RESEARCH ON THE CHANGE OF ECOSYSTEM SERVICES AND THEIR TRADE-OFF IN URBANIZATION AREA

FAN, Q. D.[*] – YANG, X. Y. – LI, H.

School of Architecture, North China University of Water Resources and Electric Power, Zhengzhou, Henan 450046, PR China

*Corresponding author
e-mail: fanqindong@126.com

Abstract. Rapid urbanization causes changes in regional ecosystem services and has an impact on human well-being. Understanding the changes and trade-offs of ecosystem services in urbanized areas is very important to improve the overall benefits of ecosystem services and maintain regional ecological security. Taking the urbanized area between Zhengzhou City and Kaifeng City in Henan Province, China as an example, the changes in ecosystem services and their trade-offs during the "2005-2010-2015" years were analyzed. The results show that in the process of urbanization, the four selected ecosystem services are in a declining state; The relationship between ecosystem services shows obvious dynamic changes. The traditional method of using a single time period or a time node to study trade-offs is often misjudged, and the research on continuous multi-time series should be strengthened in the future.
Keywords: *landscape pattern, evaluation, carbon sequestration, habitat quality, landscape aesthetics, grain yield*

Introduction

Urbanization brings agglomeration effect, which can effectively promote the comprehensive development of economy, society and culture (Ouyang et al., 2021; Asgarian et al., 2015). At the same time, in the process of urbanization, a large number of natural and semi-natural land has been transformed into construction land, and the land use type has changed significantly (Vahmani et al., 2016). Substance-recycling and energy-flowing of the ecosystem on the surface are strongly disturbed, and the process of the ecosystem cannot be completed, resulting in a serious impact on the service supply of the ecosystem (Smiraglia et al., 2016).

Ecosystem services are all material products and services obtained by human beings from the ecosystem, which are divided into provision services, regulation services, cultural services and support services (Millennium Ecosystem Assessment, 2005; Redhead et al., 2018). Urbanization leads to landscape fragmentation, reduction of natural and semi-natural habitats, etc. A large number of originally synergistic and competitive relationships among ecosystem services are transformed into trade-off relationships, resulting in a continuous decline in the overall supply of ecosystem services in urbanized areas (Ramyar et al., 2020). Urbanization is the most important factor affecting the change of landscape surface pattern in recent decades, and it is also the human behavior that has the greatest impact on ecosystem services (Moein et al., 2018). Ecosystem is facing increasing urbanization pressure. Exploring the impact of urbanization on ecosystem services has become the focus of global change research (Taylor and Hochuli, 2015; Augustynczik and Yousefpour, 2021).

The research on the impact of urbanization on ecosystem services mainly involves the quantitative evaluation (Yang, 2015), spatio-temporal change and simulation (Li et al.,

2020), driving force analysis (Ndong et al., 2020) of ecosystem services and its impact on human well-being (Yang et al., 2021; Xiao et al., 2021). Ecosystem service assessment is the most studied aspect. The initial research methods are equivalent factor method, market value method, shadow engineering method, opportunity cost method, willingness to pay method and so on. With the advancement of research, model evaluation combined with ecosystem service mechanism has gradually become the mainstream (Torres et al., 2021). Common evaluation models include ARIES (Artificial Intelligence for Ecosystem Services) (Villa et al., 2014; Bagstad, 2011), SoLVES (Social Values for Ecosystem Services) (Estoque and Murayama, 2016; Sherrouse et al., 2014) and InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) (Tallis and Polasky, 2009; Sharp et al., 2014).

The overall research moves from static ecosystem service assessment to dynamic spatio-temporal analysis and scenario simulation (Li et al., 2020). In terms of urbanization, relevant research has moved from the impact theory of urbanization on ecosystem services to the management and regulation of ecosystem services in the process of urbanization (Liang et al., 2021). Direct or indirect adoption of landscape measures (such as ecological process control, scale adjustment, spatial planning, policy intervention, etc.) has become the mainstream of ecosystem service management. However, due to the correlation between most ecosystem services, ecosystem service management without "trade-offs" often leads to another negative ecological result (Xu et al., 2018). In the process of urbanization, the trade-off of ecosystem services has become an important aspect of research (Zheng et al., 2019). However, in the current research, the trade-off determination is mostly concentrated in a single period or a time period, and there is a lack of long-term uninterrupted serial research. Moreover, there is a lack of specific mechanistic explanations between the assessment of ecosystem services and the determination of trade-offs.

Taking the urbanization area between Zhengzhou City and Kaifeng City in Henan Province, China as an example, the changes of four ecosystem services including carbon sequestration services, habitat quality, landscape aesthetics, and grain yield under the background of urbanization in 2005, 2010 and 2015 were analyzed. Then, the trade-off relationships between the four ecosystem services were determined.

Trying to explain the reasons for the trade-off relationship from the mechanism, and discussing the importance of multi-period trade-off research. It is of great significance to strengthen the accuracy of trade-off studies.

