2}$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 July 2023 doi:10.20944/preprints202307.0610.v1

α_i and α_j are the areas of green space for patch i and patch j, respectively. n is the number of green spaces. A_L is the total land area. P_{ij}^n is the maximum patch rate between patch i and patch j over all paths (direct or indirect).

Fractions of delta Probability of Connectivity，dPC，is obtained by calculating the percentage reduction of PC before and after the presence and removal of a given plaque, which is calculated as follows:

$$dPC = \frac{(PC - PC_i')}{PC}$$

Size of the Largest Component (SLC) represents the capacity of the largest mutually connected patch cluster in the ecological network. The larger the value, the higher the dominance and aggregation of the associated patch clusters, and the stronger the anti-interference ability of the core ecological source patch. The global level of connectivity is high. The calculation formula is as follows:

$$SLC = \max\{ac_k\}$$

In the formula, ac_k represents the capacity of landscape connectivity k (the total capacity of patches that make up k).

Mean Size of the Components (MSC) represents the average capacity of a mutually connected patch cluster in an ecological network. The larger the value, the better the connectivity within a single connected unit, the stronger the ability to resist ecological threats, and the higher the ecological stability. Its calculation formula is as follows:

$$MSC = \frac{1}{nc}\sum_{k=1}^{nc} ac_k$$

In the formula, nc represents the number of landscape connectivity components, and ac_k represents the capacity of landscape connectivity component k (the sum of patch capacities that form k).

6. Results

6.1. Analysis of Green Space Land Use Area from 2005-2020

Figure 3 shows the land use changes in the greenbelt interlacing zone from 2005 to 2020. The figure illustrates that there are different trends in land use changes in the greenbelt interlacing zone over the past fifteen years, with 2015 as the dividing point. Before 2015, the land use change was characterized by a significant change of green space (forests, grasslands, and water bodies) replaced by cultivated land, which was a period of rapid development of urban ecological construction. After 2015, it was replaced by a booming period of urban economic construction, mainly characterized by the expansion of construction land.

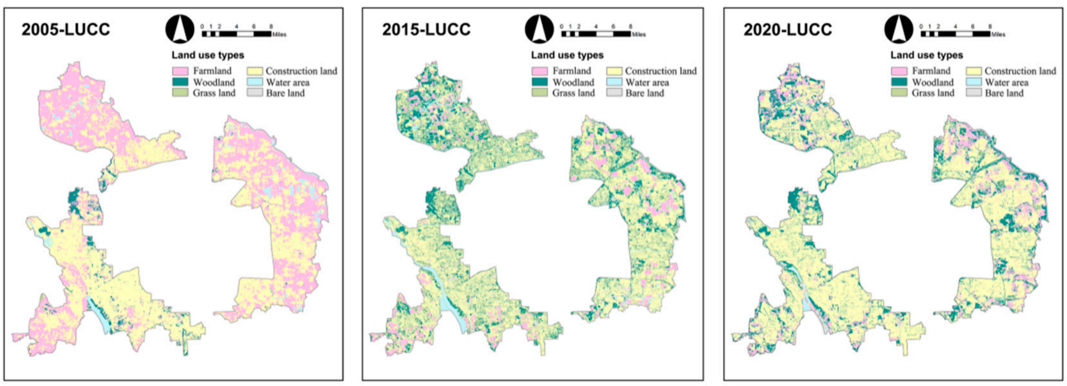

Figure 3. Land Use Classification Map（2005-2020）.

As shown in Table 1, although the characteristics of land use changes in the green belt interlaced zone vary in different periods, it is clear that the land use pattern in this region is still dominated by construction land area (with proportions of 55.52%, 50.49%, and 66.13% from 2005 to 2020, respectively), and different patterns of various green spaces still interwave with each other. Based on this pattern, one can conclude that the "contraction-expansion" mechanism of the interlaced large green space is developed around the changes in non-green space dominated by construction land and the conversion of various land uses within green space.

Table 1. Land use changes of the boundary between two green belts from 2005 to 2020.

Land use type	Farm land	Forest land	Grass land	Constructio n land	Water	Vacant land
	/km²	/km²	/km²	/km²	/km²	/km²
2005	264.43	18.96	0.49	383.48	23.21	0.14
%	38.28	2.75	0.07	55.52	3.36	0.02
2015	56.51	110.19	122.52	348.72	37.27	15.50
%	8.18	15.95	17.74	50.49	5.40	2.24
2020	77.72	107.85	13.21	456.77	7.67	27.28
%	11.25	15.61	1.91	66.13	1.11	11.25

Between 2005 and 2015, the construction land area slightly decreased from 383.48 km^2 to 348.72 km^2, a decrease of 5.03% compared to 2005. Among the various types of green spaces, forest area (110.19 km^2) and grassland area (122.52 km^2) have increased significantly, with the latter growing 250 times since 2005 and the former growing 5.8 times. There was not much growth in water bodies. The "expansion" of forest and grassland space was positively influenced by the Million Mu Afforestation Project in the plains of Beijing and environmental protection and ecological construction measures during the Eleventh Five-Year Plan period. In addition, the farm land area significantly decreased from 38.28% in 2005 to 8.18% - one fifth of the previous level - and the supply of grain in the green barrier interlaced zone has obviously weakened.

Between 2015 and 2020, the area of construction land increased significantly, showing a large difference compared to before 2015. It expanded from 348.72 km^2 in 2015 to 456.77 km^2, and the proportion of total construction land area increased from 50.49% to 66.13%. At the same time, there was a certain increase in vacant land, and the development of urban economic construction showed a rapid trend. In terms of changes in green space, the area of forest land in 2020 (107.85 km^2) was basically the same as that in 2015; grassland and water areas showed a sharp "shrinkage", with their proportions decreasing from 17.74% to 1.91% and from 5.40% to 1.11%, respectively. This result indicates that vertically simple green space is more susceptible to the impact of hard land use. The expansion of urban construction land will inevitably lead to an increase in the demand for urban population, which has led to an expansion of cultivated land area from 56.51% in 2015 to 77.72% in 2020, exacerbating the complexity of land changes in the green barrier zone during this period.

