Landscape Pattern Change and Its Impact Assessment on Ecosystem Services in Beijing's Peri-urban Area: A Case Study of Niulanshan-Mapo Town (Postprint)

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Abstract

Beijing' s peri-urban area is currently undergoing rapid economic development, during which human activities have significantly impacted landscape patterns, resulting in substantial changes in ecological service functions. Therefore, investigating landscape pattern changes and their effects on ecosystem service values in Beijing' s urban fringe is of great significance for the future development of peri-urban regions. Using Fragstats 4.2 software and based on the ecosystem service equivalent factor table, this study examines the changes in landscape patterns and ecosystem service values in Niulanshan-Mapo Town, a peri-urban area of Beijing, from 1992 to 2015, and conducts a correlation analysis between landscape metrics and ecosystem service values. The results demonstrate that from 1992 to 2015, the landscape pattern of Niulanshan-Mapo Town changed significantly, characterized by increased fragmentation, heightened heterogeneity, and a shift in the dominant landscape type from cropland to construction land; the ecosystem service value increased from 116.0934 million yuan to 149.9207 million yuan, with forest land contributing the most to this increase; enhancing the Largest Patch Index, Patch Density, and Diversity Index is beneficial for increasing ecosystem service values. In summary, landscape pattern changes caused by human disturbance under rapid urbanization do not necessarily reduce ecosystem service values in peri-urban areas; scientific ecological environment planning and protection policies are the main reasons for the increase in ecosystem service values in Niulanshan-Mapo Town.

Full Text

Landscape Pattern Change in Beijing' s Fringe Area and Its Impact on Ecosystem Services: A Case Study in Niulanshan-Mapo Town

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Abstract: Urban fringe areas, as transitional zones between urban and rural regions and future expansion areas for cities, are ecologically sensitive zones in the urbanization process and hold important positions in urban development. Many scholars believe that urbanization negatively impacts the ecological environment, reducing ecosystem service values. Industrial development in fringe areas, though rapid, is characterized by small scale and large numbers, destroying natural vegetation and interrupting hydrological systems, leading to illegal occupation of agricultural and ecological lands and altering entire ecosystem structures and functions. However, whether changes in land use structure and function caused by human interference necessarily reduce ecosystem service values in fringe areas remains inconclusive. Pickett et al. argued that expanding urban space can enhance biodiversity. Against the backdrop of vigorously promoting ecological civilization and beautiful countryside construction, exploring landscape pattern changes and their impacts on ecosystem service values in urban fringe areas holds important practical significance.

Quantitative assessment of ecosystem service value has become a hotspot in international sustainable development research and a cutting-edge interdisciplinary field of ecology, environmental science, and land management science. For ecosystem service value accounting, domestic research primarily builds upon Xie Gaodi et al.' s work, adjusting the ecosystem service equivalent factor table according to regional actual conditions to estimate ecosystem service values, thereby scientifically reflecting regional ecosystem service conditions and providing foundations for regional ecological environment construction. In terms of research scale, current ecosystem service value studies mainly focus on large-scale, multi-regional land use change impacts. For example, Zhang et al. explored land use change and its impact on ecosystem service value in Jinan; Zhao Dan et al. examined urban land use change impacts on ecosystem services in Huaibei; Liu Guilin et al. analyzed land use change impacts on ecosystem service value across the entire Yangtze River Delta region. However, applying land use pattern changes to quantify ecosystem service values in urban fringe areas remains

rare. Compared to complex policies and land use changes in large-scale studies, small-scale research more easily reveals change-driving mechanisms.

According to the "2004-2020 Beijing Urban Master Plan," Shunyi New Town is an important node in the eastern development corridor and one of the key new towns for development. Niulanshan-Mapo Town is the core area of Shunyi New Town construction and the future industrial core area of Shunyi development. Under sustained rapid economic development, land use patterns have undergone and may continue to experience dramatic changes, making ecosystem service value research crucial for local sustainable development.