Materials and methods

Study area

The study area is the core area of the integrated development of Zhengzhou city and Kaifeng city in Henan Province, China. Since 2015, with the urban development strategy of Zhengzhou to the East and Kaifeng to the west, as well as the implementation of regional plans such as "Zheng Bian Integration" and "Zheng Bian Industrial Belt Planning", the original agricultural landscape of the study area has been strongly disturbed and ecosystem services have changed greatly.

The study area is located in the east of Zhengzhou and the west of Kaifeng. It starts from Zhengzhou section of Beijing Hong Kong Macao Expressway in the west, Jinming Road in Kaifeng in the East, Lianhuo Expressway in the north and national highway 310 in the south. The geographical location is between 34°72′- 34°85′N and 113°81′- 114°30′E, with a total area of about 47314 hm^2. The details are shown in *Figure 1*.
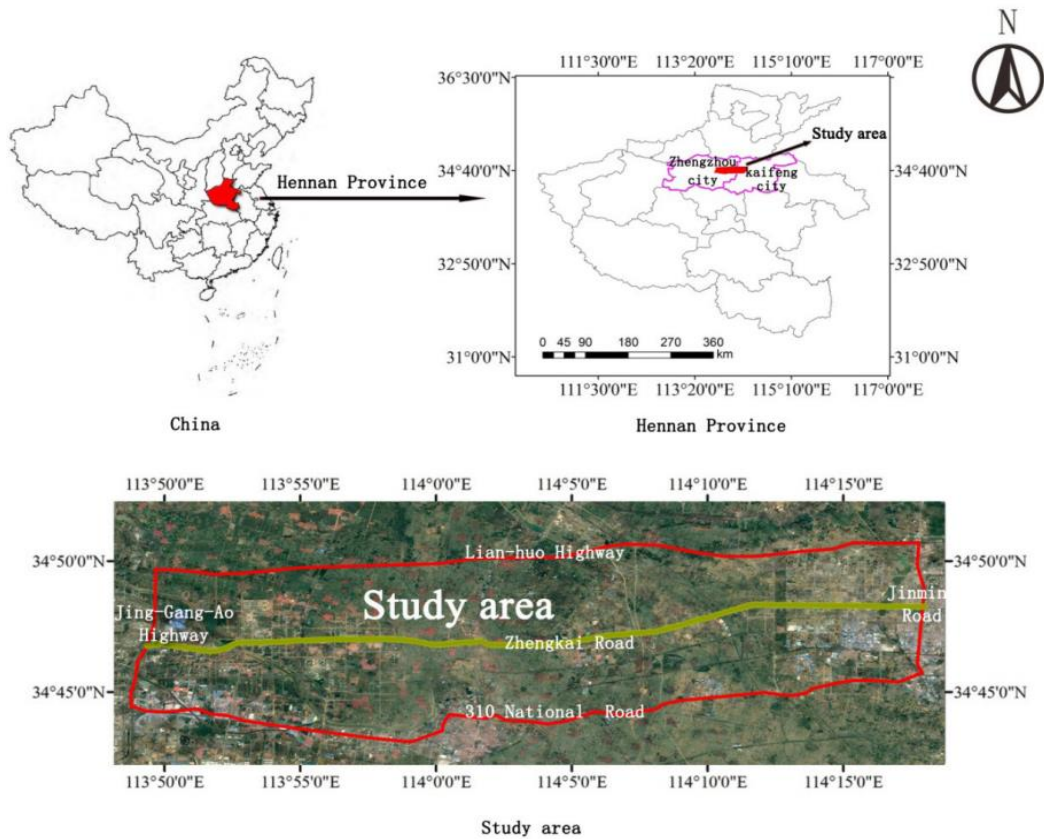
Figure 1. *Location and the study area*

Data sources

The image data are come from the geospatial cloud data platform. Three time periods of the study area in May 2005, 2010 and 2015 were obtained and processed. On the basis of the previous investigation, the landscape elements in the study area are divided into five types (farmland, forest land, water area, construction land, and unused land) by visual interpretation. The image data of the study area were processed by GIS 10.0 to obtain the landscape pattern data of the study area in three periods. According to the previous research results (Fan et al., 2018), it is determined that the best analysis grain size of landscape pattern in the study area is 20 m × 20 m.

The grain yield and area data in Henan Province mainly comes from the Henan Provincial Statistical Yearbook, National Agricultural Product Cost and Benefit Data Compilation, Zhongmu County Statistical Yearbook and other related materials.

Data related to carbon storage are mainly from local forestry departments. Part of the data comes from previous scholars' research in this region, and has been revised based on the climatic conditions of the study year (Huang et al., 2014, 2006; Guang, 2007; Chen et al., 2007; Peng et al., 2013).