6.2. Analysis of the Multiple Index System of Green Spaces from 2005 to 2020

6.2.1. Analysis of the Area Changes in the "Contraction-Expansion" Mode of Green Space

As indicated in section 6.1, the "contraction-expansion" changes of green space revolve around two aspects: the substitution of non-green space mainly used for construction and the dynamic adjustment and expansion of land use within green space. The reasons for the dynamic adjustment of green space's internal structure not only include self-regulation within the space, but also the expansion drive brought about by the conversion of non-green space. In addition, not all types of green space experience changes or unidirectional conversions, as some types of green land exhibit stability and certain green spaces eventually convert back to green space after undergoing non-green

 doi:10.20944/preprints202307.0610.v1

space conversion. Based on these complex situations, this article will determine the measure mechanism of the "contraction-expansion" change pattern through different periods of change and conversion times, dividing them into three basic pattern types: stable pattern, shrinkage pattern, and expansion pattern, and comprehensively summarize their characteristics and sub-types of change.

Stable and contraction patterns of green space

Stable mode of green space refers to the pattern of green space that has not undergone any land type change between 2005 and 2020. Shrinking mode of green space refers to the pattern of green space where the land type has been converted to other types. Based on the current situation, the top 15 shrinking patterns with significant area changes are classified into three subcategories: the early change type, which refers to the pattern of green space where land type conversion occurred only between 2005 and 2015; the late change type, which refers to the pattern of green space where land type conversion occurred only between 2015 and 2020; and the spatiotemporal change type, which refers to the pattern of green space where land type conversion occurred between both 2005-2015 and 2015-2020.

Table 2. The land use change of green spaces in the boundary between two green belts from 2005 to 2020.

Changing pattern		Time	Changing time	Pattern-change illustration	Changed area/km²	Changed ratio/%
Stable pattern		2005-2020	0	a-a-a	8.17	19.24
Contraction pattern	Early change type	2005-2015	1	a-b-b	10.42	24.54
	Late change type	2015-2020	1	a-a-b	9.84	23.17
	Spatiotemporal change type	2005-2020	2	a-b-c/a-b-a	14.03	33.04

Among the four patterns of change, the spatiotemporal change type has the highest proportion (33.04%), while the spatiotemporal stability type has the lowest proportion (19.24%). This indicates that from 2005 to 2020, the stability of green space land was poor and it was in a highly dynamic land evolution process.

Among the initial land types of early changing types of green spaces, grassland has the smallest proportion (1.31%), followed by woodland (32.29%), and water body has the largest proportion (66.40%), with the highest degree of transformation. It is worth noting that 98.66% of the woodland and 71.37% of the cultivated land are converted from water body. This indicates that the "shrinkage" of water body space in the green belt interlaced zone has been influenced by various factors. Firstly, a large amount of water body has been transformed into construction land, which is a prominent expression of the outstanding land use change of the urban interlaced space influenced by the development factors of "city". It is the direct cause of the vulnerability of water body space in the interlaced zone. On the other hand, the expansion of urban development scale has led to the rapid increase of urban population, and the demand for urban food has been constantly increasing, which has led to the increase of cultivated land area. The good environment of water body is the preferred option for enclosing and cultivating, which is one of the indirect reasons for the vulnerability of water body space. In addition, the rapid increase of population has led to the deterioration of urban ecological environment, which in turn has caused the drying up of water bodies. This situation in turn promotes the implementation of urban ecological planning policies, and afforestation of wasteland is the simplest way to change its original dried-up appearance by planting trees. This explains why almost all woodland is converted from water bodies. Repeatedly, the continuous shrinkage of water body space under positive feedback has emerged, which is another indirect reason for the vulnerability of water body space. In terms of the land types after transformation, 78.78% of the woodland, 72.16% of the water body, and 48.90% of the grassland are transformed into construction land, ranking first among the land types after transformation. This once again confirms that the main contradiction between the vulnerability and dynamism of the interlaced zone revolves around the development of construction land.

In the late change type, the area of water body continued to increase, which maintained the characteristics of water body changes in the early transformation type. In terms of land use after transformation, the area of construction land is 3.93 km², accounting for 21.90% of the total area of all transformed land types, while the proportion of forest land and grassland area has significantly increased compared to the early transformation type. Compared with the late transformation type, the spatiotemporal transformation type presents a land pattern of "multiple types of transformation out and in with uniform proportions".

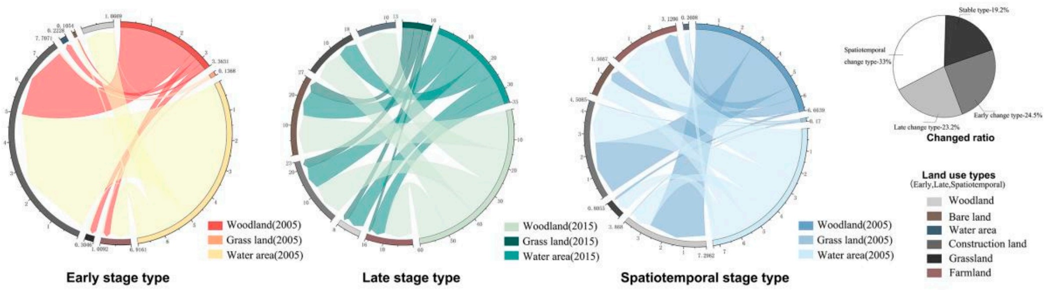

Figure 4. Sankey diagram of green space expansion pattern in the the boundary area.

