Research on the Optimization of Rural Ecological Networks and the Enhancement of Landscape Functions Based on Ecological Civilization Policies

Abstract

This study focuses on the optimization of rural ecological networks and the enhancement of landscape functions under the framework of ecological civilization policies. By integrating landscape ecology, ecological theories, and spatial analysis techniques, it delves into biodiversity-related studies of rural ecological landscapes, aiming to construct theoretical frameworks and practical strategies. Experimental designs targeting representative rural areas in China are employed to assess changes in landscape functions quantitatively before and after ecological network optimization using multi-source data and diverse analytical methods. The findings aim to provide scientific evidence and practical guidance for the construction of rural ecological civilization and the promotion of sustainable rural development.

Keywords: Ecological Civilization Policies; Rural Ecological Networks; Landscape Functions; Biodiversity; Sustainable Developmen

1. Introduction

A. Research Background and Significance

Amidst escalating global ecological challenges, ecological civilization has emerged as a pivotal strategy for sustainable development worldwide. Rural areas, as integral components of the Earth's ecosystems, play a vital role in maintaining ecological balance, delivering ecosystem services, fostering economic development, and preserving cultural heritage (Yin et al., 2023). However, accelerated urbanization poses significant challenges to rural ecological landscapes, including habitat destruction, landscape homogenization, and biodiversity loss (Yin et al., 2023). Research on optimizing rural ecological networks and enhancing landscape functions under ecological civilization policies has profound implications for protecting rural ecological environments and promoting sustainable rural development.

B. State of the Art

Extensive research has been conducted in the field of rural ecological landscapes globally. Studies on ecological network optimization mainly focus on identifying and selecting ecological sources, constructing and optimizing ecological corridors, and enhancing ecological node functionality (Zou et al., 2024; Zhang et al., 2024). Landscape function enhancement studies emphasize optimizing ecosystem service evaluations, understanding the relationships between landscape patterns and ecological processes, and preserving the cultural aesthetic value of rural landscapes (Xu et al., 2024; Jin et al., 2024). However, current studies face limitations such as insufficient interdisciplinary integration, inadequate exploration of the coupling between ecological networks and landscape functions, and limited consideration of socio-economic factors in practical applications (Liu et al., 2024; VijayKumar et al., 2024).

C. Objectives and Innovations

This study aims to analyze research hotspots and trends in rural ecological landscape biodiversity, establishing a comprehensive theoretical framework and practical model for optimizing rural ecological networks and enhancing landscape functions (Fan et al., 2023; Zhou et al., 2024). By integrating interdisciplinary theories and methods, it innovatively proposes synergistic strategies emphasizing the interactions between ecological network structures and landscape functions (Huang et al., 2021; Tong et al., 2024). Practical recommendations are developed using real-world cases, providing scientific evidence and practical guidance for rural ecological civilization construction (Shen et al., 2023; Wang et al., 2022).

D. Study Areas and Data Sources

Representative rural areas in China with diverse geographic environments, economic development levels, and cultural contexts were selected as study sites. Data sources include field surveys, remote sensing image interpretation, geographic information system (GIS) data, statistical yearbooks, and literature. Field surveys document current rural ecological landscapes, biodiversity distribution, and socio-economic conditions (He et al., 2022; Zeng et al., 2022). Remote sensing image interpretation provides land use/cover change and landscape pattern data (Chen et al., 2023; Cao et al., 2022). GIS data supports spatial analysis (Wang et al., 2024; Mok et al., 2022), while statistical yearbooks and literature are used to analyze historical trends and policies (Liu et al., 2022; Zhang et al., 2021).

2. Research Hotspots and Trends in Rural Ecological Landscape Biodiversity

E. Hotspot Analysis

1） *Impact of Urbanization on Rural Ecological Landscape Biodiversity*

Urbanization profoundly affects biodiversity in rural ecological landscapes. Earlier studies focused on habitat destruction and biodiversity loss due to land use changes, while recent research emphasizes mechanisms such as habitat fragmentation (Datri et al., 2024), changes in ecosystem service functions (McKinney, 2020), and species invasion (Schwarz et al., 2019). Urban expansion fragments natural rural landscapes, impeding species migration, dispersal, and reproduction, while pollution and climate change exacerbate biodiversity threats.