Ecosystem services assessment methods

Carbon sequestration service

Carbon sequestration services are evaluated using the Carbon Model module in the InVEST model. The formula is shown in *Equation 1:*

$$C\_stored=C\_above+C\_below+C\_soil+C\_dead \tag{Eq.1}$$

where C_stored is the total carbon storage; C_above is the above-ground material carbon storage (t/hm2); C_below is the underground material carbon storage (t/hm2); C_soil is the soil carbon storage (t/hm2); C_dead is the litter carbon storage (t/hm2).

Habitat quality assessment

The Habitat Quality module in the InVEST model was used to evaluate the habitat quality of the study area. The formula is as follows (*Eq. 2*):

$$Q_{xj}=H_j-H_j\times\frac{D_{xj}^z}{D_{xj}^z+k^z} \tag{Eq.2}$$

where Q_{xj} is the habitat quality of grid X in land use type J; D_{xj} is the stress level of grid X in land use type J; K is the semi-saturation constant, usually half of the maximum value of D_{xj}; Hj is the habitat suitability of habitat J in land use type. When habitat is studied only from a macro perspective without involving species, the Hj value is often defined by dichotomy; Z is the normalization constant, generally 2.5. The dxj calculation is shown in *Equation 3*:

$$D_{xj}=\sum_{r=1}^{R}\sum_{y=1}^{y_r}\left(\frac{W_r}{\sum_{r=1}^{R}W_r}\right)r_y i_{rxy}\beta_x S_{jr} \tag{Eq.3}$$

In the formula, R is the habitat stress factor; y is the grid number of the habitat stress factor r grid layer; Yr is the number of grids occupied by the habitat stress factor; Wr is the weight of the stress factor, indicating that a certain stress factor affects all habitats. The relative damage degree of r is 0-1; ry is the stress factor value of grid y (0 or 1); irxy is the stress factor value of grid y and the stress level of ry to habitat grid x; βx is accessibility level of grid x, and the value 0-1, 1 means extremely easy to reach; Sjr is the sensitivity of the habitat type j to the stress factor r, and the value is 0-1, the closer the value is to 1, the more sensitive it is. irxy can be obtained by *Equation 4*:

$$i_{rxy}=1-\frac{d_{xy}}{d_{rmax}} \tag{Eq.4}$$

In the formula, dxy is the straight-line distance between grid x and grid y; drmax is the maximum influence distance of stress factor r.

Landscape aesthetics

Landscape aesthetics is evaluated by the expert knowledge-based ecosystem service value assessment method constructed by Xie et al. (2015). This is a dynamic equivalent factor method for the evaluation of ecosystem services in China, which has been verified and recognized in many regions of China (Fan, 2016). The equivalent factor method is a dynamic equivalent data accounting based on the sowing area and net profit of local main agricultural products in the current year. The calculation is shown in *Equation 5*:

$$D=S_r\times F_r+S_w\times F_w+S_c\times F_c \tag{Eq.5}$$

where d represents the ecosystem service value of one standard equivalent (yuan/hm²); Sr, SW and SC respectively represent the percentage of the sown area of rice, wheat and corn in the total sown area of the three crops in the study year; FR, FW and FC respectively represent the national average net profit per unit area of rice, wheat and corn in the study year (yuan/hm²).

After the D value is obtained, combined with different land use types, the value equivalent of each land use type can be calculated. Then multiply the area of the land use type to get the landscape aesthetic value of the land use type.

Grain yield

It is calculated based on the unit area yield and planting area of grain crops in the study year.