Before the conversion, the main types of contraction were forests and water bodies. After the conversion, the main types of expansion were croplands, forests, and construction land, and the proportions between the main types were relatively even. It is worth noting that 41.84% of forests were still converted into forests, indicating a high degree of repetitiveness in the conversion of land types in the transition zone. In addition, the "contraction" of water bodies remains one of the main temporal and spatial problems. 59.69% of water bodies were converted into construction land (26.01%) and cropland (33.68%), and water bodies showed significant one-way contraction under different types of change patterns.

expansion patterns of green space

Green space expansion mode refers to the mode in which non-green space land types are transformed into green space land types, resulting in an increase in green space area. This includes the transformation of farmland, construction land, and unused land into green space land types during different periods.

Similar to the contraction mode of green spaces, the expansion mode of green spaces categorizes the top 15 changing types into three pattern types: early change type, late change type, and spatiotemporal change type, as shown in Table 3. Among the three pattern types, the spatiotemporal change type has the highest proportion (43.04%), indicating that over 15 years, the area of land that underwent different land type transitions and eventually transformed into green space was more than the area of land that was transformed into green space at any one time, which may provide evidence for the sustained greening of Beijing's million-acre afforestation over 15 years. Moreover, the policy of returning farmland to forests in Beijing during the 15 years had a significant impact on the urban green space pattern, especially from 2005 to 2015. In the early change type, the area of land converted from farmland to green space was significantly higher than that from construction land,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 July 2023 doi:10.20944/preprints202307.0610.v1

accounting for as high as 83.03%, and all the converted forest land came from farmland types. This trend continued from 2015 to 2020, with nearly half of the total conversion area coming from the conversion of construction land to green space, given the limited amount of farmland in the interlacing zone.

Table 3. Land use change of green space contraction in the boundary between two green belts from 2005 to 2020.

Stable and contraction pattern		Time	Changing time	Pattern-change illustration	Changed area/km²	Changed ratio/%
Stable pattern		2005-2020	0	a-a-a	8.17	19.24
Contraction pattern	Early stage type	2005-2015	1	a-b-b	10.42	24.54
	Late stage type	2015-2020	1	a-a-b	9.84	23.17
	Spatiotemporal change type	2005-2020	2	a-b-c/a-b-a	14.03	33.04

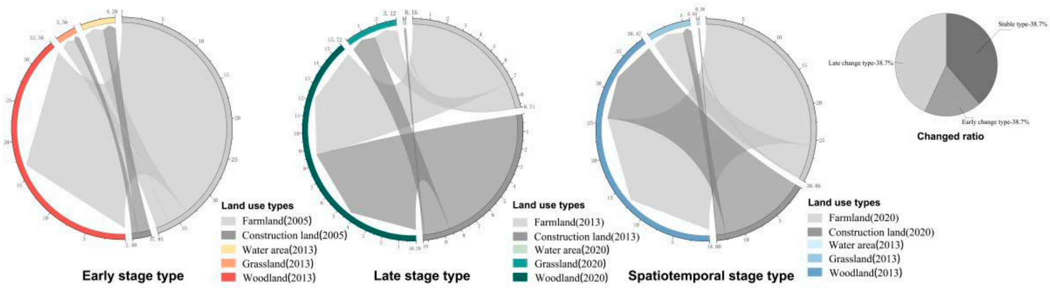

Figure 5. Sankey diagram of green space contraction pattern in the boundary area.

Regarding the land use types within the green space, forest land dominates as the land use type that is converted into green space, with an area and proportion during each change pattern as follows: in the early change pattern, the area is 35.51km, accounting for 91.71%; in the late change pattern, the area is 15.73km, accounting for 82.75%; in the spatiotemporal change pattern, the area is 38.48km, accounting for 85.76%. These findings indicate that afforestation is the main solution for urban greening in the implementation of urban ecological planning and construction. On the one hand, it is beneficial to the urban tree canopy environment and can alleviate the urban heat island effect; on the other hand, for the rapidly shrinking water bodies and grasslands, urban greening may not provide targeted solutions for their reduction problems. Therefore, a single solution may not be suitable for ecological restoration of the land use.

6.2.2. Analysis of Green Space Feature Distribution

Characteristics of spatially aggregated effect

Agglomeration of land use types refers to the phenomenon of non-uniform distribution of land use. In this section, ArcGIS software raster calculator is used to calculate the land use map formula for the 2005-2020 land use map, and then the agglomeration of green space is analyzed through the analysis of green barrier-interlaced belt.

Agglomeration Characteristics of Green Space Contraction Mode. Geospatial maps of different land change patterns are shown in Figure 6. In the stable pattern, the converted green spaces are mainly distributed in the western part of the second green belt, the northern part of Chaoyang District

doi:10.20944/preprints202307.0610.v1

in the east, i.e. the mixed area of farmland and residential areas near the Second Airport Expressway, and a small amount of green space conversion in the south bank of Wenyu River in Yan'an District. Among them, regions I, II, and A are high aggregation areas, which are respectively the Yongding River section of Fengtai, the shallow mountainous area near the west fifth ring road in Shijingshan District, and the southern Shahe Tuqiao-Shangzhuang Reservoir section in the northwest suburbs. Regions B, C, and III are medium aggregation areas, where the aggregation range and conversion area are relatively small. The current situation is the junction of Yongding River Shijingshan section and Xishan Forest Farm, and Lao Shan urban leisure park. In the early change type, region IV appeared as a wedge-shaped, high aggregation distribution from the outskirts to the suburbs. The current situation is that the green space from Jingshan Park to Feicui Lake, the Yongding River Shijingshan section (D), the International Camping Park in the southern part of Fengtai District (E), and the area north of the Wenyu River Bridge to the Ginkgo Farm (F) are medium aggregation areas. The land area in other regions is small and scattered. In the late change type, similar to the stable pattern, aggregation appeared in the Yongding River section of Fengtai, and medium aggregation distribution appeared in the shallow mountainous areas near the west fifth ring road in Shijingshan District and Xiangshan shallow mountainous areas in Haidian District, while the aggregation distribution in other regions was not obvious. There are three high aggregation areas in the entire period, namely the Yongding River section of Fengtai, the Yongding River section of Shijingshan, and the Jingshan Park-Feicui Lake section in Chaoyang District.

