SPATIAL AND TEMPORAL VARIABILITY OF ECOSYSTEM SUPPORT SERVICES AND DRIVERS IN METROPOLITAN AREAS BASED ON THE INVEST MODEL

Jiping Wen[1], Wei Fu[1,*]

[1] School of Architecture and Urban Planning, Beijing University of Civil Engineering and Architecture, Beijing, China, fuwei@bucea.edu.cn

KEY WORDS: InVEST Model, Beijing, Carbon Storage, Habitat Quality.

ABSTRACT:

With the rapid economic growth since the turn of the 21st century, the fast-degrading environment has emerged as a significant factor limiting the continued development of megacities such as Beijing and Shanghai. It has also placed unprecedented pressure on ecosystem services. Therefore, the present study uses the morphological spatial pattern analysis model and the index of connectivity (IIC) and possible connectivity (PC) indices to analyse changes in the spatial pattern of Beijing and combines the carbon sequestration module and habitat quality module of the InVEST model to evaluate the supporting functions of Beijing's ecosystems from 2000 to 2020, to investigate the characteristics of spatial and temporal changes and the drivers of these changes, and to provide a scientific basis for urban ecosystem management. The results show that between 2000 and 2020, the overall area of green space in Beijing decreased, and the IIC and the index of PC decreased, indicating that the overall spatial connectivity of green space decreased and fragmentation increased. During this period, the carbon stock within the Beijing city area decreased by a total of about 2.94 Tg, and the habitat quality index decreased from 0.71 to 0.67, indicating a trend of degradation. This paper suggests that the expansion of urban and rural land use is a major factor in the decline of ecosystem support services, while the spatial pattern of the landscape also has an impact on habitat quality, which is generally higher in areas with better landscape connectivity.

1. INTRODUCTION

Irrational human activities have significantly altered the structure of the ecosystem in the process of rapid urbanisation in China, resulting in a reduction in the capacity of ecosystem services to provide services and seriously threatening sustainable development and the quality of life of the inhabitants (Yu et al., 2010). In 2015, the Paris Agreement was adopted at the 21st United Nations Climate Change Conference to set a goal of achieving net zero emissions by the second half of the century. In 2020, China proposed during the 75th United Nations General Assembly that it would increase its autonomous national contribution, aiming to peak carbon dioxide (CO_2) emissions by 2030 and achieve carbon neutrality by 2060. As the capital of China and an international metropolis, Beijing has entered a phase of superfast development since the 1990s, with the resident population and the built-up area of the city expanding northwards (Liu et al., 2021). The expanding urban and rural land areas are putting enormous pressure on ecosystem services.

Ecosystem Services are the goods and services obtained by humans from ecosystems and are classified into four categories, i.e. regulating services, provisioning services, supporting functions and cultural services (Yu et al., 2010). National and international scholars have already studied the impact of land use change on urban ecosystem services (Goldstein et al,2012; Li et al., 2013; Yang et al., 2018). Simultaneously, changes in landscape patterns lead to corresponding changes in the composition of ecosystems and the supporting capacity of ecosystems. In recent years, an increasing number of scholars have focused on ecosystem connectivity, with connectivity indices such as the overall connectivity index (IIC) and possible connectivity index (PC) prevalently used in research (Zhang and Wu, 2018). Morphological Spatial Pattern Analysis (MSPA) is widely used to analyse a wide range of landscape morphological changes (Zhang and Wu, 2018). Moreover, the combination of the two allows for a more comprehensive quantification and assessment of landscape connectivity.

The present study combines the MSPA model, the IIC index, the PC index and the Carbon Storage and Habitat Quality models from the InVEST model to assess the carbon sequestration capacity and habitat quality in Beijing in order to understand the spatial and temporal variability of ecosystem support services in Beijing between 2000 and 2020 and analyse the drivers of ecosystem service change during urbanisation.

2. METHODS

2.1 Research area

Beijing is located at 39°26'N–41°03'N, 115°25'E–117°30'E in the northwestern part of the North China Plain. It consists of 16 municipal districts with a total area of 16,808 km^2. The plains cover 39.02% of the total area. The climate is a temperate continental monsoon climate with four distinct seasons. The average annual precipitation is approximately 644 mm, and the average annual temperature ranges between 11 to 13°C. Beijing has experienced rapid social and economic development since the reform and opening up, with a resident population of 218.90 million and a total gross domestic product of 3,610.26 billion yuan by 2020.