This study aims to analyze and discuss landscape pattern change trends and their induced dynamic changes in ecological service values and driving mechanisms in Niulanshan-Mapo Town against the background of rapid socio-economic development. The main innovation lies in analyzing how spatial differences and structural changes in land use caused by temporal changes affect ecological service values in rapidly developing areas, and identifying the main land use types and indices determining regional ecological service value changes. Using land use data from 1992, 2001, and 2015, this study employs Fragstats 4.2 to establish landscape pattern indices and SPSS statistical software to analyze relationships between landscape pattern indices and ecosystem service values. Based on Xie Gaodi' s ecosystem service equivalent factor table and adjusted for Beijing' s actual grain production and prices, we explore landscape pattern and ecosystem service value changes in Beijing' s fringe area from 1992-2015, and conduct correlation analysis between landscape indices and ecosystem service values.

Results show that landscape patterns in Niulanshan-Mapo Town changed dramatically, with fragmentation and heterogeneity significantly increasing. Dominant landscape types shifted from farmland to built-up areas. Ecosystem service value increased from 116.0934 million yuan to 149.9207 million yuan. Forest ecosystem service value increased from 11.0967 million yuan to 89.4098 million yuan, contributing the largest share to the total increase. Improving the largest patch index, patch density, and diversity index benefits ecosystem service value increase. Under rapid urbanization, landscape pattern changes caused by human interference do not necessarily reduce ecosystem service values in urban fringe areas. Scientific ecological environment planning and protection policies constitute the main reasons for ecosystem service value increase in Niulanshan-Mapo Town.

Keywords: Beijing urban fringe area; landscape pattern; ecosystem service value; impact; Niulanshan-Mapo Town

1. Study Area Overview

The study area of Niulanshan-Mapo Town (40°00′-40°18′ N, 116°28′-116°58′ E) is located in Shunyi District on the outer fringe of Beijing. The region has a warm temperate semi-humid continental monsoon climate, with an average annual temperature of 11.5°C, minimum temperature of -19.1°C, maximum temperature of 40.5°C, and average annual rainfall of approximately 625 mm concentrated in summer. The frost-free period lasts 195 days, annual sunshine hours total 2750 h, and average annual relative humidity is 62%. Local fiscal revenue grew from 0.11 billion yuan to 1.173 billion yuan in Mapo Township and from 0.11 billion yuan to 1.126 billion yuan in Niulanshan Town, showing significant exponential growth. The total area is 7029 hm^2.