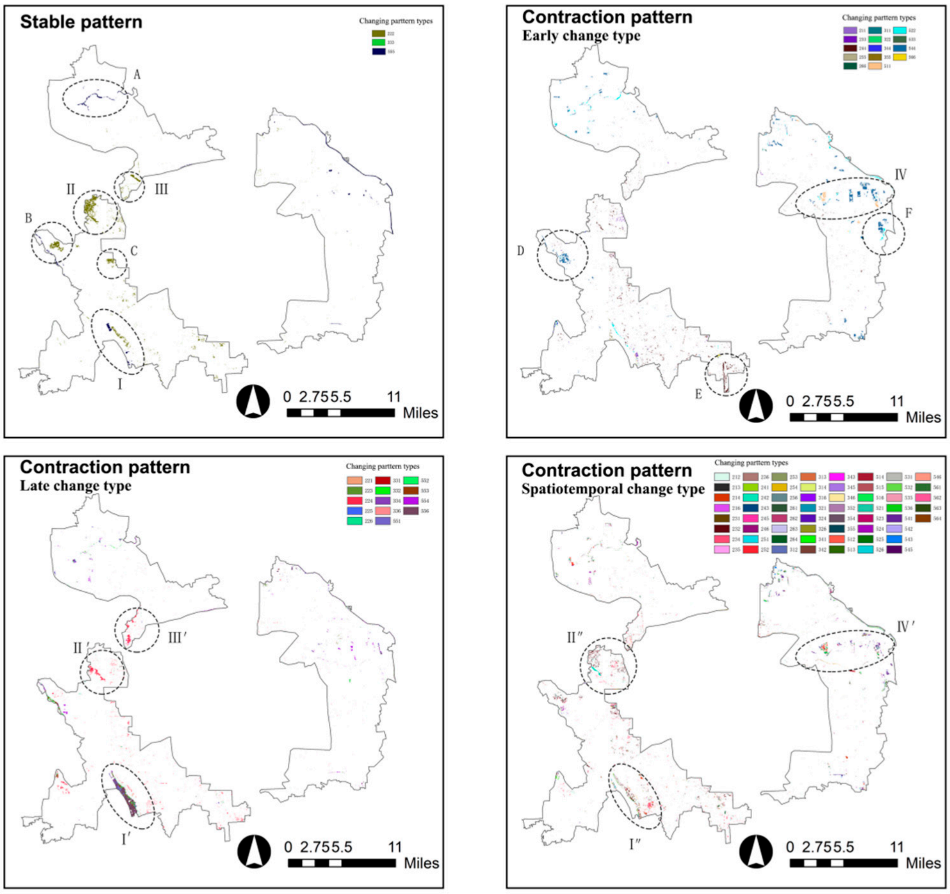

Figure 6. Spatial agglomerations of contraction pattern in the green space (2005-2020).

Among the four transformation modes, the Yongding River Fengtai section and the shallow mountainous area near the western Fifth Ring Road in Shijingshan are connected to three transformation modes, namely regions numbered as I, I', I'', and II, II', II''; while Lao Shan urban leisure park and the green space of Jianguo Park-Feicui Lake section are connected to two transformation modes, namely regions numbered as III, III' and IV, IV', indicating that the green space land types in these four regions have a strong tendency to "shrink" with the development of time and space, and therefore require emphasis on land management and control.

Agglomerative Characteristics of Green Space Expansion Modes. Unlike the aggregation characteristics of the contraction mode, the expansion mode of the green barrier-interlacing space has obvious distribution patterns in the early and complete change types. As shown in Figure 7, in the early change type (2005-2015), regions A to G showed a clear circular centripetal trend, while region I was arranged in a horizontal connected trend. This trend basically laid the basic pattern of the "contraction-expansion" changes in the green barrier-interlacing space. In the late change type (2015-2020), there was no strong aggregation trend that formed a large area, and only a few local small-scale aggregation distributions (II to V) appeared, and their specific locations did not depart from the aggregation areas of the early change type. In the complete change type (2005-2020), the distribution of the "expansion" of the green space still extended the basic tone of the early change type, and the "expansion" change occurred at its periphery.

It is worth noting that the land types of the Fengtai section of the Yongding River undergo drastic changes in time and space evolution, mainly reflected in the following characteristics: Firstly, this area exhibits strong transformation and aggregation distribution on the type dimension under the "contraction" and "expansion" modes of green space. Secondly, whether it is in the early or full period of change, this area has shown persistent transformation in the time dimension.