2） *Sustainable Development of Rural Ecological Landscapes*

Sustainable development of rural ecological landscapes remains a core issue, involving biodiversity conservation alongside economic and social prosperity. Key research areas include ecological agriculture, ecotourism, and rural ecological planning and design. Ecological agriculture reduces environmental impacts while enhancing product quality and economic benefits. Ecotourism leverages rural natural and cultural resources for sustainable tourism, fostering economic growth. Ecological planning rationalizes land use, protects ecologically sensitive areas, and constructs infrastructure to ensure ecosystem health and stability.

3) *Biodiversity in Rural Landscapes from a Socio-Ecological Systems Perspective*

The socio-ecological systems perspective highlights interdependencies between human societies and ecosystems, emphasizing comprehensive consideration of ecological, economic, and social factors in rural ecological landscape conservation. Research focuses on mechanisms for community participation in ecological protection, effectiveness of ecological compensation policies, and stakeholder relationships in land use decision-making. Community participation enhances conservation awareness and the effectiveness of protective measures, while ecological compensation policies balance ecological and economic benefits.

F. Future Trends

1) *Interdisciplinary Research Integration*

Future research will emphasize interdisciplinary integration. Landscape ecology, ecology, sociology, economics, geography, and planning theories will intersect to better understand rural ecological landscape complexities. Ecological principles will address biodiversity processes and functions, sociological methods will analyze community behavior, geographical techniques will optimize spatial analysis, economic theories will assess ecosystem service values, and planning methodologies will establish rational rural ecological spatial patterns.

2) *Synergistic Studies on Ecological Network Optimization and Landscape Function Enhancement*

As understanding of ecosystem structure-function relationships deepens, synergistic studies combining ecological network optimization and landscape function enhancement are emerging. These studies focus on how ecological network structures influence landscape ecosystem services, exploring strategies to enhance connectivity, stability, and service capacities of landscapes through optimized networks. Highly connected corridor networks facilitate species migration and diffusion, boosting ecological regulatory functions.

3) Applications of Big Data and Emerging Technologies

The era of big data introduces new opportunities for rural ecological landscape research. Technologies such as remote sensing, GIS, GPS, IoT, cloud computing, and artificial intelligence enable comprehensive, accurate, and timely data acquisition. Applications include identifying ecological sources, simulating ecological corridors, analyzing landscape patterns, and evaluating ecosystem services. High-resolution remote sensing and machine learning algorithms can pinpoint biodiversity hotspots and ecological corridors, while IoT-based ecological monitoring systems provide real-time environmental data for conservation management.

3. Theories and Methods for Rural Ecological Network Optimization

G. Concept and Components of Ecological Networks

An ecological network consists of interconnected spatial elements, including ecological sources, corridors, and nodes, designed to promote biodiversity conservation, maintain ecosystem functions, and enhance ecosystem services. Ecological sources are core areas of biodiversity, ecological functionality, or sensitivity, such as nature reserves, forests, and wetlands. Ecological corridors, comprising linear or belt-shaped landscape elements like rivers, green belts, and shelterbelts, provide pathways for species migration, dispersal, and genetic exchange, maintaining the connectivity and integrity of ecosystems. Ecological nodes, such as habitat patches and buffer zones, are critical junctions within the network that regulate ecological flows and support ecosystem functionality.

H. Identification and Selection of Ecological Sources

1) Evaluation Indicators for Biodiversity and Ecological Function Importance

Identifying ecological sources is fundamental to constructing an ecological network. Biodiversity indicators, such as species richness, diversity indices, and the distribution of endemic species, directly reflect the biodiversity level of a given area. Ecological function importance is assessed using ecosystem service values (e.g., water retention, soil conservation, carbon storage), ecosystem stability, and ecological sensitivity. Comprehensive evaluations determine areas with high biodiversity and ecological function importance as ecological sources.

2) *Application of Spatial Analysis Techniques in Ecological Source Identification*

Spatial analysis techniques, such as Geographic Information Systems (GIS), are crucial for identifying ecological sources. GIS integrates biodiversity, ecological environment, and land-use data to accurately locate ecological sources using spatial algorithms. Overlay analysis identifies potential sources by combining biodiversity-rich areas with ecologically important regions. Spatial clustering analysis detects biodiversity hotspots as candidates for ecological sources. Remote sensing technology provides extensive ecological data to support source identification.

I. Construction and Optimization of Ecological Corridors

1) *Types and Functions of Ecological Corridors*

Ecological corridors can be categorized into natural corridors (e.g., river and mountain corridors) and artificial corridors (e.g., greenways and protective shelterbelts). Natural corridors provide essential functions, including habitats, migration pathways, and hydrological regulation, while artificial corridors connect ecological sources, improve environmental conditions, and mitigate human activity interference. The functions of ecological corridors include promoting biodiversity conservation, maintaining ecosystem connectivity, enhancing ecosystem services (e.g., air quality improvement and microclimate regulation), and preserving ecological culture.

