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Advances and Prospects in Research of Land Ecosystem Service Value

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Abstract Ecosystem provides supply, regulation, support and cultural services. The value assessment of ecosystem service functions is helpful for people to understand the importance of natural ecosystems to production and life. Through analyzing domestic and foreign research on ecosystem service value, this paper sorted out the research process of value assessment. Based on the assessment process, the existing assessment methods and the introduced model methods were summarized, and the methods and models used by the latest research were classified. According to the weakness of the existing studies, it discussed prospects of future research. It is expected to promote multi-scale and multi-directional research exploration and enrich the theory and method of value assessment.

Key words Land ecosystem service value, Research advances, Prospects

1 Introduction

An ecosystem has extremely high or even immeasurable value and is extremely closely related to human well-being[1]. Although domestic and foreign scholars have carried out extensive research activities on ecosystem service value (ESV), there is still no mature ESV pricing method. From an ecological point of view, the land itself is an ecosystem, and it can be called a land ecosystem[2]. The natural landscape of an area with rapid urbanization development will change greatly, which will lead to the decline of the ecological function of the area, and then a series of studies have been carried out successively. For the research on regional ESV, foreign countries started earlier, and the research content is also relatively rich and comprehensive. In comparison, domestic research started basically after 1997, and the research has also shifted from value research to driving force research. After a series of studies, the research content is very rich in both time and space scales. According to the research findings of domestic and foreign scholars, we divided the accounting methods into two categories: ecological service product price method and value equivalent factor method. We summarized the technical means and model system introduced by the research, and explored the future research direction.

2 Research advances

2.1 Advances in foreign research In 1997, Daily stated that ecosystem services refer to the natural environment conditions and functions that are formed in the ecosystem and ecological process to maintain the survival of human beings[3]. In 1997, Costanza *et al.*[4] assessed the value of global ecosystem services for the first time. Johanna *et al.*[5], Turner *et al.*[6] estimated the ESV of agricultural land. Through research, Firbank *et al.*[7] and Kragt *et al.*[8] found that biodiversity and soil organic matter would affect the ecosystem service value. Capitani *et al.*[9] and Kubiszewski *et al.*[10] set up a variety of development scenarios to simulate land use patterns and assess ecosystem service values. In recent years, many foreign scholars have evaluated the ecosystem service value of a certain area or a certain land use type. Paudyal *et al.*[11], Gashaw *et al.*[12], Davidson *et al.*[13], and Soto *et al.*[14] used analytical models to assess the ecosystem service value of rivers and lakes, wetlands and forests. Some scholars have explored the destruction of the ecological environment in the process of developing production in some regions and countries. Arowolo assessed the ecosystem service value in Nigeria from 2000 to 2010 based on the value transfer method. The total ESV in the study area decreased by 4.83%, and about 70% of Nigeria's ecosystem services were degraded[15].

2.2 Advances in domestic research Basically, after the publication of the research results of Costanza *et al.* in 1997, domestic scholars carried out extensive studies. In addition to conducting research on ESV based on land use and land cover change (LUCC), domestic scholars have carried out research on driving forces, ecological risks and ecological compensation, and some scholars have introduced prediction models to start simulation research. Xiao Han *et al.*[16] and Zong Yueguang *et al.*[17] used engineering method and alternative cost method to estimate forest ESV. Xie Gaodi *et al.* revised the equivalent factor of Costanza *et al.* and constructed an equivalent factor system in line with national conditions[18-19]. Liu Yongqiang *et al.*[20], Xue Minggao *et al.*[21], Li Yuanyuan *et al.*[22] analyzed the response relationship between ecosystem service value and land use change. Chen Wanxu *et al.*[23] and Yan Yan *et al.*[24] assessed the ecosystem service value of river basins by introducing ecological change degree and regression analysis. Using the GWR model, Geng Tianwei *et al.*[25] analyzed the strength of the dominant factors causing ESV changes. Ouyang Xiao *et al.*[26], Wang Peijun *et al.*[27],