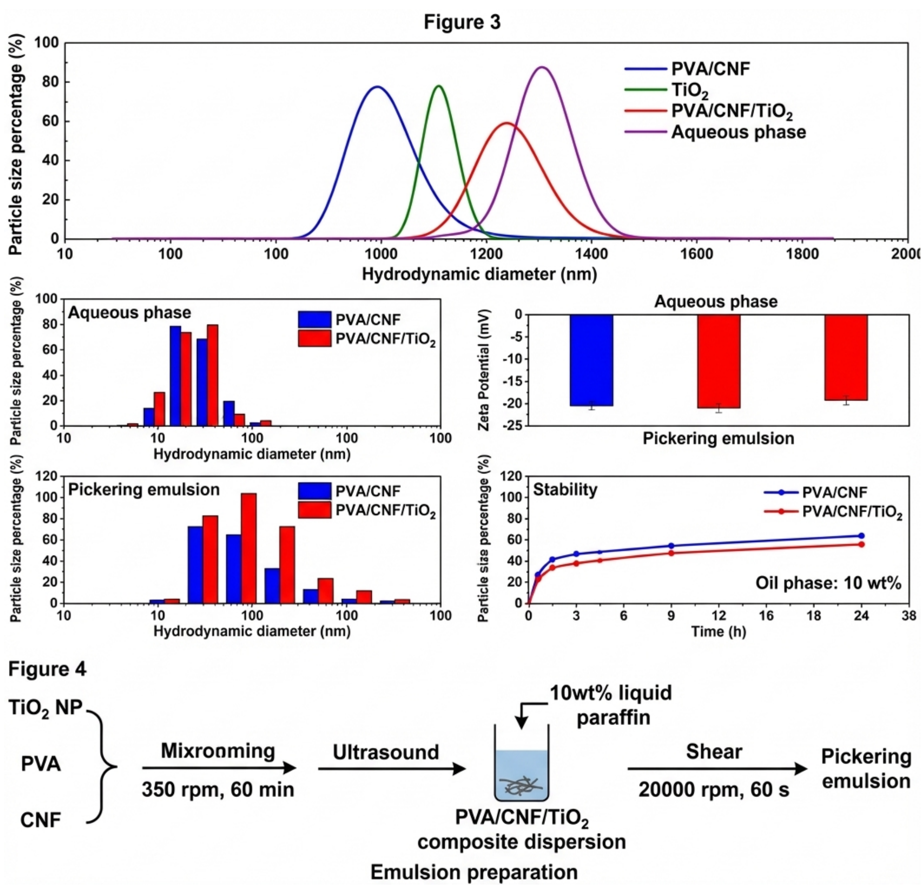

Figure 1: Figure 1

Schematic map of the geographical location of Niulanshan-Mapo Town

2. Data Sources

The study area covers Niulanshan-Mapo Town. Land use data were obtained from the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (http://www.radi.ac.cn/) and Beijing Municipal Bureau of Land and Resources for three periods (1992, 2001, 2015). The 2015 land use data were interpreted from high-resolution WorldView-2 imagery through visual interpretation. Based on the "Current Land Use Classification Standard" (GB/T21010-2007) and ecological land classification systems, the study area' s landscape types were divided into two primary categories: built-up area and ecological land. Ecological land includes farmland, forest land, water bodies, and unused land. Specific classifications are shown in Table 1.

Landscape types classification in Niulanshan-Mapo Town

3. Methods

3.1 Landscape Pattern Analysis Landscape pattern changes directly affect habitat quality and nutrient element migration pathways, indirectly altering energy flow and material cycling processes in ecosystems. Quantitative analysis of landscape patterns and their dynamic characteristics forms the basis for understanding ecological processes. While many landscape indices exist and are often highly correlated, this study uses Fragstats 4.2 as the technical platform to obtain landscape pattern dynamics. Based on different functions and attributes, we selected: Number of Patches (NP), Largest Patch Index (LPI), Landscape Shape Index (LSI), Patch Density (PD), Shannon' s Diversity Index (SHDI), Interspersion Juxtaposition Index (IJI), and Contagion Index (CONTAG).

NP reflects landscape fragmentation degree. Higher PD indicates smaller patch sizes per unit area and higher landscape heterogeneity. LPI, the ratio of the largest patch area to total area, helps identify dominant landscape types. LSI, the ratio of total landscape boundary length to the square root of total area, indicates patch separation. SHDI reflects landscape type richness and complexity; higher values indicate no dominant type and more uniform distribution of landscape types. IJI characterizes overall landscape dispersion; higher values indicate more obvious alternating patterns of different patches. CONTAG generally characterizes the clustering degree or spread trend of different patch types; high values indicate good connectivity of a dominant patch type, while low values indicate fragmented landscapes with multiple elements.

3.2 Land Ecosystem Service Value Estimation For ecosystem service value assessment, this study primarily adopts Xie Gaodi et al.' s Chinese ecosystem service value equivalent factor table. Since this study' s land use classification differs from Xie Gaodi' s, we compared and adjusted the ecosystem types. Similar to Cheng Lin et al.' s research on land use classification and urban ecological service values, we referenced their method to adjust the equivalent factor for built-up ecosystems, incorporating losses from other land types converted to built-up areas into the built-up ecosystem service value calculation. The study assumes that when built-up area green space reaches a certain proportion, the ecosystem service value of built-up area in 2015 is set at 0.

Based on the ecosystem service value coefficients of each land use type and Xie Gaodi et al.' s research, the ecosystem service value coefficients were calculated as: service value equivalent × market value of national average grain yield. The ecosystem service value of Niulanshan-Mapo Town was calculated as follows:

$$ESV = V \times A$$

where V is the value coefficient of the nth ecosystem service for land use type i, and A is the area of land use type i.

3.3 Correlation Analysis Between Landscape Indices and Ecosystem Service Value Establishing the coupling relationship between landscape indices and ecosystem service value can effectively reflect how landscape index changes impact ecosystem service values. Following Gu Zexian et al.' s research on landscape pattern changes and their correlation with ecosystem service values in Lancang County using 1995, 2005, and 2015 imagery, this study uses three periods of interpreted results (1992, 2001, 2015) to establish Spearman correlation analysis between landscape indices and ecosystem service values.