Result

Carbon sequestration services

The four carbon pool values and landscape pattern data in the study area were input into the InVEST model to calculate the carbon sequestration service distribution map in three periods (*Fig. 2*).
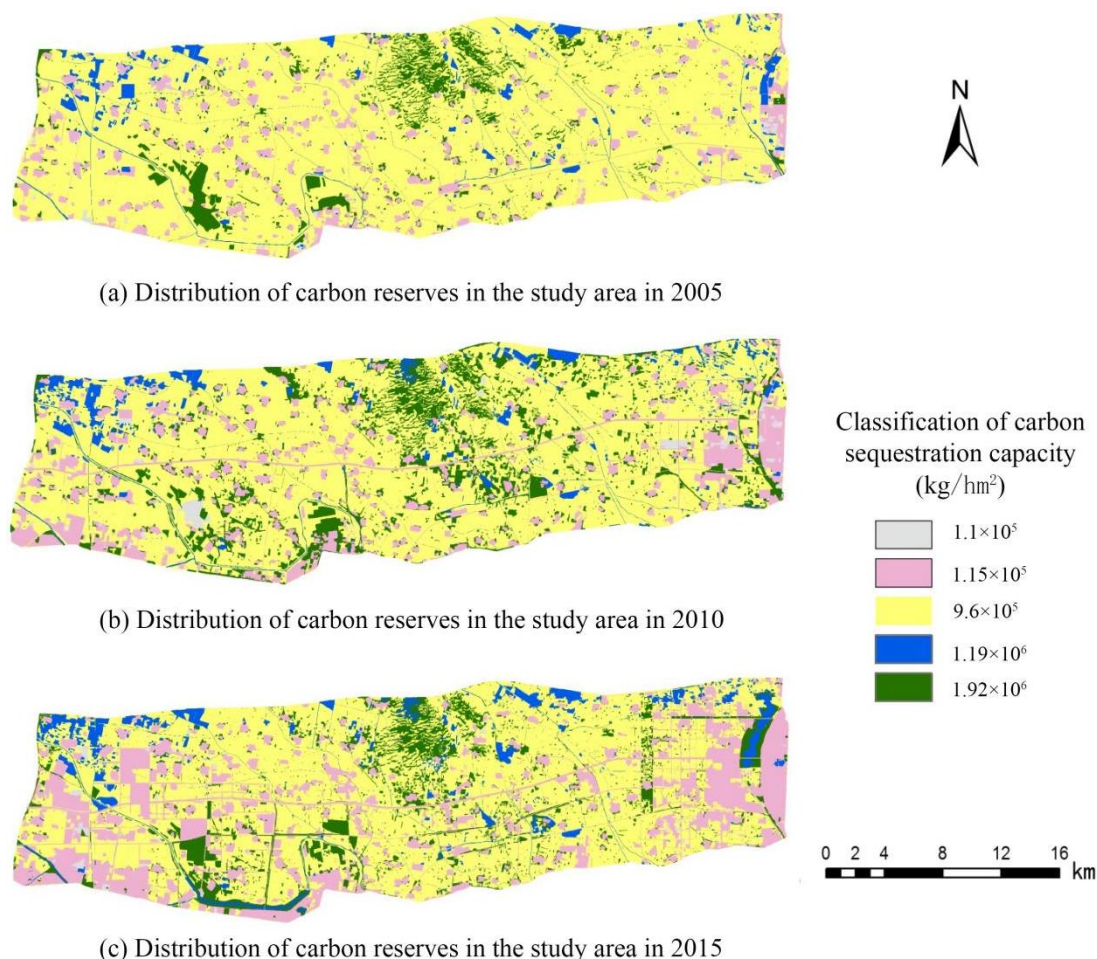

(a) Distribution of carbon reserves in the study area in 2005

(b) Distribution of carbon reserves in the study area in 2010

(c) Distribution of carbon reserves in the study area in 2015

Figure 2. *Distribution of carbon storage per unit area in the study area in 2005, 2010 and 2015*

Subsequently, using the spatial statistical tool of ArcGIS 10.0, the carbon storage in the three periods of the study area was summarized and mapped in *Figure 3*.
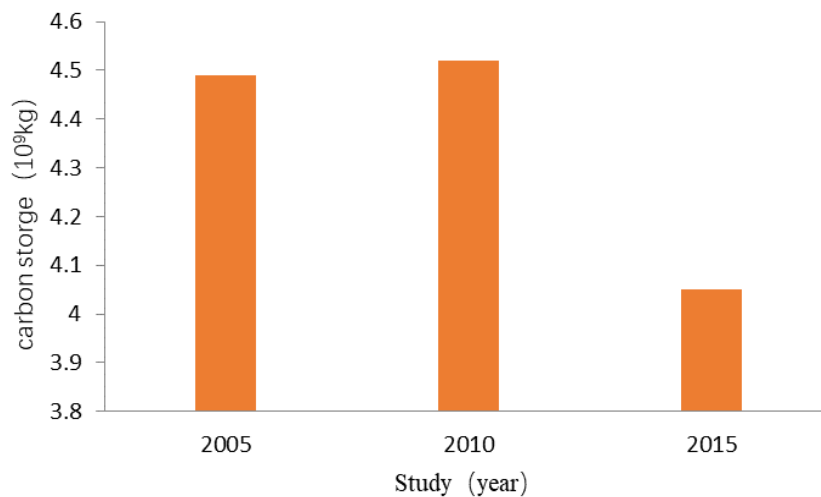

Figure 3. *Changes in carbon storage in the study area from 2005 to 2015*

The overall carbon storage in the study area is in a downward trend, from 2005 to 2015, it decreased by about 3.9×108 kg. In 2010, it fluctuated slightly, reaching 4.52×109 kg, which was 3×107 kg higher than that in 2005. The carbon storage in the study area is in a trend of rising first and then falling ($\uparrow$, $\downarrow$).

Habitat quality assessment

The 20 m × 20 m landscape pattern data, threat factor layer data, threat factor attribute table and the sensitivity attribute table data of different landscape types to threat factors in the three periods of the study area are input into the Habitat Quality module in the InVEST model for calculation, and evaluation results of habitat quality is obtained. Then, the habitat quality of the three periods of 2005, 2010 and 2015 is divided into three intervals from low to high under the GIS platform: poor (0-0.2), medium (0.21-0.55), and good (0.56-0.9). The details are shown in *Figure 4*.