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Chu Zhi *et al.*[28], and Chen Bingfei *et al.*[29] used the FLUS model to simulate the impact of land use change on ESV under different situations. Yu Miao *et al.*[30] and Zhang Mufeng *et al.*[31] used the CLUE-S model to estimate the ESV. Zhang Xiaoyao *et al.*[32] and Wang Jinfeng *et al.*[33] used the Markov-CA model to predict the ecosystem service value. Li Hui *et al.*[34] analyzed the correlation between ESV and ecological risk index in the Three Gorges Reservoir area. In recent years, many domestic scholars have studied the future ecosystem service value with the help of geographic prediction models, which have enriched and improved the value assessment theory.

3 Estimation methods and technical means

Based on the different value units, the methods can be divided into the ecological service product price method and the value equivalent factor method. In recent years, in the research of ESV calculation, domestic and foreign scholars have introduced some new technical means and model methods into different assessment methods, and successfully combined these models with ecosystem service value assessment, and have made significant achievements.

3.1 Ecological service product price method The ecological service product price method is based on statistics and market value theory. The ecological service product price method usually adopts the direct market method, the alternative market method and the simulated market method, and the various services provided by the region are reflected in the form of monetary value. The assessment of ecosystem service value based on this method requires a large amount of data and has many assessment calculation steps, but the result of the land value assessment is highly accurate, which is suitable for the research on the ecosystem service value of townships and towns with high precision. If an inappropriate calculation method is selected and some basic data are missing, the assessment results will be not representative. Different methods will be used in the assessment, mainly market method, cost method, shadow price method, substitution method, *etc.* With the development of 3S technology, based on ecological data, the value calculation method is optimized, and the model is constructed based on GIS to reflect the spatial distribution and changes of the assessed value in the region. The InVEST[35] model is relatively mature, and is widely used in ecosystem service value assessment (Table 1).

Table 1 Technical means introduced by the ecological service product price method and its representative achievements

Research methods and technical means	Representative achievements	Research area	Method application
Questionnaire and linear relationship analysis	Wu Gang *et al.*, 2001	Changbai Mountain	Dynamically assessing the functions of forest ecosystems in terms of ESV and product value
Establishing the evaluation indicator system	Zhao Tongqian, *et al.*, 2004	Whole China	Establish the evaluation indicator system, and assessing the ecological economic value based on the service function mechanism through analyzing the forest ecosystem service functions
Functional relationship simulation	Wu Shuang *et al.*, 2014	1 266 forest plots across the country	Establishing the functional relationship between China's forest emergy and service function value based on emergy theory and ecosystem service function theory
Substitution and market pricing methods	Zheng Jiayu *et al.*, 2015	Villages in south Anhui Province	Exploring the ecological value of cultivated land and its changes in the land consolidation area of Shanghai – Anhui Modern Tobacco Agriculture High-tech Demonstration Park
Shadow price method and conditional value method	Chen Cui, *et al.*, 2018	Nanhe National Wetland Park	Dividing 11 ecosystem service values into social human value, ecological process value and future potential value, and estimating each ecosystem service value
Constructing a non-monetary assessment framework for wetland ecosystem service value	Yang Qing *et al.*, 2018	Pearl River Delta city cluster	Using the emergy analysis method to establish a value assessment framework, solve the problem of double counting, and account the wetland ecosystem service value
Environmental value assessment methods	Zhou Xiaoping *et al.*, 2020	Sanxing Town, Jintang County, Chengdu City	Selecting appropriate methods and parameters to measure the value of various ecosystem services
Surrogate market method and replacement cost method	Hao Linhua *et al.*, 2020	Sea area in Wenzhou City	Assessing the value of the regulation services provided by the ecosystem, revealing its spatial distribution rules, and then comparing it with the results of the national standard method assessment
InVEST model	Zhong Juntao *et al.*, 2021	Yanchi County, Ningxia	Calculating changes in grassland ecosystem service value before and after grazing prohibition
Hedonic price-structural equation double model	Tong Lingling *et al.*, 2022	Urban wetland in Xining City	Analyzing the factor data of community sample sites around wetland to assess the service value of urban wetland ecosystems