4. Results and Analysis

4.1 Spatial Changes in Landscape Patterns in Niulanshan-Mapo Town Based on spatial change characteristics of landscape patterns from 1992, 2001, and 2015, built-up areas in Niulanshan-Mapo Town showed expansion trends in all directions, farmland contracted extensively, forest land expanded significantly outward, and water body spatial distribution changed from dispersed (in north and east) to concentrated (in southeast).

Changing landscape patterns of Niulanshan-Mapo Town from 1992 to 2015

4.2 Analysis of Landscape Pattern Index Changes From 1992-2015, landscape patch numbers (NP) and patch density (PD) showed increasing trends, though the growth rate weakened. The interspersion juxtaposition index (IJI) showed a decreasing trend, but the decreasing trend weakened. Shannon' s diversity index (SHDI) increased, indicating richer and more diversified landscape types with more uniform patch distribution. Although landscape fragmentation intensified, the trend weakened. The contagion index (CONTAG) showed a decreasing trend, indicating reduced adjacency probability between different patch types. The largest patch index (LPI) first decreased then increased, while landscape shape index (LSI) showed the opposite pattern, indicating severe human interference and dramatic changes in dominant landscape types and shapes.

Landscape index changes in Niulanshan-Mapo Town from 1992 to 2015

Index	Unit	Crude Oil	Gasoline	Diesel	Kerosene
Density	gg/mila	4.00	0.95	0.64	0.92
Kinematic Viscosity (40°C)	μg/m^{-2}	0.14	1.62	1.15	1.35
Pour Point	μg °C	-20	-10	-10	-10
Flash Point	°C	130	250	175	120
Sulfur Content	μg/g	0.015	0.055	0.10	0.26
Water Content	%	0.09	0.003	0.13	0.26
Mechanical Impurities	%	0.70	1.39	1.97	1.62
Ash Content	μg/g	0.17	0.024	0.18	0.43

Table 1 Physical Properties of Several Petroleum Products

Figure 2: Figure 2

4.3 Dynamic Changes in Different Landscape Types From 1992-2015, farmland area continuously decreased while built-up and forest land areas increased. Water body and unused land areas changed little. Built-up and forest land mainly converted from decreasing farmland. By 2015, built-up land had become the dominant landscape type. From 1992-2001, urban land area increased from 1988.7 hm^2 to 2078.54 hm^2 (4.52%), indicating unobvious urbanization. From 2001-2015, Mapo Town experienced severe human interference, with urban land area increasing from 2078.54 hm^2 to 3091 hm^2 (32.76%), showing significantly accelerated expansion.