2.2 Sources of land use data

The present combines the LUCC classification system established by Liu Jiyuan et al. in the construction of the 'China 20th Century LUCC Spatio-temporal Platform' according to the national land use classification method with Landsat 30 m remote sensing images of Beijing for the periods 2000, 2010 and 2020. Land use types were classified into six primary categories,

https://doi.org/10.5194/isprs-annals-X-3-W2-2022-29-2022

including arable land, forest land, grassland, water, construction land and unused land, and 25 secondary categories, including wooded land, shrubland, open woodland, other woodlands and grassland with high, medium and low cover. The geometry, colour characteristics, texture characteristics and spatial distribution of features were analysed with the help of experts based on the spectral characteristics of the images, combined with field measurements and references to relevant geographical maps before the national land use data used in this paper were interpreted.

2.3 Source landscape connectivity evaluation index

The overall connectivity index IIC and the possible connectivity index PC combine the carrying capacity of each factor in the landscape for ecological processes and can directly reflect the dynamics of landscape connectivity (Shi and Xu, 2011), identifying the relative importance of each patch to ecological connectivity (Shi and Xu, 2011; Xie et al., 2014; Qi and Fan, 2016). The IIC and PC indices were used to analyse the spatial distribution of source landscapes in Beijing and to calculate the trends of the indices for each landscape at different distance thresholds (Du et al., 2019). The indices were calculated using the following equations:

$$\mathrm{IIC} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i \times a_j}{1+nl_{ij}}}{A_L^2} \quad (1)$$

$$\mathrm{PC} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}p_{ij}^{*} \times a_i \times a_j}{A_L^2} \quad (2)$$

where n = the number of patches in the landscape
a_i, a_j = the area of patches i and patch j, respectively
nl_i = number of connections between patches i and j
A_L = the area of the landscape
P^*_{ij} = the maximum of the product of all path probabilities between patches i and j

The core areas of woodland, grassland and water were selected as the 'source' ‘source’ landscape, and the connectivity resistance thresholds were set to 1km, 2km, 3km, 4km, 5km, 7km, 10km, 12km, 15km, 20km, 30km, 50km1 km, 2 km, 3 km, 4 km, 5 km, 7 km, 10 km, 12 km, 15 km, 20 km, 30 km, 50 km according to previous studies. 0.5A connectivity probability of 0.5 was chosen, and the final calculation was carried out by Conefor26Conefor 2.6 software.

2.4 Morphological spatial pattern analysis model (MSPA)

MSPA applies a range of image processing techniques to the raster layers so that the target features are classified into seven mutually exclusive types: cores, islands, edges, perforations, bridges, roundabouts and branches (Table 1).

We have taken woodland, grassland and water as the foreground of the study and other lands as the background based on land use data for 2000, 2010 and 2020. Guidos software was used to obtain the spatial distribution of each landscape land and determine its indicative significance in terms of landscape ecological source land connectivity according to the definitions and characteristics of different MSPA landscape classifications.

2.5 InVEST model

The InVEST model, developed by Stanford University in collaboration with The Nature Conservancy and the World Wide Fund for Nature, is a GIS-based model that simulates the impact of land cover on ecosystem service functions. The model is based on GIS and simulates the impact of land cover on ecosystem service functions by incorporating land use scenarios that allow for the detection of potential changes in the supply of ecosystem services and trade-offs between services at different geographical and socio-economic scales.

In this study, InVEST version 3.5 was used, and two models were selected to analyse the support services of Beijing’s ecosystems: carbon storage and sequestration and habitat quality.

Landscape type	Ecological definition
Core	Large natural patches, wildlife habitats, forest reserves, etc.
Islet	Small, isolated, fragmented natural patches that are not connected, usually including small urban green spaces within built-up areas
Perforation	Building sites within the core ecological space that do not have ecological benefits
Edge	It is a transition between the core area and the built-up area, with a marginal effect.
Bridge	Connecting ribbon ecological sites between core areas, i.e. corridors in the regional green infrastructure, facilitating the formation of the eve and energy flows and networks within the five centres of the region
Loop	Ecological corridors connected to the same core area, small in scale and with low connectivity to outlying natural patches
Branch	Ecological patches linked to only one section of the core area, with poor landscape connectivity

Table 1. Ecological implications of MSPA.

2.5.1 Carbon storage:

The InVEST carbon stock model uses four types of carbon pools: above-ground biogenic carbon pools, below-ground biogenic carbon pools, dead organic matter carbon pools and soil organic matter carbon pools.