3.2 Value equivalent factor method The value equivalent factor method fully considers the characteristics of regional ecosystems and then modifies the equivalent factor, so it is suitable for assessing the value of ecosystem services in larger spatial

scales such as provinces, cities and counties. This method is simple to operate, can be widely used, and is easier to combine with statistical prediction models on the basis of ecosystem service value research. At present, in the research of value assessment, some scholars have introduced the methods of geography, ecology and mathematics. The methods can be summed up as follows: index analysis method, statistical and quantitative analysis model, geographic prediction model, *etc.* (Table 2). With the continuous development of science and technology, the remote sensing (RS), geography information system (GIS), and global positioning system (GPS), collectively called 3S technology, is gradually applied in the field of ecological research. with the aid of 3S technology, it is able to obtain accurate and detailed geographic location and land use data in the process of estimating the value of ecosystem services, and provide support for spatial analysis of the data.

Table 2 Technical means introduced by value equivalent factor method and its representative achievements

Research methods and technical means	Representative achievements	Research area	Method application
Ecosystem service value coefficient method	Costanza *et al.*, 2003	Global	Establishing the ecosystem service value coefficient of each land type in the global terrestrial ecosystem and assessing the global ecosystem service value
Index analysis method	Liu Yubin *et al.*, 2020	Yellow River Delta	Studying changes in land use patterns and their impact on ecosystem service value
Correlation analysis and multiple regression models	Li Hui *et al.*, 2021	Three Gorges Reservoir Area	Calculating temporal and spatial differentiation characteristics of ecosystem service value and ecological risk index and their correlation
GWR model	Geng Tianwei *et al.*, 2020	Shaanxi Province	Analyzing the spatial and temporal evolution characteristics of ESV, the influence factors and the spatial differentiation characteristics of the dominant factor's action intensity based on the ESV evaluation system, geographic detector and GWR model
Sensitivity analysis	Chen Wanxu *et al.*, 2019	Middle reaches of Yangtze River	Constructing land use ecosystem service value contribution and ecosystem service value sensitivity measurement methods to study the response and sensitivity of ecosystem service value to land use changes
SD model	Yi Alan *et al.*, 2020	Wetland ecosystem of Shanghai	Building an SD model, using the Vensim PLE modeling platform to simulate and predict ESV, and examine the impact of changes in various factors on ecosystem services
Logistic-CA model	Huang Huanchun *et al.*, 2013	Binhai District of Tianjin	Simulating and predicting spatial evolution characteristics of ecosystem services under the influence of urban expansion from 2011 to 2020
Cellular automata model	Zhang Xiaoyao *et al.*, 2021	Qinghai – Tibet Plateau	Analyzing the impact of land use change on the temporal and spatial distribution of ESV, and simulating the relationship between land use and ESV under natural development and ecological protection scenarios
Grey system model	Zhao Zhigang *et al.*, 2017	Poyang Lake Ecological Economic Zone	Predicting the ecosystem service value data from 2016 to 2024, and analyzing the driving forces causing changes in ecosystem service value
CLUE-S model	Zhang Mufeng *et al.*, 2021	Dongguan Section of Shima River Basin	Simulating the land use pattern in 2025, and obtaining the spatial distribution and optimal allocation results of land use under three situations, and analyzing the temporal and spatial pattern of ESV in the basin under each situation
FLUS model	Ouyang Xiao *et al.*, 2020	Changsha – Zhuzhou – Xiangtan urban cluster	Simulating the impact of land use change on ecosystem service value in Changsha – Zhuzhou – Xiangtan urban cluster under three situations: benchmark, cultivated land protection and ecological protection
Gradient analysis model	Li Quan *et al.*, 2017	Wuhan City	Taking the city center as the origin to set up the echelon ring and considering the urban development axis to set up the sampling strip, select the two indicators of ESV change and change rate for gradient analysis
3S technologies	Cheng Guangbin *et al.*, 2021	Urumqi urban circle	Calculating the contribution rate of land use type to ecosystem service value and the correlation between land use type and ecosystem service value

4 Research prospects

In recent years, scholars at home and abroad have carried out various researches on the ecosystem service value, but they are still in the exploratory stage. There is no unified standard and indicator system for value assessment, dynamic value assessment is weak, less in-depth research on the value of a single service, lack of monthly and quarterly value assessment research, and lack of an assessment model that conforms to China's national conditions. Therefore, the future research should focus on the following aspects.