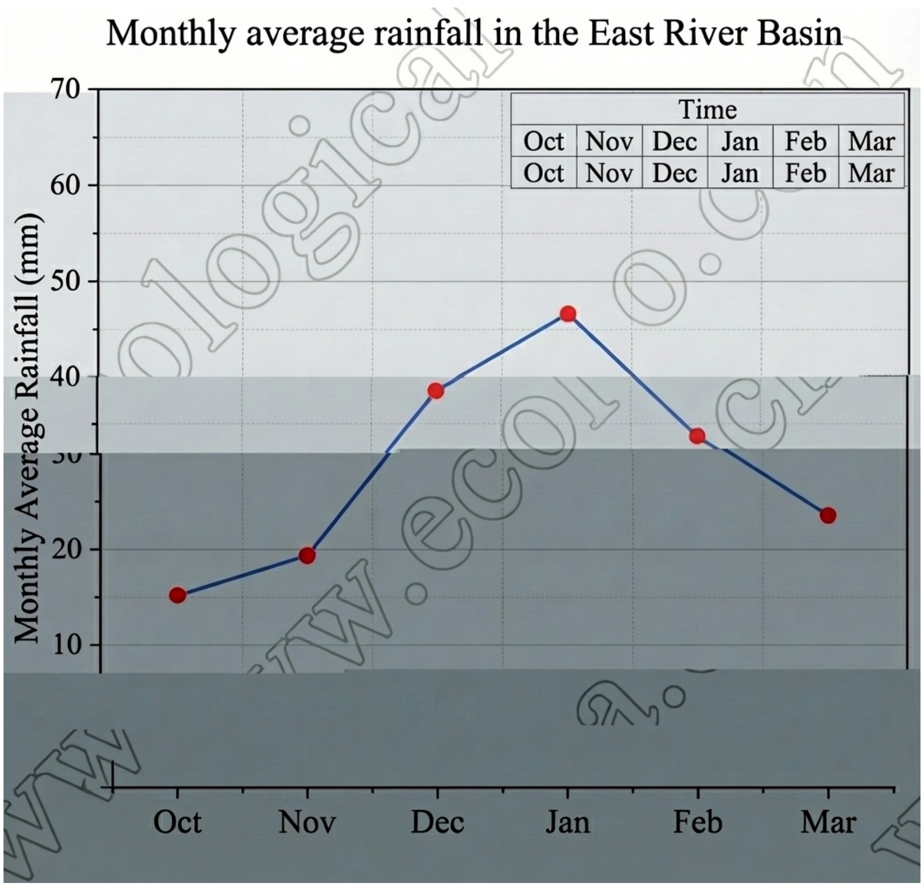

Figure 3: Figure 3

Changing area of different landscape types in Niulanshan-Mapo Town

4.4 Ecosystem Service Function Value Analysis of Different Landscapes Based on land use change data and ecosystem service value coefficients, ecosystem service values caused by landscape pattern changes were analyzed.

Total ecosystem service value increased by 89.4098 million yuan from 1992-2015. Farmland and built-up area changes were not significant. Forest land ecosystem service value increased from 11.0967 million yuan to 89.4098 million yuan, becoming the main land type providing ecosystem services. As landscape patterns changed, all ecosystem service function values increased except food production and waste treatment values.

Ecosystem service value per unit area of different landscape types in Niulanshan-Mapo Town

[FIGURE:4] Changes of ecosystem services value of Niulanshan-Mapo Town from 1992 to 2015

[FIGURE:5] Ecosystem values of different functions in Niulanshan-Mapo Town from 1992 to 2015

4.5 Contribution Rate Analysis of Different Landscape Types to Ecosystem Service Value From the contribution rates of each landscape type to total ecosystem service value across different periods (Figure 6), forest land contributed the most to ecosystem services from 1992-2015, while farmland and built-up areas contributed the least. Water bodies and unused land showed no significant changes in contribution rates. The main reason for the increase in total ecosystem service value was forest land increase. Farmland area reduction and built-up area increase caused decreases in total ecosystem service value. For built-up areas, the contribution rate increased significantly from 2001-2015.

[FIGURE:6] Ecosystem services value contribution of five landscape types in Niulanshan-Mapo Town

4.6 Correlation Analysis Between Landscape Indices and Ecosystem Service Value Correlation analysis between different landscape indices and ecosystem service functions from 1992-2015 showed that total ecosystem service value was highly correlated with Shannon's diversity index (SHDI), largest patch index (LPI), patch density (PD), and contagion index (CONTAG). Among all landscape indices, SHDI, LPI, IJI, and PD showed high correlations with ecosystem service values, indicating that richer landscape types and larger patch areas benefit overall service value, while more dispersed landscape types may not.

Although connectivity gradually decreased in the study area, ecosystem service value increased annually. Forest ecosystem service value showed highly positive correlations with patch density, largest patch index, and landscape shape index, but highly negative correlation with interspersion juxtaposition index, indicating that improving forest patch density, largest patch index, and landscape shape index benefits forest ecosystem service value and thus total value. SHDI, IJI, and CONTAG showed high correlations with various ecosystem service functions, suggesting that improving SHDI and patch density benefits raw material production, biodiversity maintenance, and aesthetic landscape values, while improving IJI benefits food production and waste treatment values, and CONTAG may improve other service values.

Correlation between landscape metrics and ecosystem services values

5. Discussion

5.1 Analysis of Ecosystem Service Value Changes Human disturbances such as built-up area expansion typically cause ecosystem service value degradation. Wang Jiaojiao' s research in Beijing found that rapid land use growth and substantial reductions in farmland and water areas caused ecosystem service values in Shunyi District to gradually decline with economic development. Zhang Yixiu et al. studied Guangzhou' s fringe area from 2000-2006, and Ma Feng et al. studied Shanghai' s Lingang New City, finding that ecosystem service values decreased due to economic development. In contrast, this study found that although built-up areas continuously encroached on farmland and ecological land from 1992-2015, ecosystem service values in Niulanshan-Mapo Town did not decrease but rather increased, with accelerated growth after 2001. This is because, although all are urban fringe areas, economic development and policy orientations differ between cities.