The model employs land use data and carbon density data as the assessment unit and calculates ecosystem carbon stocks by raster overlay:

$$C_i = C_{i\_above} + C_{i\_below} + C_{i\_dead} + C_{i\_soil} \quad (3)$$

where C_i = the carbon density of species i
C_{i_above} = the carbon density of above-ground organisms of species i
C_{i_below} = the carbon density of below-ground organisms of species i
C_{i_dead} = the carbon density of dead organic matter of species i
C_{i_soil} = the carbon density of soil organic matter of species i

Later, the model calculates ecosystem carbon stocks based on carbon intensity and land use data for each species:

$$C_{i\_total} = C_i \times A_i \quad (4)$$

where C_{i_total} = the total carbon stock of species i in the region

C_i = the carbon density of species i
A_i = the area of species i

Finally, the total ecosystem carbon stocks in the region are calculated by adding the carbon stocks of each species. The present study summarises the carbon pool data of this study based on the land use data of Beijing in 2000, 2010 and 2020 and with reference to the results of previous studies (Table 2).

LULC	C_above	C_below	C_soil	C_dead	References
Cropland	5.00	3.13	22.51	0.63	Kong et al,2019
Woodland	20.04	4.54	65.59	2.26	Yang et al, 2012
Grassland	12.97	1.69	40.60	1.12	Xu et al,2018
Water	0.00	0.00	0.00	0.00	Xu et al,2018
Wetland	3.73	0.62	56.00	1.87	Xu et al,2018
Urban and rural construction land	5.12	1.02	23.11	0.00	Xu et al,2018
Unused land	6.34	1.15	20.76	0.57	Xi et al, 2013; Li et al, 2020

Table 2. InVEST carbon stock model with four types of carbon pools.

2.5.2 Habitat quality: Habitat quality in the InVEST model refers to the ability of the environment to provide suitable productive conditions for the survival of individuals or populations. The word model combines land use data with data on biodiversity threat factors to produce a habitat quality map. The model assesses the quality of habitat based on its calculated habitat quality index (HQI), a dimensionless indicator that evaluates the suitability and degradation of habitats in the area, which is calculated as follows:

$$Q_{xj} = H_j\left[1-\left(\frac{D_{xj}^z}{D_{xj}^z+k^z}\right)\right] \qquad (5)$$

where Q_{xj} = the habitat quality index for raster cell x of landscape type j
H_j = the habitat suitability of land type j
D_{xj} = the habitat degradation of raster cell x in land type j
k = the half-saturation constant (half of the maximum value of degradation)
z = the default parameter of the model

$$D_{xj} = \sum_{r=1}^{R}\sum_{y=1}^{Y_r}\left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_y i_{rxy} \beta_x S_{jr} \qquad (6)$$

where r = the threat source of the habitat
y = the raster in threat source r
d_{xy} = the distance between raster x (habitat) and raster y (threat source)
$d_{r\,max}$ = the influence range of threat source r

Based on previous research, this study defines urban construction land, rural residential land, arable land and other construction land as sources of threat to the habitat and sets the impact they produce as a linear decay trend.

3. RESULTS

3.1 Analysis of landscape connectivity changes in ecological source sites based on connectivity indices

Figure 1 depicts the variation of the connectivity index with distance threshold from 2000 to 2020. The results show that the overall connectivity index and the possible connectivity index gradually increase as the distance threshold increases, indicating that the larger the scale at which ecological processes occur, the higher the connectivity of the same landscape. Furthermore, in terms of the temporal dimension, the landscape connectivity of ecological source sites in Beijing shows a gradually deteriorating trend.