4.1 Research on the spatio-temporal dynamic assessment model of innovation ecosystem service value In order to accurately assess the value, it is necessary to strengthen the research on the calculation of the value per unit area by the equivalent factor method. The two mainstream methods of cellular automata CA and multi-agent ABM model for land use simulation have made significant achievements in both theoretical research and practical application. It is necessary to eEstablish a set of value coefficients in line with national conditions, and dynamically simulate the spatial pattern of ESV changes with the help of prediction models. Besides, it is recommended to enrich model research on dynamic value assessment, focusing on changes in land ecosystems under different situations.

4.2 Strengthening the research on the ecosystem service value of an individual ecosystem At present, many scholars have conducted value assessments for individual ecosystems such as wetlands, forests and grasslands. On this basis, it is necessary to comprehensively use a variety of assessment methods to innovate value assessment, and use GIS to explore the spatial pattern of ESV. The existing land resource classification system in China has some problems such as few classification levels, confusing classification standards and unclear classification standards, resulting in a lack of scientificity and logical rigor in the study of ecosystem service value[36]. These problems will lead to disagreements in how ecosystems are divided and the value of services assessed.

4.3 Cross-validation of ecosystem service value assessment methods At present, there are various value assessment methods and combined models, and the results obtained by different methods for value assessment are also different. Comparing the value results obtained under different assessment methods can improve the scientificity and accuracy of value estimation, and at the same time compare the advantages and disadvantages of assessment model methods, and explore suitable assessment methods for different regions. Using different assessment methods to assess the value of ecosystem services in multiple regions can also explore whether the results obtained by different assessment methods are quantitatively related, and the final assessment results can reflect the ecosystem service value of the region more comprehensively and accurately.

4.4 Research of quarterly and monthly changes of ecosystem service value On the time scale, most studies of ecosystem service value are on the scale of years. Most of the analysis of value change is based on five-year or ten-year intervals, and there are few studies on the monthly and quarterly changes of ESV within the same year. Studying the changes in ESV over a year in an area can find the months with the highest and lowest service value. Exploring the influence of seasonal changes on ecosystem service value can obtain the fitting curve of ESV monthly changes, and find the relationship between ESV and temperature and precipitation. In addition, according to the research, it can be seen that the changes of various land ecosystems in different months, and the service value provided for different land types is ranked according to the sensitivity of the seasons.

5 Conclusions

At the end of the 20th century, the value of ecosystem services attracted extensive attention from scholars both at home and abroad. With the deepening of research, the value assessment system and the standard of equivalent factor coefficient become more scientific and perfect. On the basis of a deep understanding of ecosystem service value assessment theory, exploratory experiments are carried out in the complex reality of China to seek verification methods for value assessment results. It is recommended to establish a national ESV assessment database to compare the value assessment results of different scholars in the same region and the same period, and establish a value assessment system in line with national conditions of China Besides, it is necessary to strengthen the research on the value of individual ecological services, explore the connotation of each service, and enhance the ecological value of the region. In addition, it is necessary to simulate the spatial pattern of the land ecosystem under different situations as needed to deal with the negative impact of rapid urbanization on the ecological environment, optimize the layout of land use, and enhance the service value of the land ecosystem.

References

[1] XIE GD, ZHANG CX, ZHANG CS. The value of ecosystem services in China[J]. Resources Science, 2015,37(9): 1740 - 1746. (in Chinese).

[2] YANG ZS. Research on land use change and ecological benefit of different landform regions in Yunnan driven by China's returning farmland to forest project[M]. Beijing: China Science and Technology Press, 2011: 63 - 67. (in Chinese).