The closer the habitat value is to 1, the higher the habitat quality, and the closer the habitat value is to 0, the worse the habitat quality. It can be seen from the above three figures that the areas with poor habitats in the study area are generally dominated by construction land, while the areas with good habitats are dominated by forest land and water areas, and the habitat quality of farmland is between construction land and forest land. The area proportion comparisons of different habitat qualities in the study area in 2005, 2010 and 2015 are shown in *Figure 5*. According to *Figure 5*, it can be concluded that the overall habitat quality in 2005 > the overall habitat quality in 2010 > the overall habitat quality in 2015. Therefore, the change trend of habitat quality is ($\downarrow$, $\downarrow$).

Landscape aesthetic evaluation

According to the method described above and the relevant data of the study area, the aesthetic value of the study area in the three periods was obtained (*Table 1*). According to *Table 1,* the landscape aesthetic value of the study area increases first and then decreases ($\uparrow$, $\downarrow$).

Grain yield evaluation

According to the data of crop yield and area in the study area, the grain production value in the study area is obtained (*Table 2*). According to *Table 2*, it can be concluded that the grain yield in the study area is in a downward trend (↓, ↓).
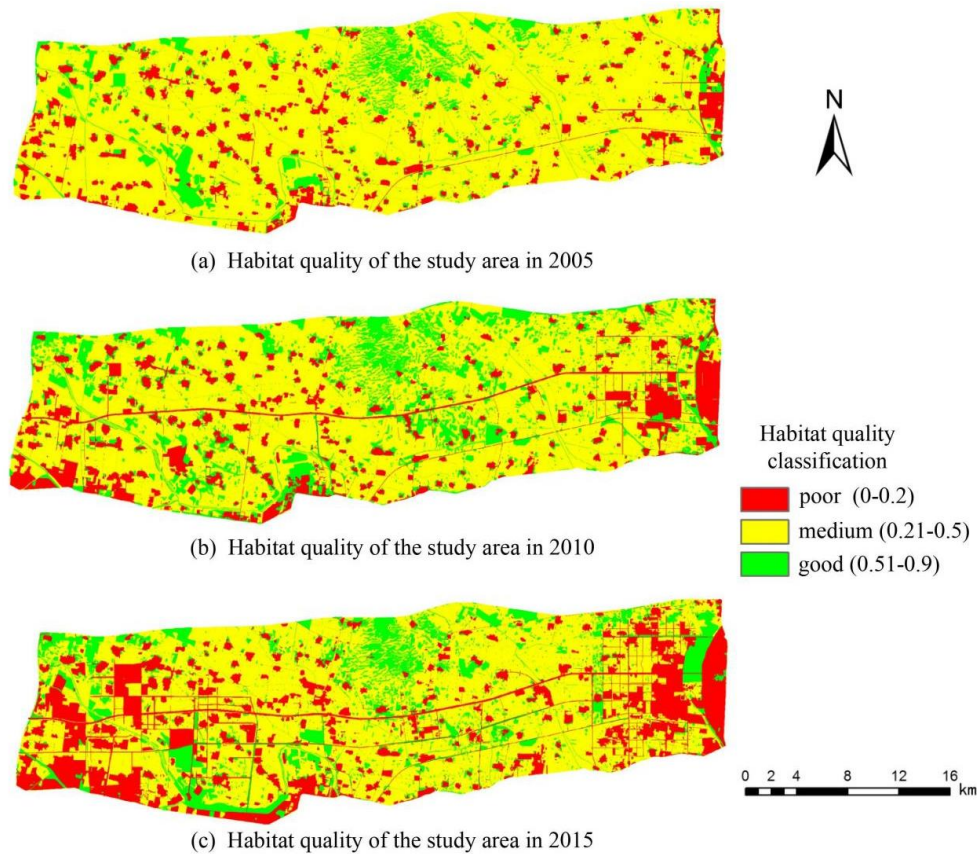

(a) Habitat quality of the study area in 2005

(b) Habitat quality of the study area in 2010

Habitat quality classification
- poor (0-0.2)
- medium (0.21-0.5)
- good (0.51-0.9)

(c) Habitat quality of the study area in 2015

Figure 4. Distribution of habitat quality in the study area in 2005, 2010 and 2015