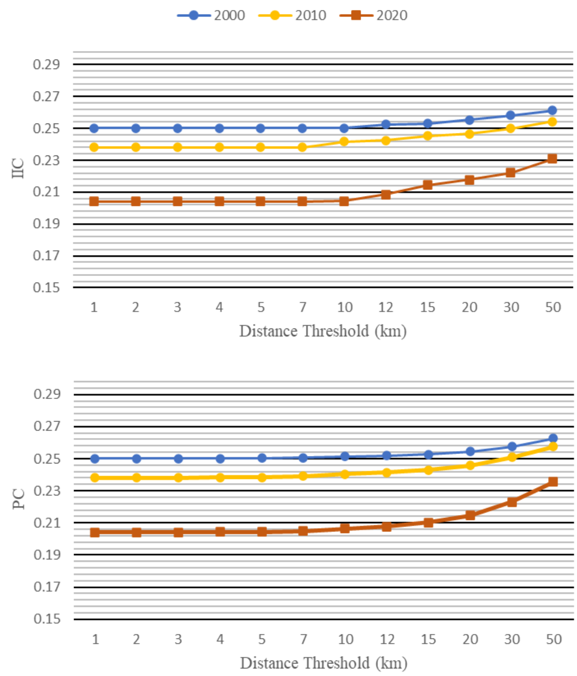

Figure 1. IIC and PC changes in Beijing from 2000 to 2020

3.2 Analysis of the spatial pattern of ecological source landscapes based on MSPA

Table 3 illustrates the pattern of functional types of ecological sourceland connectivity in Beijing for each period obtained through MSPA analysis, and the area and proportion of each type are shown in Table X. The results show that the core area accounts for more than 90% of the foreground, and its spatial distribution has a large image with the overall distribution of ecological sourcelands, with isolated islands and roundabouts accounting for too small an area to have a minor impact on them.

In terms of spatial distribution, between 2000 and 2020, in the western and northern mountainous regions, the edges of large core patches at the intersection of mountains and plains in the Yanqing, Changping and Haidian areas are gradually eroded by the background. The scattered tiny core patches in the plain area outside the Sixth Ring Road gradually recede in the central plain areas, while tiny core patches are generated between the first green belt and the second green belts in Beijing and have shown a wedge-shaped distribution pattern as of 2020.

Landscape type	2000		2010		2020	
	Area / km²	Percentage /%	Area / km²	Percentage /%	Area / km²	Percentage /%
Core	8721.36	95.30	8670.62	95.43	8649.10	95.36
Islet	0.30	0.00	0.36	0.00	0.42	0.00
Perforation	153.10	1.67	166.61	1.83	144.67	1.59
Edge	248.78	2.72	222.44	2.45	249.21	2.75
Bridge	7.98	0.09	7.37	0.08	7.47	0.08
Loop	1.48	0.02	1.14	0.01	1.08	0.01
Brand	18.19	0.20	17.59.	0.19	18.18	0.20
Foreground	9151.18	100.00	9086.14	100.00	9070.13	100.00
Background	7254.62	/	7319.66	/	7335.67	/

Table 3. Change in area and proportion of MSPA class from 2000 to 2020

Furthermore, between 2000 and 2020, the core area and foreground area as a whole show a gradual decrease in area and proportion, with the foreground area decreasing by a total of 81.05 km^2. Additionally, the core area decreased, which was accompanied by a decrease in the area of edge areas, connecting bridges, spur lines and other types of areas. Spatially, it also displays a decrease in the plain areas outside the Sixth Ring, in addition to a decrease in large patches. The spatial reduction is reflected in the receding of small patches in the plains outside the Sixth Ring, in addition to the reduction of large patches. Moreover, the area of core patches continues to shrink, while the area of fringe areas connecting bridges and spurs increased, mainly reflecting the receding of micro-patches throughout Beijing.

In summary, the total area of ecological source areas in Beijing decreased between 2000 and 2020, while the spatial distribution became more fragmented. This is primarily due to the disappearance of large patches and the formation and disappearance of micro-patches. 1. The data show a decrease in the core areas and an increase in the area of edge areas due to erosion of the edges of large core patches and the fragmentation of their interiors, accompanied by the conversion of pore spaces to edges and the disappearance and new creation of existing linking bridges and spurs. 2. The formation of new micro-patches, in addition to the increase in core areas, is accompanied by an increase in pore space, isolated islands, edge areas, connecting bridges, roundabouts and spurs all decrease due to their partial conversion to core areas.

3.3 Analysis of spatial and temporal variability in ecosystem support services

3.3.1 Spatial and temporal changes in carbon storage: Total carbon stock in Beijing in 2000, 2010 and 2020 was calculated to be 84.52 Tg, 83.36 Tg and 81.58 Tg, respectively. This indicates that the overall annual carbon stock in Beijing has been decreasing from 2000 to 2020, with a cumulative decrease of about 2.94 Tg, indicating that the carbon sequestration capacity of Beijing has decreased during these 20 years.

According to the spatial distribution of carbon stocks in Beijing in 2000, 2010 and 2020 determined by the InVEST model (Figure 3), the spatial distribution of carbon stocks in Beijing has not changed significantly during these three periods. Higher carbon stock areas are concentrated in the northwest and west of Beijing, where the land is primarily forested and has a relatively strong carbon sequestration capacity, while lower carbon stock areas are primarily found in the central and eastern plains of the central urban areas, as well as the surrounding urban and rural construction land, arable land, water areas and bare land areas.