[3] DAILY GC. Nature's services: Societal dependence on natural ecosystems [M]. Washington: Island Press, 1997.

[4] COSTANZA R, D'ARGE R, DE GROOT R, *et al.* The value of the world's ecosystem services and natural capital[J]. Nature: International Weekly Journal of Science, 1997, 387(6630): 253 - 260.

[5] BJÖRKLUND J, LIMBURG KE, RYDBERG T. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services:an example from Sweden[J]. Ecological Economics, 1999, 29 (2): 269 - 291.

[6] TURNER KG, ODGAARD MV, BOCHER PK, *et al.* Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape [J]. Landscape and Urban Planning, 2014(125): 89 - 104.

[7] FIRBANK LG, ELLIOTT J, DRAKE B, *et al.* Evidence of sustainable intensification among British farms[J]. Agriculture, Ecosystems and En-

vironment, 2013(173): 58 – 65.
[8] KRAGT ME, ROBERTSON MJ. Quantifying ecosystem services trade-offs from agricultural practices [J]. Ecological Economics, 2014 (102): 147 – 157.
[9] CAPITANI C, VAN SOESBERGEN A, MUKAMA K, *et al.* Scenarios of land use and land cover change and their multiple impacts on natural capital in Tanzania[J]. Environmental Conservation, 2018, 46(1): 17 – 24.
[10] KUBISZEWSKI I, COSTANZA R, ANDERSON S, *et al.* The future value of ecosystem services: Global scenarios and national implications[J]. Ecosystem Services, 2017(26): 289 – 301.
[11] PAUDYAL K, BARAL H, KEENAN RJ. Assessing social values of ecosystem services in the Phewa Lake Watershed, Nepal[J]. Forest Policy and Economics, 2018(90): 67 – 81.
[12] GASHAW T, TULU T, ARGAW M, *et al.* Estimating the impacts of land use/land cover changes on ecosystem service values: The case of the Andassa watershed in the Upper Blue Nile basin of Ethiopia[J]. Ecosystem Services, 2018(31): 219 – 228.
[13] DAVIDSON NC, VAN DAM AA, FINLAYSON CM, *et al.* Worth of wetlands: Revised global monetary values of coastal and inland wetland ecosystem services[J]. Marine and Freshwater Research, 2019, 70(8): 1189 – 1194.
[14] SOTO JR, ESCOBEDO FJ, KHACHATRYAN H, *et al.* Consumer demand for urban forest ecosystem services and disservices: Examining trade-offs using choice experiments and best-worst scaling[J]. Ecosystem Services, 2018(29): 31 – 39.
[15] AROWOLO AO, DENG XZ, OLATUNJI OA, *et al.* Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria[J]. Science of the Total Environment, 2018(636): 597 – 609.
[16] XIAO H, OUYANG ZY, ZHAO JZ, *et al.* Forest ecosystem services and their ecological valuation: A case study of tropical forest in Jianfengling of Hainan island[J]. Chinese Journal of Applied Ecology, 2000, 11(4): 481 – 484. (in Chinese).
[17] ZON YG, ZHOU SY, WEN L, *et al.* Ecological value evaluation of sustainable development of regional ecosystem: Taking Lingwu City, Ningxia as an example[J]. Acta Ecologica Sinica, 2002, 22(19): 1573 – 1580. (in Chinese).
[18] XIE GD, LU CX, LENG YF, *et al.* Ecological assets valuation of the Tibetan Plateau[J]. Journal of Natural Resources, 2003, 18(2): 189 – 196. (in Chinese).
[19] XIE GD, ZHANG CX, ZHANG CS. The value of ecosystem services in China[J]. Resources Science, 2015, 37(9): 1740 – 1746. (in Chinese).
[20] LIU YQ, LIAO LW, LONG HL, *et al.* Effects of land use transitions on ecosystem services value: A case study of Hunan Province[J]. Geographical Research, 2015, 34(4): 691 – 700. (in Chinese).
[21] XUE MG, XING L, WANG XY. Spatial correction and evaluation of ecosystem services in China[J]. China Land Science, 2018, 32(9): 81 – 88. (in Chinese).