(a) Proportion of different habitat quality areas in 2005 and 2010

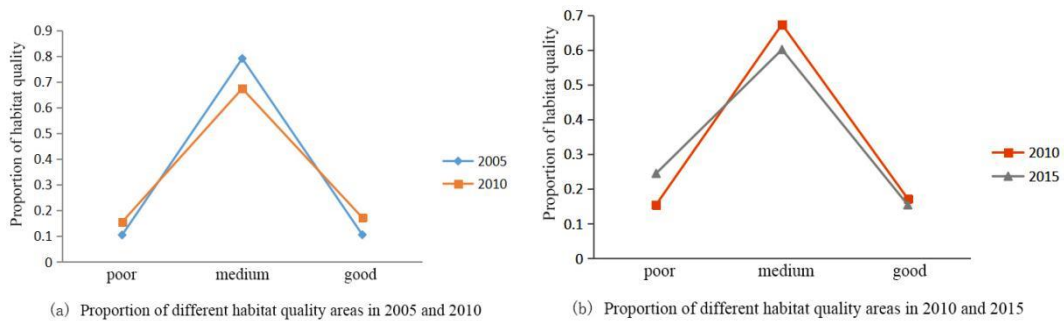(b) Proportion of different habitat quality areas in 2010 and 2015

Figure 5. Comparison of different habitat quality areas in different periods

Table 1. Aesthetic value of the study area in different periods (RMB: yuan)

Year	2005	2010	2015
Total	$3.79*10^7$	$4.25*10^7$	$2.42*10^7$

Table 2. The grain production value of the three periods in the study area

Year	2005	2010	2015
Total output (kg)	1.91×108	1.88×108	1.69×108

Overall trade-off relationship of four ecosystem services

Combined with 3.1-3.4, the change trend of four types of ecosystem services is tabulated (*Table 3*).

Table 3. Change trend of four types of ecosystem services

Types of ecosystem services	Trend from 2005 to 2010	Trend from 2010 to 2015
Carbon sequestration services	↑	↓
Grain production	↓	↓
Habitat quality	↓	↓
Landscape aesthetics	↑	↓

As shown in *Table 3,* the relationship between any two ecosystem services in the same period can be obtained. But the relationship between them may be inconsistent at different periods. For example, carbon sequestration services and food production showed a trade-off relationship from 2005 to 2010, but a synergistic relationship from 2010 to 2015. Therefore, studying the relationship of ecosystem services in a short period is likely to lead to misjudgment results. Looking at the entire time period 2005-2020 and 2010-2015, carbon sequestration services (↑, ↓) and aesthetic landscape (↑, ↓) show a synergistic relationship, as well as the relationship between food production (↓, ↓) and habitat quality (↓, ↓).

Discussion

Research period of ecosystem service trade-offs

At present, the research on ecosystem service trade-off is mainly based on spatial distribution mapping and correlation analysis (Deng et al., 2020), and the research is mostly concentrated in a single period or between two periods. There are few studies on three or more consecutive periods (Yin et al., 2019; Wang et al., 2020). This study found that the trade-off study in a single period may misjudge the relationship between ecosystem services. Therefore, strengthening multi period research is helpful to improve the scientificity of research.

Determination of research methods on trade-offs

There are many previous studies on trade-offs. Almost all studies first evaluate ecosystem services, and then make trade-offs according to the changes of results (Li et al., 2021). There are many evaluation methods of ecosystem services. Different evaluation methods often get different evaluation results of ecosystem services, so the accuracy of trade-off judgment is also affected. In addition, the traditional research does not analyze the relationship between different ecosystem service assessment methods, which is also the limitation of the current research.

Take the carbon sequestration service and landscape aesthetics studied in this paper as an example. The carbon module in the InVEST model is used for valuing carbon sequestration service. The calculation method of carbon reserves in the study area can be simplified as: area of different landscape elements × Carbon reserves per unit area, and then sum; The aesthetic landscape value is evaluated by dynamic equivalent method, which can also be simplified as: the area of different landscape elements × The value equivalent per unit area is then summed.

These two ecosystem services have a relatively consistent calculation method: the area of different landscape elements × the ecological value service per unit area, and then summed. In terms of calculation principle, these two ecosystem services have relatively consistent calculation methods. At the same time, in the process of urbanization, the change area of landscape elements they contain is also the same, so carbon sequestration services and landscape aesthetics show a synergistic relationship.

In fact, the ecosystem service assessment method is the determinant of the trade-off relationship and the basis for explaining the trade-off of ecosystem services. Therefore, a scientific method of ecosystem services assessment is a prerequisite for trade-off studies.

Conclusion

Through the research on the changes of ecosystem services in the process of urbanization in the study area in 2005-2010-2015, some obvious conclusions and suggestions for future research are as follows:

Main conclusions

Ecosystem services are greatly affected by urbanization

The four ecosystem services in this study are selected from supply service, support service, regulation service and cultural service. They have all undergone significant changes in the process of urbanization and are obviously representative. In addition, a large number of ecosystem services exist on the surface landscape as a carrier, and urbanization drives changes in landscape patterns, which will inevitably lead to a large number of changes in ecosystem services.

Ecosystem services research only in a single period may misjudge the trade-off relationship between them

For example, in this study, carbon sequestration services and food production showed a trade-off relationship in 2005-2010, and a synergistic relationship in 2010-2015. Analysis of a single time period will misjudge their relationship.