Characteristics of space stability. The spatial structure stability index (SSSI) is calculated based on the spatial structure conflict index (SCCI). It combines the spatial complexity index (CI), spatial vulnerability index (FI), and spatial stability index (SI) to comprehensively evaluate the stability of spatial form from the perspectives of morphological differentiation, land resilience, and stability. This section will use the standard deviational

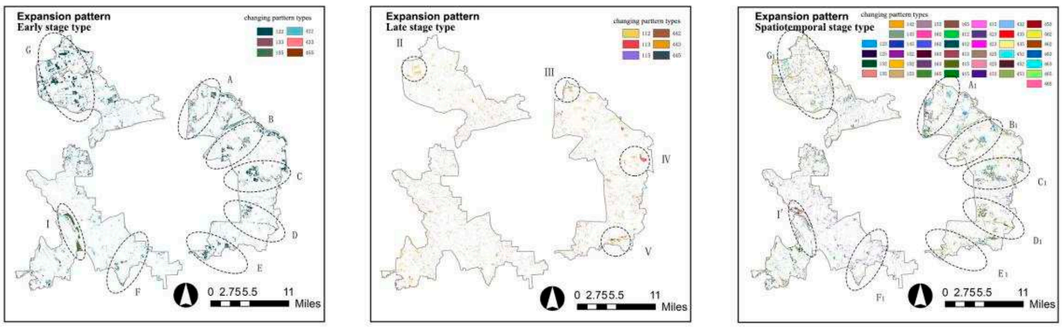

Figure 7. Spatial agglomerations of expansion pattern in the green space (2005-2020).

ellipse (SDE) analysis method to analyze the overall distribution trend of SSSI and high SSSI in the green space interlacing belt from 2005 to 2020, including changes in stability gravity center, distribution direction, and distribution shape.

Gravity Center of Distribution. In 2005, the gravity center of distribution for high stability moved northwestward compared to the overall stability center, indicating a denser distribution of high stability green spaces in the northwest direction of two green belts. The current situation in the northwest mainly consists of continuous forests and grasslands with a good ecological environment. In 2015, the high stability center of gravity moved slightly southward compared to the overall stability center of gravity. While the overall green space area increased significantly, the improvement of the green space quality in the southern Yongding River basin had a positive impact on its center of gravity. In 202S0, the high stability center of gravity moved significantly eastward to the north of Chaoyang District. From 2005 to 2020, the high stability center of gravity first shifted slightly southward from the northwest, and finally moved to the northeast. Generally speaking, the stability of the northern green space is significantly higher than that of the southern green space. Secondly, its center of gravity change is greatly affected by green space planning and construction within a time limit. The northwest suburbs, influenced by their superior historical ecological environment, have a good ecological barrier and environmental foundation, so the center of gravity of their green space had an obvious bias in the early stage of urban construction. However, with the impact of urban planning policies such as the construction of Beijing's Yizhuang New City and the construction of Beijing's sub-center, its center of gravity has moved southward.

Distribution shape. The distribution shape is mainly analyzed by changes in the long and short axes of the standard deviation ellipse and their ratio. The larger the ratio of the long and short axes, the more obvious the directional characteristics, and vice versa. As shown in Figure 8 , the SSSI values of the second green barrier from 2005 to 2020 are generally evenly distributed, and the ratio of the long and short axes of the standard ellipse is generally small, with a flatness in the range of 1 to 1.5. Among them, the long and short axis ratio of high SSSI and overall SSSI in 2005 and 2020 was higher than that in 2015, indicating that the spatial stability of the second green barrier's form in 2005 and 2020 was more directional and stronger in the northwest direction. Among them, the directional force of the distribution of high SSSI values is stronger than that of the overall SSI direction and centripetal force. The long and short axis ratio of SSSI in 2015 was 1.20 and 1.21, respectively, which is closer to a circle, so the overall directional characteristics are weaker.