[22] LI YY, TAN MH, HAO HG. The impact of global cultivated land change on terrestrial ecosystem service value from 1992 to 2015[J]. Journal of Geographical Sciences, 2019, 29(3): 323 – 333.
[23] CHEN WX, LI JF, ZHU LJ. Spatial heterogeneity and sensitivity analysis of ecosystem services value in the Middle Yangtze River region[J]. Journal of Natural Resources, 2019, 34(2): 325 – 337. (in Chinese).
[24] YAN Y, YAO LY, LANG LM, *et al.* Revaluation of ecosystem services in inland river basins of China: Based on meta-regression analysis[J]. Acta Geographica Sinica, 2019, 74(5): 1040 – 1057. (in Chinese).
[25] GENG TW, CHEN H, ZHANG H, *et al.* Spatiotemporal evolution of land ecosystem service value and its influencing factors in Shaanxi province based on GWR[J]. Journal of Natural Resources, 2020, 35(7): 1714 – 1727. (in Chinese).
[26] OUYANG X, HE QY, ZHU X. Simulation of impacts of urban agglomeration land use change on ecosystem services value under multi-scenarios: Case study in Changsha – Zhuzhou – Xiangtan urban agglomeration[J]. Economic Geography, 2020, 40(1): 93 – 102. (in Chinese).
[27] WANG PJ, SUN H, HUA BL, *et al.* Evaluation and dynamic simulation of ecosystem service value in coastal area of Fuzhou City[J]. Transactions of the Chinese Society for Agricultural Machinery, 2020, 51(3): 249 – 257. (in Chinese).
[28] CHU Z, XU CC, LUO YX, *et al.* Land use simulation and ecological benefit evaluation in the Tarim River basin based on ecological protection red line management [J]. Acta Ecologica Sinica, 2021, 41 (18): 7380 – 7392. (in Chinese).
[29] CHEN BF, LIAO TJ, ZHANG LK. Simulation of land use situation and ecological value assessment in Wanzhou District under the constraints of ecological red line[J]. Research of Soil and Water Conservation, 2020, 27(5): 349 – 357, 364. (in Chinese).
[30] YU M, LIAN LS, LI BF, *et al.* Assessment of land use and ecological effects of Nansi Lake Basin based on CLUE-S model[J]. Bulletin of Soil and Water Conservation, 2018, 38(6): 231 – 239, cover 2. (in Chinese).
[31] ZHANG MF, LIU WX, WANG JE, *et al.* Scenario simulation of ecosystem service value change in Dongguan section of Shima River Basin based on Clue-S model[J]. Bulletin of Soil and Water Conservation, 2021, 41 (1): 152 – 160. (in Chinese).
[32] ZHANG XY, LU L, YU H, *et al.* Multi-scenario simulation of the impacts of land-use change on ecosystem service value on the Qinghai – Tibet Plateau[J]. Chinese Journal of Ecology, 2021, 40(3): 887 – 898. (in Chinese).
[33] WANG JF, LIU F, BAI XY, *et al.* The spatial and temporal evolution and simulation forecast of ecosystem service values in southwest China [J]. Acta Ecologica Sinica, 2019, 39(19): 7057 – 7066. (in Chinese).
[34] LI H, ZHOU QG, LI B, *et al.* Spatiotemporal change and correlation analysis of ecosystem service values and ecological risk in Three Gorges Reservoir area in the past 30 years[J]. Resources and Environment in the Yangtze Basin, 2021, 30(3): 654 – 666. (in Chinese).
[35] ZHONG JT, WANG B, MI WB, *et al.* Spatial recognition of ecological compensation standard for grazing grassland in yanchi county based on INVEST model[J]. Scientia Geographica Sinica, 2020, 40(6): 1019 – 1028. (in Chinese).
[36] YANG ZS, YANG SQ, YANG RY, *et al.* Classification method of land resources based on land use perspective[J]. Resources Science, 2021, 43(11): 2173 – 2191. (in Chinese).