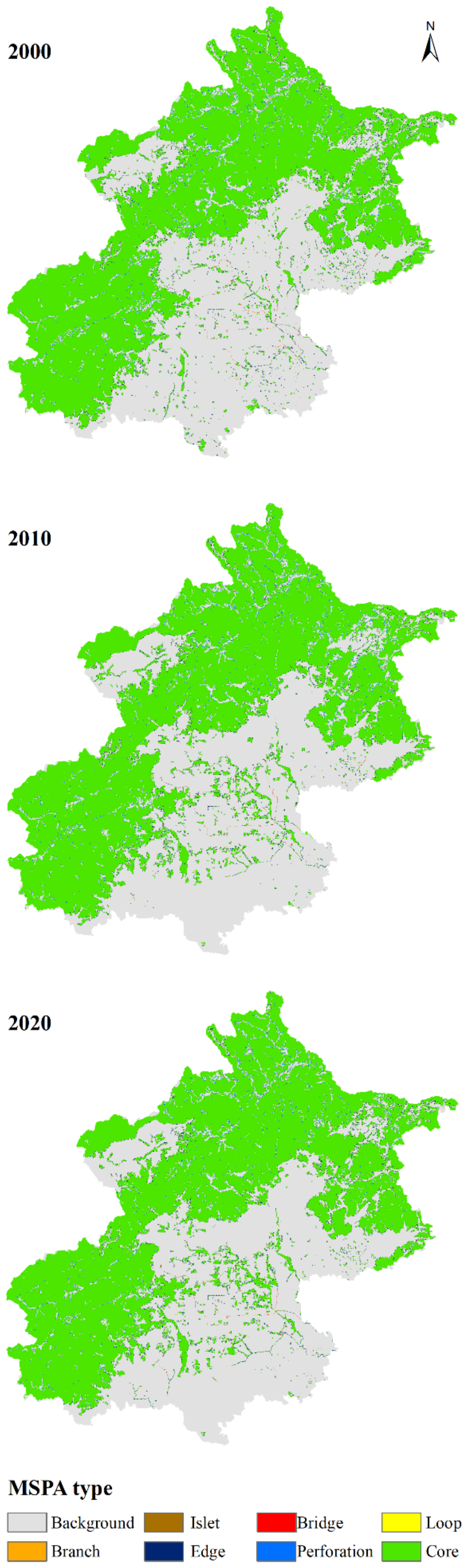

Figure 2. MSPA types distribution maps from 1990 to 2015 in Beijing.

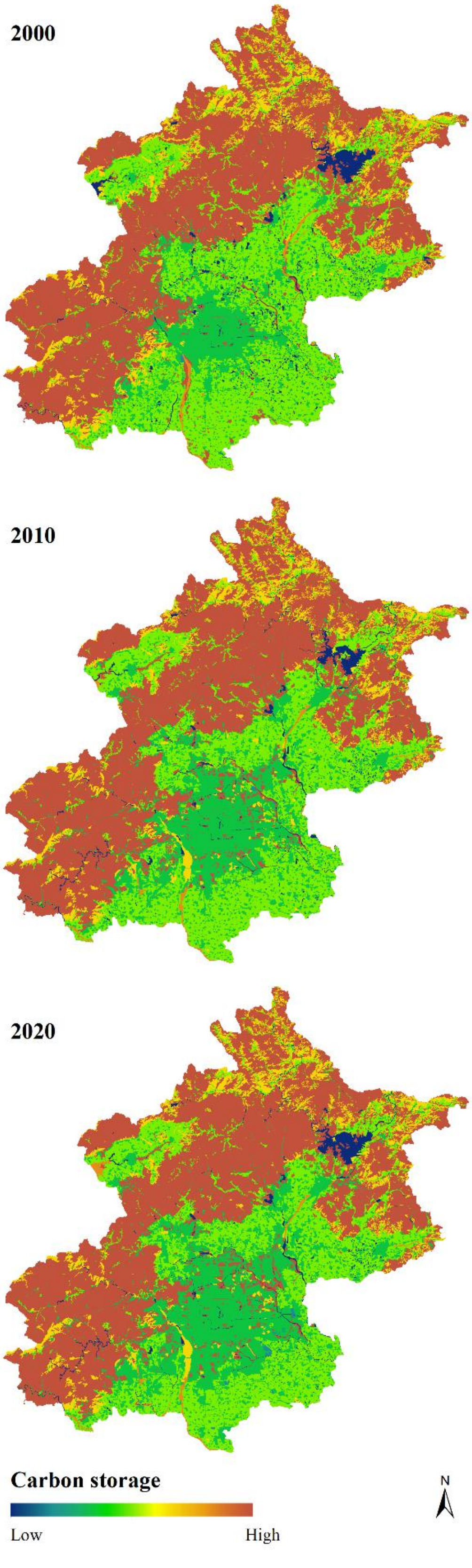

Figure 3. Spatial distribution of carbon storage from 2000 to 2020 in Beijing.