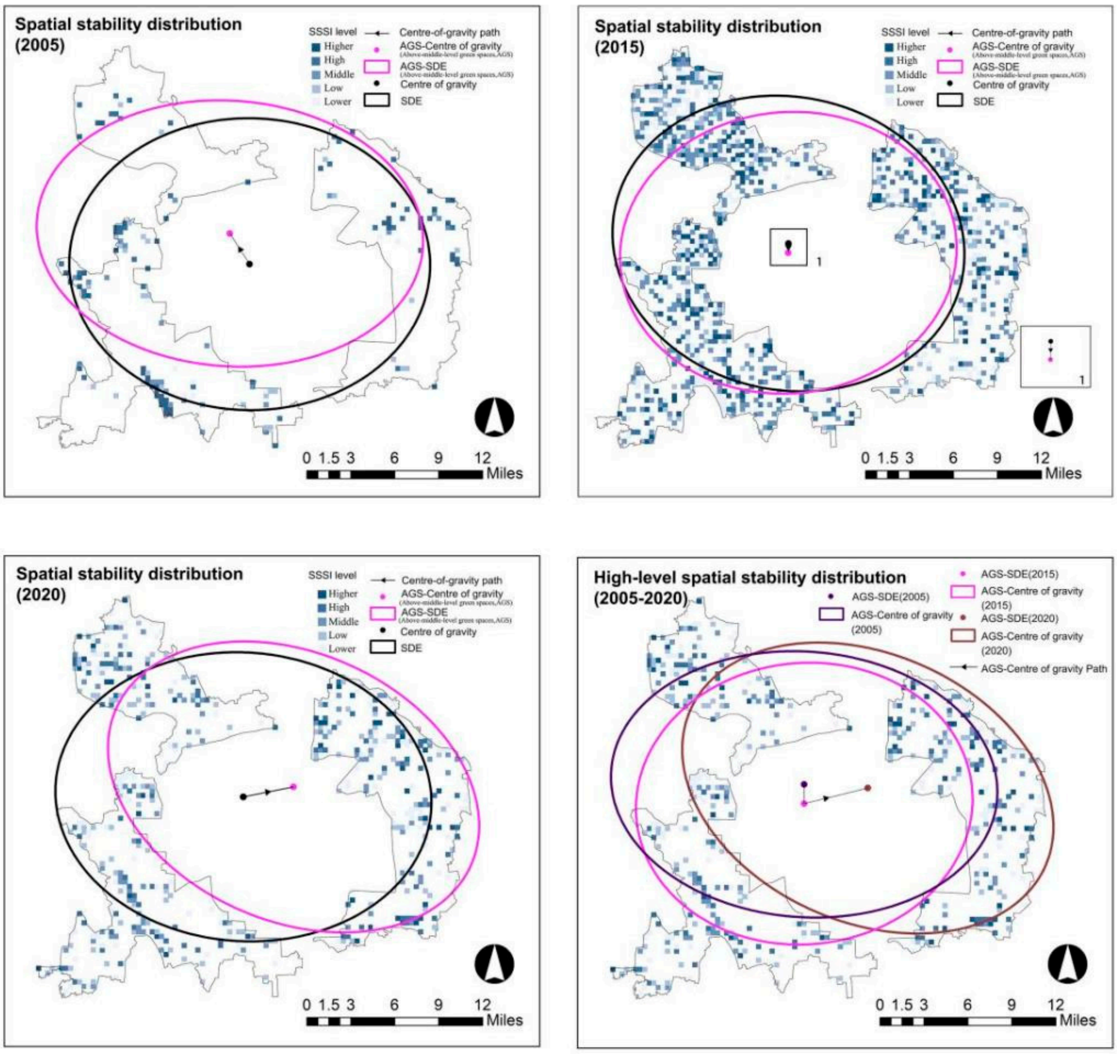

Figure 8. Gravity Center of Distribution.

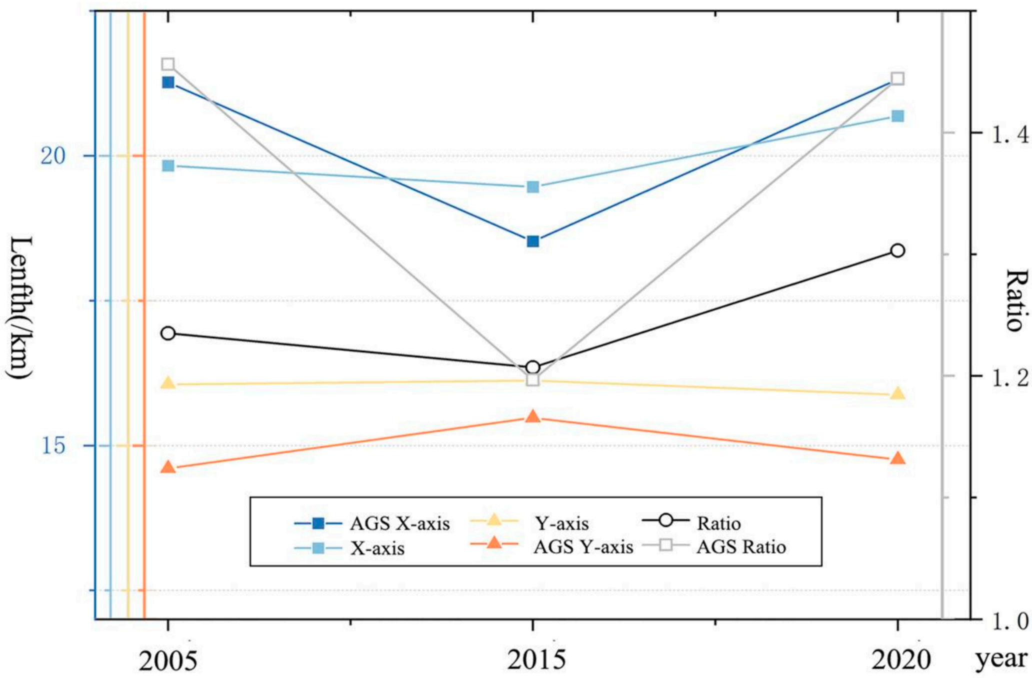

Figure 9. Distribution shape of green space in the boundary,2005-2020.

6.2.3. Analysis of Green Space Connectivity Level

global connectivity. Figure 10 shows the changes in connectivity indicators (PC, SLC, MSC) of green interlaced belts and green space land use from 2005 to 2020. The global connectivity level (PC) remained stable from 2005 to 2020, with a slightly higher value in 2015 than in the other two years. The SLC value in 2015 was significantly higher than in 2005 and 2020, indicating better dominance and aggregation of the largest patches of green space in 2020. The MSC value in 2015 was also higher than in other years, indicating a better average connectivity level in 2015.

Local connectivity. Compared with 2005 and 2015, the highest level of connectivity in 2020 was found in nodes, with the most in 2020 and the least in 2005. As for connectivity corridors, the distribution was the most dense and the connectivity was the strongest in 2015, followed by 2020 and the least in 2005.

In 2005, the distribution of connectivity nodes and corridors showed a "three dominant positions, overall scattered distribution" pattern. The three dominant positions were mainly distributed in the high connectivity nodes and high corridor connectivity characteristics of the Wenyu River Chaoyang section, the North West Mountain Plain in Haidian district, and the Yongding River Fengtai section. Among them, the Yongding River Fengtai section had the strongest connectivity nodes, followed by the Wenyu River Chaoyang section, and the North West Mountain Plain in Haidian district had lower connectivity nodes. In terms of the distribution structure of high connectivity corridors, the corridors in the Wenyu River Chaoyang section formed a "one-character" connection pattern, with the strongest corridor connectivity and the longest connection length. The North West Mountain Plain in Haidian district showed a "net-like" connection pattern, with the Nan Sha River Tuqiao section as the center, radiating in all directions. The corridors in the Yongding River Fengtai section showed characteristics of being short, strong, and few.