The main reasons for the increase in Niulanshan-Mapo Town include: large-scale conversion of farmland to forest land (accounting for 81.25% of total forest growth), with forest land' s high ecological value coefficient playing a decisive role; significantly improved vegetation coverage due to programs such as the Grain for Green Project (2000), ecological corridor construction, the "Hundreds of Villages and Thousands of Households" greening project, water-based Olympic venues and supporting greening projects, and the Capital Plain Million-Mu Afforestation Project. Increased vegetation coverage enhances carbon sequestration, oxygen release, and air/water purification functions, significantly improving gas regulation and soil conservation values. Forest land increase also enhances precipitation interception and groundwater recharge capacity, contributing substantially to water conservation and hydrological regulation. Economically, fruit industry profits exceed grain crop profits, leading to more traditional farmland being used for orchards, directly increasing vegetation coverage. The ecological and economic benefits from forest and orchard land in Mapo Town compensated for losses from built-up area expansion.

The main measures to improve ecosystem service value in Niulanshan-Mapo Town include strengthening forestry construction, expanding orchard area, and increasing green space coverage in built-up areas. This development model can provide references for other fringe areas.

5.2 Analysis of Landscape Pattern Impacts on Ecosystem Service Value Close correlations exist between landscape pattern evolution and ecosystem service changes. Landscape functions determine ecological processes, thereby affecting ecosystem services. Landscape pattern changes affect landscape indices, which influence ecosystem service values. Wang Yun et al., using Xi' an as an example, found that largest patch index showed strong positive correlations with ecosystem service values, while patch density and separation index showed negative correlations. Cen Xiaoteng' s research on the south bank of Hangzhou Bay showed that increasing landscape diversity, fragmentation, and dispersion benefits overall service value. Current research shows that relationships between landscape indices and ecosystem service values vary by region, requiring deeper investigation into each index' s impact degree.

Results show that Niulanshan-Mapo Town, affected by urbanization, experienced increased patch density, decreased largest patch index initially then increase, and continuously decreasing contagion. Based on these findings, we propose the following recommendations for future Beijing fringe area development: strengthen forest land protection, strictly control encroachment of farmland and other land types on forest land and water bodies, and enhance the ecological barrier service function of the Chaobai River. Mapo Town should protect and increase forest and water areas while completing farmland protection targets, maintain existing nursery areas and economic forest areas, control built-up area proportions, and increase green space coverage in built-up areas to mitigate ecosystem service value decline caused by built-up area expansion. Beijing' s fringe areas should improve patch area and quantity, increase patch density index, largest patch index, landscape shape index, and diversity index, with emphasis on improving forest density index, largest patch index, and landscape shape index to enhance ecosystem service value.

6. Conclusions

Based on three periods of land use data (1992, 2001, 2015), this study analyzed landscape pattern changes and their impacts on ecosystem service values in urban fringe areas. With large year spans and constructed ecosystem service value coefficients, it effectively reflects small-scale landscape pattern changes and spatial impacts in urban fringe areas. Through correlation analysis between land use landscape indices and ecosystem service values, we identified main land use types and related indices determining ecosystem service value changes in Niulanshan-Mapo Town, enabling analysis of driving and feedback mechanisms between natural and human social systems.

(1) From 1992-2015, Niulanshan-Mapo Town experienced severe human interference, with landscape patterns changing significantly, fragmentation intensifying, and dominant landscape types shifting from farmland to built-up areas. Landscape types became richer and more diversified, with patch types tending toward uniform distribution.

(2) From 1992-2015, total ecosystem service value in Niulanshan-Mapo Town continuously increased. Except for decreases in food production and waste treatment values, all other ecosystem service function values showed increasing trends. Total ecosystem service value increased by 29.5556 mil-

lion yuan, with landscape type changing from water body to forest land as the main contributor. Strengthening forestry construction and increasing forest patch number and area are decisive for improving ecosystem service value. Increasing green space coverage in built-up areas is an effective measure to overcome ecosystem service function degradation caused by built-up area expansion.

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