Figure 4 shows that the spatial distribution of carbon storage in Beijing has changed significantly in local areas between the period 2000 and 2020. Furthermore, the area where the northwestern protective forests are located had the highest degree of degradation in carbon sequestration capacity, with approximately 831.87 t/km^2 of carbon storage per unit of land area; whereas the second green belt in the central plain area had the highest increase in carbon sequestration capacity. The spatial and temporal distribution of carbon storage and changes in carbon storage are highly consistent with changes in land use types.

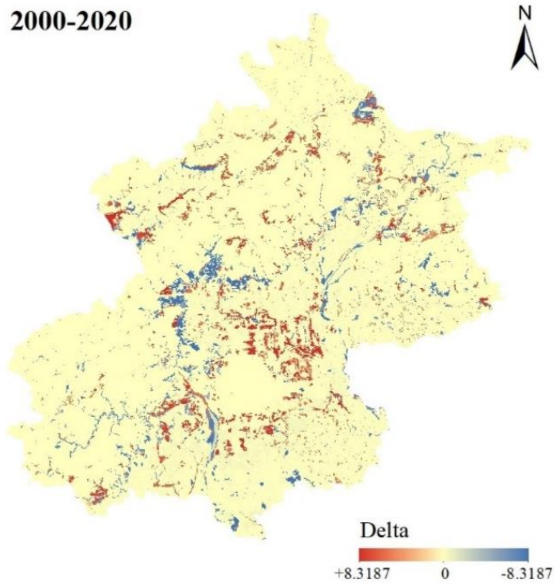

Figure 4. Change of carbon storage between 2000 to 2020.

3.3.2 Spatial and temporal changes in habitat quality: According to the calculated data output from the InVEST model, from 2000 to 2020, the overall habitat quality in Beijing is mostly of good quality and above, but the overall habitat quality in Beijing shows a slightly decreasing trend. Further, in 2000, 2010 and 2020, the overall habitat quality index in Beijing has decreased from 0.71 to 0.61.

Based on the spatial distribution of habitat quality output from the InVEST model, the natural breakpoint method was used to classify the output habitat quality into five classes: lower-quality, low-quality, medium-quality, high-quality and higher-quality, and the spatial distribution of habitat quality in Beijing for the three periods was obtained (Figure 5). The analysis shows that the overall spatial distribution of habitat quality in Beijing has not changed considerably during the period 2000–2020, with only local areas changing significantly. The areas with high habitat quality scores were located in the river corridors, such as the Yongding River, Chaobai River and Dashi River, while the areas with low habitat quality scores were mainly in the central part of the Beijing Plain.

From 2000 to 2010, the classified areas of high-quality and higher-quality habitats decreased by 17.9 km^2 and 31.7 km^2, respectively, whereas the area of lower-quality habitats increased, and their spatial distribution expanded. This indicates that the quality of habitats in Beijing was degraded over the last decade, with most of the key areas of habitat degradation concentrated in the western and northern mountainous areas, mainly the local segments of Yongding River and Chaobai River, the Miyun Reservoir area and the plain-mountainous border area in Changping District. Furthermore, from 2010 to 2020, the area of high-quality habitat increased by 23.43 km^2, and the area of higher-quality habitat decreased by 138.95 km^2. The total area of low and lower-quality habitat decreased by 21.87 km^2, indicating that the quality of habitat in some areas of Beijing had improved. The quality of habitats had improved, with the most noticeable improvements occurring primarily in the plain areas of Miyun Reservoir and Yanqing, where the classification of low and lower quality has been upgraded to higher and higher quality. The habitat quality is deteriorating in most areas, with the degraded areas primarily located in the plain-mountain border in Changping and Haidian and in Tongzhou in the southeastern plain of Beijing. There has been a slight increase in areas of medium-quality habitat, with the most pronounced areas being located in the second green belt in Beijing.