The scientificity of ecosystem services assessment directly affects the accuracy of trade-offs

From the trade-off study of four ecosystem services in this paper, it can be seen that the evaluation method of ecosystem services has obvious explanatory power for the trade-off judgment between them. Inconsistent ecosystem service assessment methods may lead to different trade-off results. Therefore, a scientific ecosystem service assessment method involving mechanism is very important for trade-off research.

Main recommendations

Ecosystem services research needs to choose research methods derived from ecosystem mechanisms

Evaluating ecosystem service trade-offs requires quantifying different ecosystem services. However, there are many evaluation methods for the same ecosystem service, and the evaluation methods for different ecosystem services are also different. Different methods will lead to different results. Therefore, scientific evaluation methods which were selected from the ecosystem mechanism, can ensure the accuracy of the research.

Accurate trade-off law research needs continuous and long-time data support

Due to the dynamicity of ecosystem services, the trade-offs between them will inevitably change. Short time trade-off performance cannot represent the accurate trade-off law. In future research, it is necessary to add long-time series data to ensure the accuracy of research results.

REFERENCES

[1]   Asgarian, A., Amiri, B. J., Sakieh, Y. (2015): Assessing the effect of green cover spatial patterns on urban land surface temperature using landscape metrics approach. – Urban Ecosystems 18(1): 209-222.

[2]   Augustynczik, A., Yousefpour, R. (2021): Assessing the synergistic value of ecosystem services in European beech forests. – Ecosystem Services 49: 101264.

[3]   Bagstad, K. J., Villa, F., Johnson, G., Voigt, B. (2011): ARIES – Artificial Intelligence for Ecosystem Services: A Guide to Models and Data, Version 1.0 Beta. – The ARIES Consortium, Bilbao, Spain.

[4]   Chen, G. S., Yang, Y. S., Liu, L. Z., Li, X. B., Zhao, Y. C., Yuan, Y. D. (2007): Research review on total belowground carbon allocation in forest ecosystems. – Journal of Subtropical Resources and Environment 2(1): 34-42.

[5]   Deng, C. X., Zhu, D. M., Nie, X. D., Liu, C. C., Li, Z. W., Liu, J. Y., Zhang, G. Y., Xiao, L. H., Zhang, Y. T. (2020): Progress of research regarding the trade-offs of ecosystem services. – Chinese Journal of Eco-Agriculture 28(10): 1509-1522.

[6]   Estoque, R. C., Murayama, Y. (2016): Quantifying landscape pattern and ecosystem service value changes in four rapidly urbanizing hill stations of Southeast Asia. – Landscape Ecology 31(7): 1481-1507.

[7]   Fan, Q. D. (2016): Response of Ecosystem Service to the Core Area of Zhengzhou & Kaifeng Integration. – Henan University, Henan.

[8]   Fan, Q. D., Liang, Z. Z., Liang, L. K., Ding, S. Y., Zhang, X. P. (2018): Landscape pattern analysis based on optimal grain size in the core of the Zhengzhou and Kaifeng integration area. – Polish Journal of Environmental Studies 27(3).

[9]   Guang, Z. Y. (2007): Study on forest biomass carbon storage in Henan Province. – Areal Research and Development 1: 76-79.

[10]   Huang, M., Ji, J. J., Cao, M. K., Li, K. R. (2006): Modeling study of vegetation shoot and root biomass in China. – Acta Ecologica Sinica 12: 4156-4163.

[11] Huang, C. H., Yang, J., Zhang, W. J. (2014): The application of forest inventory data in an ecosystem service evaluation model: InVEST. – Forest Resources Management 05: 126-131.

[12] Li, L., Wu, D. F., Wang, F., Liu, Y. Y., Liu, Y. H., Qian, L. X. (2020): Prediction and trade off analysis of ecosystem service value in the rapidly urbanizing Foshan City of China: a case study. – Acta Ecologica Sinica 40(24): 9023-9036.

[13] Li, D. H., Zhang, X. Y., Wang, Y., Zhang, X., Li, L., Lu, L. (2021): Evolution process of ecosystem services and the trade-off synergy in Xin'an River Basin. – Acta Ecologica Sinica 41(17).

[14] Liang, C., Zeng, J., Shen, Z. J., Wang, Q. W. (2021): Spatial pattern analysis and management of urban ecosystem services under rapid urbanization: a case study of Xiamen. – Acta Ecologica Sinica 41(11): 4379-4392.

[15] Millennium Ecosystem Assessment (2005): Ecosystems and Human Well-Being: Biodiversity Synthesis. – Island Press, Washington, DC.

[16] Moein, M., Asgarian, A., Sakieh, Y., Soffianian, A. (2018): Scenario-based analysis of land-use conflict in central Iran: finding the trade-off between urban growth patterns and agricultural productivity. – Sustainable Cities & Society, S221067071731199X.

[17] Ndong, G. O., Therond, O., Cousin, I. (2020): Analysis of relationships between ecosystem services: a generic classification and review of the literature. – Ecosystem Services 43: 101120.