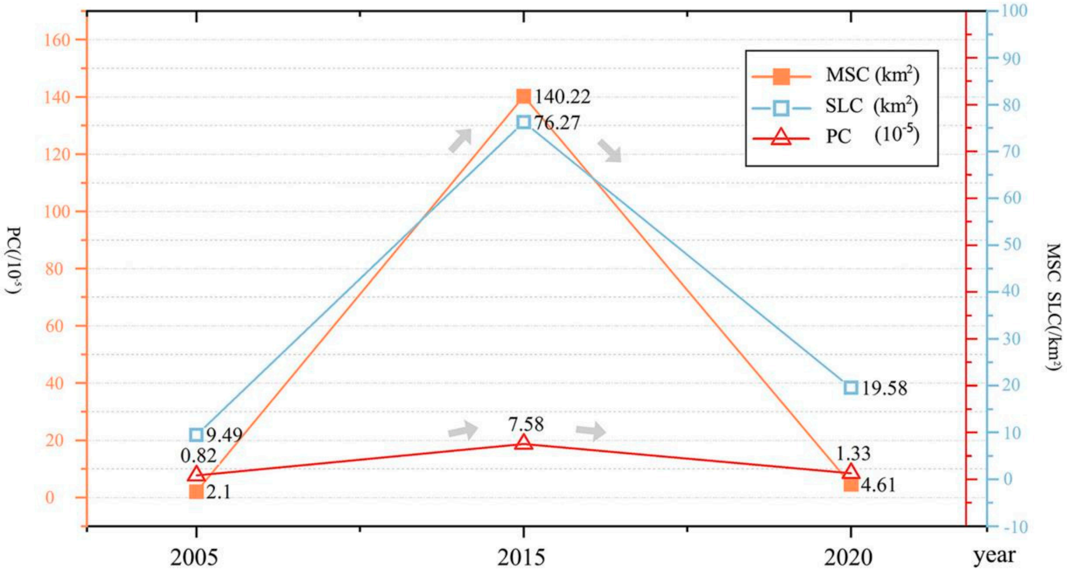

Figure 10. Changes in green space connectivity at the global level, 2005-2020.

In 2015, the distribution of connectivity nodes and corridors showed a "one dominant position, three cores, and overall density" pattern. The "one dominant position" refers to the complex and radially distributed network characteristics of multiple centers in the northwest suburban plain area of Haidian district. The area with Cuihu National Urban Wetland Park as the core node had the strongest connectivity, with strong connectivity to the north and south, and strong connectivity to the middle, forming a gradient difference. The Cuihu National Urban Wetland Park node was the primary node, connecting the other four nodes to form a high-connectivity dense radial corridor. The "three cores" refer to the Yongding River Fengtai section, the Wenyu River Chaoyang North section, and the Jiufu Park group. Among them, the corridor connectivity and length of the Yongding River Fengtai section were greatly enhanced, extending north to the Shijingshan Park in Shijingshan district and south to the World Park in Fengtai district. The Wenyu River Chaoyang North section and the Jiufu Park group were linked by the Dongba suburban park node, forming a radial corridor network. In 2020, the distribution of connectivity nodes and corridors showed a "multi-center, short corridors, and even distribution" pattern. In 2020, there was no obvious dominant node in the distribution of connectivity nodes. High connectivity patches appeared in the north of Haidian district, the north of Chaoyang district, the middle of Chaoyang district, the northwest of Fengtai district, and the north of Shijingshan district. The distribution of corridors changed from the long, multiple, and dense single-center radial corridors in 2015 to the multi-center short corridors distribution pattern.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 July 2023 doi:10.20944/preprints202307.0610.v1

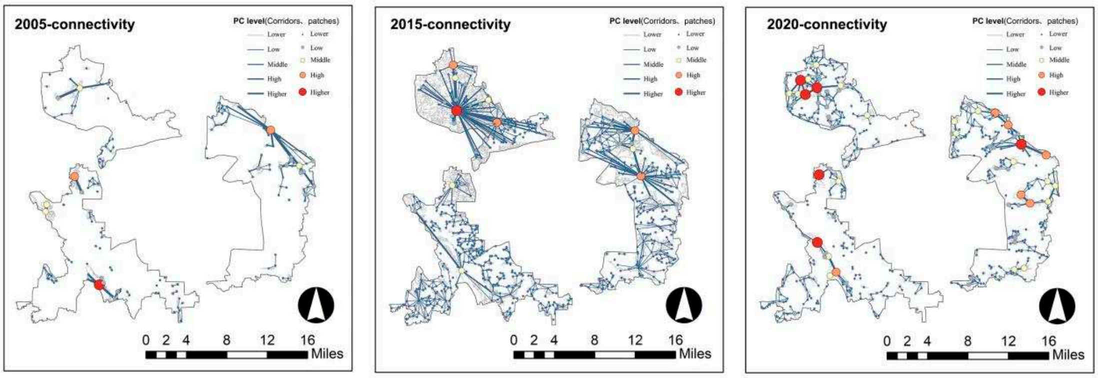

Figure 11. Changes in green space connectivity at the local level, 2005-2020.

7. Discussion

Based on the theory of landscape ecology, this article measures the ecological value of the area through the changes in land use of green space interlaced belts. It emphasizes the active change pattern of green space as the main subject, rather than the passive change caused by urban expansion. The formation of the "shrinkage-expansion" change mechanism of green space is influenced by the dual factors of the spread of construction land under urban economic construction and the drive of urban ecological policies for greening construction. The dynamic relationship of the two not only brings about the transformation of green space and non-green space land use types, but also changes the internal structure of green space, which is the profound mechanism of the current situation and planning promoting the urban land pattern together.

In the definition of the concept of green ecotone zone, we will focus our research on large-scale green belts within the urban built-up area, which is relatively rare. The reason is that constructing large green belts in the urban built-up area to avoid the disorderly spread of urban land is a common solution on a global scale, but people have limited discussion on the ecological value and transitional nature of green spaces within the green belts, ignoring the special "urban" attribute. On the other hand, the intense land contradictions often make it difficult to implement such construction. The value of green spaces as urban land that can be "cut" does not have fair treatment, and a scientific identification method and value expression that can provide effective proof of the value of green spaces are important for the planning and construction of special transitional green spaces. There is a blank in the investigation of the historical and current tree species and vegetation characteristics in the Second Ring Green Buffer Zone of Beijing, which is also the difficulty of research in this area. In the future, based on the existing defined concept, more in-depth practical investigation and research should be conducted on the vegetation characteristics of the first and second green belts.