4. CONCLUSIONS

4.1 Spatial and temporal distribution and changes in ecosystem support services

According to the results of the above study, there is a high degree of overlap in the spatial distribution of areas with high carbon stocks and high habitat quality within Beijing. In particular, the northern and western mountainous areas of Beijing are areas with high carbon stocks and high habitat quality, where the main land uses are woodlands and grasslands. The central and southeastern plains are areas where low carbon stocks and low habitat quality are concentrated, with construction land and arable land being the main types of land uses.

4.2 Analysis of the drivers of change in ecosystem support services

Despite a series of initiatives to promote green development in Beijing since 2000, the results of the above study show that its ecosystem support services continue to show an overall degradation trend over the period 2000–2020.

Land use change should be the main influencing factor of carbon storage function (Ke and Tang, 2019; Liu et al., 2021; Bai et al., 2018). The carbon sequestration capacity of each land use type per unit area is in descending order: forest land, wetland, grassland, arable land, urban and rural construction land, unused land and water. Moreover, since the last century, Beijing has implemented a series of measures to increase forest lands, such as the construction of the first green belt and the second green belt, the construction of protective forests in 2000, and the million mu of plains reforestation projects since 2012, which have all increased the area of forest land in Beijing. Additionally, the rapid expansion of urban and rural land use in Beijing has encroached on the arable land and grassland around the city, resulting in the degradation of grassland and a significant reduction in the area of arable land. Therefore, increasing the area of forest land alone is not enough to maintain the carbon sequestration capacity of Beijing''s ecosystem. It is crucial to control the further expansion of urban and rural land use, achieve intensive land use and practice high-quality development.

Furthermore, according to the principles of the InVEST model, habitat quality is influenced by both habitat suitability and threat sources. The IIC and PC indices show a general downward trend between 2000 and 2020, representing a deepening fragmentation of the overall habitat in Beijing, while the MSPA results indicate

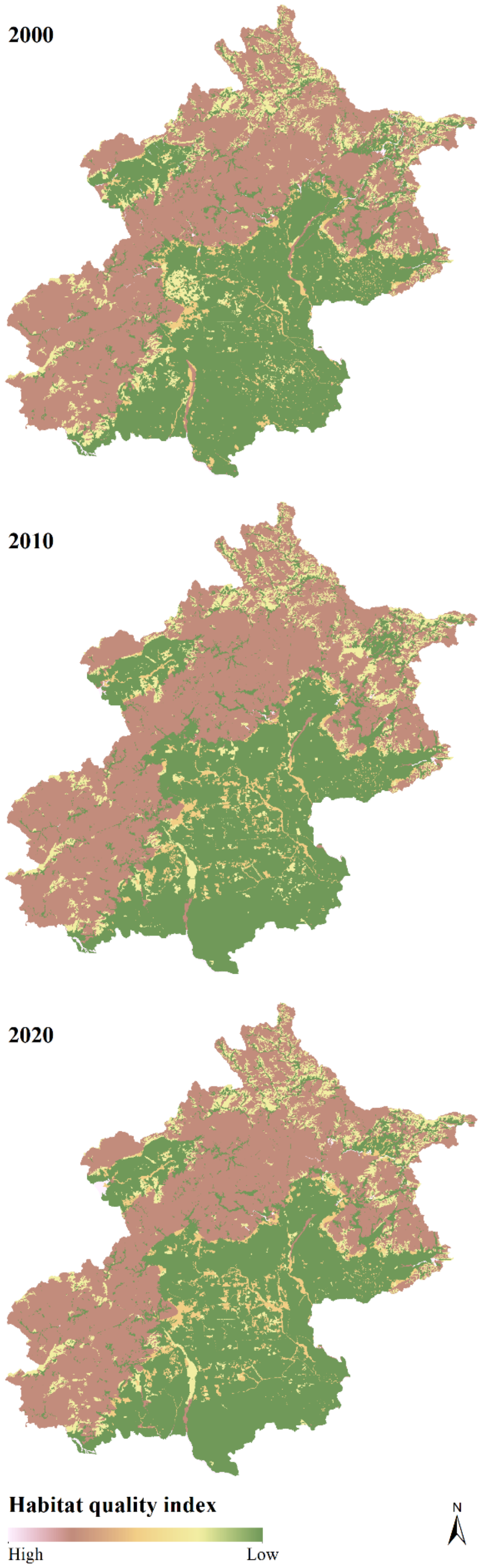

Figure 5. Spatial distribution of habitat quality from 2000 to 2020 in Beijing.