[18] Ouyang, X., Tang, L., Wei, X., Li, Y. (2021): Spatial interaction between urbanization and ecosystem services in Chinese urban agglomerations. – Land Use Policy 109(4): 105587.

[19] Peng, Y., Wang, Y. K., Fu, B., Ma, F. (2013): Spatial distribution of carbon storage function and seismic damage in Wenchuan earthquake stricken areas. – Acta Ecologica Sinica 03: 798-808.

[20] Ramyar, R., Saeedi, S., Bryant, M., Davatgar, A., Hedjri, G. M. (2020): Ecosystem services mapping for green infrastructure planning – The case of Tehran. – Science of the Total Environment 703: 135466.

[21] Redhead, J. W., May, L., Oliver, T. H., Hamel, P., Sharp, R., Bullock, J. M. (2018): National scale evaluation of the InVEST nutrient retention model in the United Kingdom. – Science of the Total Environment 610-611: 666-677.

[22] Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Chaplin-Kramer, R., ... Vogl, A. L. (2014): InVEST user's guide. – The Natural Capital Project: Stanford, CA.

[23] Sherrouse, B. C., Semmens, D. J., Clement, J. M. (2014): An application of social values for ecosystem services (SolVES) to three national forests in Colorado and Wyoming. – Ecological Indicators 36: 68-79.

[24] Smiraglia, D., Ceccarelli, T., Bajocco, S., Salvati, L., Perini, L. (2016): Linking trajectories of land change, land degradation processes and ecosystem services. – Environmental Research 147: 590-600.

[25] Tallis, H., Polasky, S. (2009): Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. – Annals of the New York Academy of Sciences 1162(1): 265-283.

[26] Taylor, L., Hochuli, D. F. (2015): Creating better cities: how biodiversity and ecosystem functioning enhance urban residents' wellbeing. – Urban Ecosystems 18(3): 747-762.

[27] Torres, A. V., Tiwari, C., Atkinson, S. F. (2021): Progress in ecosystem services research: a guide for scholars and practitioners. – Ecosystem Services 49(2): 101267.

[28] Vahmani, P., Sun, F., Hall, A., Ban-Weiss, G. (2016): InVEST igating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California. – Environmental Research Letters 11(12): 124027.

[29] Villa, F., Bagstad, K. J., Voigt, B., Johnson, G. W., Portela, R., Honzák, M., Batker, D. (2014): A methodology for adaptable and robust ecosystem services assessment. – PLoS One 9(3): e91001.

[30] Wang, S. H., Huang, L., Xu, X. L., Xu, S. W. (2020): Spatial and temporal evolution of ecosystem services and its trade-offs and synergies in Guangdong- Hong Kong- Macao Greater Bay Area. – Acta Ecologica Sinica 40(23): 8403-8416.

[31] Xiao, H. B., He, X. Y., Wang, Y., Wang, J. N., Jiang, Q. Z. (2021): Research progress on the correlation between urban green space and residents' physical and mental wellbeing from a perspective of matching ecosystem services supply and demand. – Acta Ecologica Sinica 41(12): 5045-5053.

[32] Xie, G. D., Zhang, C. X., Zhang, L. M., Chen, W. H., Li, S. M. (2015): Improvement of the evaluation method for ecosystem service value based on per unit area. – Journal of Natural Resources 30(08): 1243-1254.

[33] Xu, X. B., Yang, G. S., Tan, Y., Liu, J. P., Hu, H. Z. (2018): Ecosystem services trade-offs and determinants in China's Yangtze River Economic Belt from 2000 to 2015. – Science of the Total Environment 634: 1601-1614.

[34] Yang, W. R. (2015): Spatiotemporal change and driving forces of urban landscape pattern in Beijing. – Acta Ecologica Sinica 35(13): 4357-4366.

[35] Yang, X. T., Qiu, X. P., Xu, Y., Zhu, F. B., Liu, Y. W. (2021): Spatial heterogeneity and dynamic features of the ecosystem services influence on human wellbeing in the West Sichuan Mountain Areas. – Acta Ecologica Sinica 41(19): 7555-7567.

[36] Yin, L. C., Wang, X. F., Zhang, K., Xiao, F. Y., Cheng, C. W., Zhang, X. R. (2019): Trade-offs and synergy between ecosystem services in National Barrier Zone. – Geographical Research 38(09): 2162-2172.

[37] Zheng, H., Wang, L. J., Peng, W. J., Zhang, C. P., Li, C., Robinson, B. E., Wu, X. C., Kong, L. Q., Li, R. N., Xiao, Y., Xu, W. H., Ouyang, Z. Y., Daily, G. C. (2019): Realizing the values of natural capital for inclusive, sustainable development: informing China's new ecological development strategy. – Proceedings of the National Academy of Sciences of the United States of America 116(17): 8623-8628.