The spatiotemporal evolution pattern of the "contraction-expansion" mechanism in the boundary between two green belts is in line with the overall development trend of Beijing's urban development. After 2015, Beijing entered a transitional period of urban economic development and ecological construction, which is also the fundamental reason for the appearance of the "contraction-expansion" mechanism in the boundary between two green belts. In addition, the empirical evidence of the significant "expansion" of forest land indicates that the implementation of a single green space implementation plan has had a negative impact on other green spaces, such as the significant reduction of water space, which should be given sufficient attention. The non-circular ring pattern and center of gravity deviation presented by the interspersion zone space indicate the unfair distribution of green spaces in different regions. This unfairness may be a reflection of the differences in strategic layout of different administrative regions. In other words, pursuing a green space compensation mechanism for different regions may be more meaningful than forming an absolute circular pattern based on green space fairness. This article emphasizes the definition of ecological source areas as key connectivity nodes in forming a green network. It broadens the existing binary judgments of "quality" and "quantity" and focuses on the integrated regional ecological network planning mode of "space" and "relationship".

8. Conclusion

During a 15-year period, the construction land in the area increased by 10%, leading to a significant shift from "expansion" to "contraction" in the urban green space. The urban greenery also reflected in the land use structure during this period, such as the significant "expansion" of green space from 2005 to 2015, which was a positive result of Beijing's urban planning policies and practices that aimed to "restrain" urban expansion. After 2015, the trend of further expansion of urban construction land intensified, and the phenomenon of "contraction" of urban green space became evident. In addition, there was a phenomenon of repeated transformation of a certain area of green space in time and space. Although the area of such land is small, it continues to change and shatter in the geographic space, which deserves the attention of land management. In general, from 2005 to 2020, the green space of the green belt interlaced zone experienced a dual trajectory of "expansion-contraction" and presented a differentiated land pattern change around 2015. In terms of the morphological characteristics of green space, although different types of green space land under different transformation modes have different transformation results, they have similar aggregation effects in geographic space. This study refutes the previous single concept of stability or instability explored on a medium scale, indicating that at a medium scale, land can simultaneously possess stability and extreme instability characteristics. For example, the Yongding River Fengtai section and the shallow mountainous area near the west fifth ring of Shijingshan both showed aggregation effects of land under stable, early change, late change, and full period change types, indicating that these two areas have stable, relatively stable, and extremely unstable land change phenomena within a small range. In the expanding green space changes, there was also a significant aggregation effect in the spatial morphology, such as the appearance of five evenly distributed wedge-shaped and longitudinal green space forms in Chaoyang District, which was the result of upper-level planning on land. The stability and high stability gravity center and standard deviation elliptical shape and direction were influenced by urban historical ecological texture in the early stage, and the greening measures and ecological strategies of different urban divisions significantly reshaped the spatial stability. Although the interlaced network pattern presented at different time periods was not exactly the same, it formed a supporting trend of "extreme north-west-northeast" as the source of ecological connectivity, which should be regarded as an important connecting skeleton to link the green ecological network of the interlaced zone.

References

1. Bao, W., Yang, Y., & Zou, L. (2021). How to reconcile land use conflicts in mega urban agglomeration? A scenario-based study in the Beijing-Tianjin-Hebei region, China. *Journal of Environmental Management*, *296*, 113168. https://doi.org/10.1016/j.jenvman.2021.113168
2. Immergluck, D., & Balan, T. (2018). Sustainable for whom? Green urban development, environmental gentrification, and the Atlanta Beltline. *Urban Geography*, *39*(4), 546–562. https://doi.org/10.1080/02723638.2017.1360041
3. Jayasinghe, A., Kalpana, L. D. C. H. N., Abenayake, C. C., & Mahanama, P. K. S. (2021). Urban Boundary Demarcation—An iCN Model Approach. *Social Sciences*, *10*(12), Article 12. https://doi.org/10.3390/socsci10120448
4. Li, H., Chen, H., Wu, M., Zhou, K., Zhang, X., & Liu, Z. (2022). A Dynamic Evaluation Method of Urban Ecological Networks Combining Graphab and the FLUS Model. *Land*, *11*(12), Article 12. https://doi.org/10.3390/land11122297
5. Liu, S., Zhang, X., Feng, Y., Xie, H., Jiang, L., & Lei, Z. (2021). Spatiotemporal Dynamics of Urban Green Space Influenced by Rapid Urbanization and Land Use Policies in Shanghai. *Forests*, *12*(4), Article 4. https://doi.org/10.3390/f12040476
6. Ma, L. J. C. (2005). Urban administrative restructuring, changing scale relations and local economic development in China. *Political Geography*, *24*(4), 477–497. https://doi.org/10.1016/j.polgeo.2004.10.005
7. Ramesh, R. M., & Nijagunappa, R. (2014). Development of urban green belts—A super future for ecological balance, Gulbarga city, Karnataka. *International Letters of Natural Sciences*, *27*, 47–53.

https://doi.org/10.18052/www.scipress.com/ILNS.27.47
8. Wu, Z., Chen, R., Meadows, M. E., Sengupta, D., & Xu, D. (2019). Changing urban green spaces in Shanghai: Trends, drivers and policy implications. *Land Use Policy*, *87*, 104080. https://doi.org/10.1016/j.landusepol.2019.104080
9. Zhou, X., & Wang, Y.-C. (2011). Spatial–temporal dynamics of urban green space in response to rapid urbanization and greening policies. *Landscape and Urban Planning*, *100*(3), 268–277. https://doi.org/10.1016/j.landurbplan.2010.12.013