a high degree of connectivity in the mountainous areas of Beijing and a more fragmented landscape in the plains. The MSPA results indicate that the mountainous areas of Beijing have a high degree of connectivity, while the plains show a more fragmented distribution. In particular, the expansion of urban land in the plains of Beijing has led to the encroachment of some of the lower-quality habitats in this area, which has led to further degradation, particularly in Tongzhou. Simultaneously, the construction of the second green belt in Beijing has been effective in recent years, maintaining the area in which the second green belt is located at a medium habitat quality in the context of the expanding urban centre. Figure X shows that the highest habitat quality in Beijing is found in the wetlands around the Miyun Reservoir, the Huairou Reservoir, the Guanxiao Reservoir, the Danma River and the Haizi Reservoir, which are located in the suburbs, while the waters in the central plain of the city show only moderate or even low habitat quality, which leads to the assumption that in areas with higher connectivity, the landscape has higher habitat quality and is more resilient to threats. It can be assumed that in areas of higher connectivity, the landscape is of higher habitat quality and more resilient to threats.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (No. 41901220), and Youth Backbone Individual Program of Beijing Excellent Talents Training Project.

REFERENCES

Bai Y., Zheng H., Zhuang, C.W., Ouyang, Z.Y., Xu, W.H., 2013: Ecosystem services valuation and its regulation in Baiyangdian baisn: Based on InVEST model. *Acta Ecologica Sinica*, 33(3), 0711-0717.

Du, Z.B., Li, H.Y., Meng, W.Q., 2019: Distance thresholds of wetland landscape connectivity in Tianjin Binhai New Area. *Acta Ecologica Sinica*, 39(17), 6534-6544.

Goldstein, J.H., Caldarone G., Duarte, T.K., et al., 2012: Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences*, 109(19), 7565-7570.

Ke, X.L., Tang, L.P., 2019: Impact of cascading processes of urban expansion and cropland reclamation on the ecosystem of a carbon storage service in Hubei Province, China. *Acta Ecologica Sinica*, 39(2), 672-683.

Kong, X.B., Hu, Y.J., Li Y., et al., 2019: Distribution and influencing factors of soil organic carbon of cultivated land topsoil in Beijing. *Resources Science*, 41(12), 2307-2315.

Li, J.P., Xia, S.X., Yu X.B., et al., 2020: Evaluation of carbon storage on terrestrial ecosystem in Hebei province based on InVEST model. *Journal of Ecology and Rural Environment*, 36(7) , 854 − 861.

Li, Y.F., Luo, Y.C., Liu G., Ouyang, Z.Y., Zheng H., 2013: Effects of Land Use change on ecosystem services, a case study in Miyun reservoir watershed. *Acta Ecologica Sinica*, 33(3), 0726-0736.

Liu, H.Y., Xiao, W.F., Li Q., et al., 2021: Spatiotemporal variations and trade-offs of ecosystem services in Beijing. *Chinese Journal of Ecology*, 40(1),209-219.

Qi K., Fan, Z.Q., 2016: Evaluation method for landscape connectivity based on graph theory: a case study of natural forests in Minqing County, Fujian Province. *Acta Ecologica Sinica*, 36(23), 7580-7593.

Shi H., Xu, Y.N., 2011: Research on planning method of urban green space core region based on landscape connectivity. *Journal of Nanjing Forestry University (Natural Sciences Edition)*, 35(1), 51-56.

Xi, X.H., Li M., Zhang, X.Z., et al., 2013: Research on soil organic carbon distribution and change trend in middle-east plain and its vicinity in China. *Earth Science Frontiers*, 20(1),154-165.

Xie, H.W., Zhou, N.X., Guan J., 2014: The construction and optimization of ecological networks based on natural heritage sites in Jiangsu Province. *Acta Ecologica Sinica*, 34(22), 6692-6700.

Xu L., Yu G., He N., 2019: Increased soil organic carbon storage in Chinese terrestrial ecosystems from the 1980s to the 2010s. *Journal of Geographical Sciences*, 29(1), 49-66.

Yang, Z.G., Zhou B., Yu, X.X., et al., 2012: Biodiversity analysis and carbon storage assessments in Beijing mountainous areas. *Bulletin of Soil and Water Conservation*, 32(3), 42-46.

Yu, K.J., Wang, S.S., Li, D.H., et al., 2010: Ecological baseline for Beijing's urban sprawl: Basic ecosystem services and their security patterns. *City Plan. Rev*, 34, 19-24.

Zhang, M.M., Wu, X.Q., 2018: Changes in hydrological connectivity and spatial morphology of Baiyangdian wetland over the last 20 years. *Acta Ecologica Sinica*, 38(12), 4205-4213.