2) *Principles and Methods for Ecological Corridor Construction*

Ecological corridor construction follows principles of connectivity, ecological suitability, diversity, and conservation priority. Connectivity ensures effective linkage between ecological sources to form a continuous network. Ecological suitability involves selecting corridor locations and widths based on species' ecological requirements and environmental conditions. Diversity entails creating varied habitats to meet the needs of different species. Conservation priority minimizes disruption to existing ecosystems, protecting biodiversity and the environment. Methods include employing the least-cost path (LCP) model and circuit theory to determine optimal pathways. The LCP model calculates the path of least resistance for species dispersal, while circuit theory simulates species migration and identifies critical areas. Construction should incorporate vegetation restoration, habitat protection, and ecological rehabilitation to enhance corridor functionality.

J. Layout and Function Enhancement of Ecological Nodes

1) *Importance and Classification of Ecological Nodes*

Ecological nodes serve as critical connecting points within the network, providing habitats and feeding grounds for species and facilitating ecological flow exchanges. They can be classified into natural nodes (e.g., lakes, wetlands, forest patches) and artificial nodes (e.g., eco-parks, eco-squares, farmland shelterbelt nodes). Natural nodes possess higher ecological value and biodiversity, while artificial nodes represent zones of interaction between human activities and ecosystems.

2) *Strategies for Node Layout and Function Enhancement*

The layout of ecological nodes should consider their functional roles within the network, ensuring their strategic distribution between ecological sources and corridors to enhance connectivity and stability (Hilty et al., 2020; Nevřelová & Novota, 2020). For example, nodes placed at critical corridor intersections promote species migration and dispersal (Chen et al., 2023; Gao et al., 2023). Function enhancement measures include habitat conservation and restoration to improve conditions and increase biodiversity. Strengthening ecological functions, such as wetland restoration for water purification and flood control or afforestation for carbon storage and climate regulation, is also essential. Additionally, ecological culture development can create spaces for ecological education, tourism, and cultural experiences, raising public awareness and participation in conservation.

4. Pathways and Strategies for Enhancing Rural Landscape Functions

K. Classification and Evaluation of Rural Landscape Functions

1) *Ecological Service Functions*

Rural landscapes provide critical ecological services, including provisioning services (e.g., food, fiber, fuel), regulating services (e.g., climate regulation, air purification, water retention, soil conservation, flood regulation), and supporting services (e.g., habitat provision, biodiversity maintenance, ecosystem balance). These functions are essential for maintaining regional ecological security and human well-being (Zhang & Ye, 2024; Xu et al., 2023; Wang et al., 2022). For example, forest landscapes regulate the climate through photosynthesis, while wetland landscapes purify water, mitigate flood peaks, and provide habitats for species.

2）*Production Functions*

The productive functions of rural landscapes are primarily reflected in agricultural activities, including crop cultivation, livestock farming, and aquaculture. Effective planning and management can achieve sustainable agriculture, increase the yield and quality of agricultural products, and ensure food security. Ecological farming practices, such as intercropping, mixed cropping, and crop rotation, improve land use efficiency, reduce pests and diseases, and protect soil fertility.

3）*Cultural and Aesthetic Functions*

Rural landscapes possess rich cultural and aesthetic values. Historical architecture, traditional villages, folk customs, and pastoral scenery constitute unique cultural landscapes, serving as reservoirs of cultural memory and heritage while offering significant aesthetic appeal (Ding, 2024; Wu et al., 2023). These distinctive landscapes not only foster rural tourism development (Zhao et al., 2022; Feng et al., 2021) but also provide new economic growth drivers and promote rural revitalization (Li & Zhang, 2023). Examples include ancient water towns in southern China and ethnic minority villages in Yunnan, which attract tourists with their distinctive charm.

L. Mechanisms for Enhancing Landscape Functions Through Ecological Network Optimization

1）*Impact of Ecological Network Structure on Landscape Functions*

Characteristics of ecological network structures, such as connectivity, integrity, and network density, significantly influence rural landscape functions. Highly connected ecological networks promote species migration and dispersal, facilitate material and energy flows within ecosystems, and enhance ecological service functions (Yin et al., 2023). Well-connected ecological corridors support wildlife migration, reproduction, and genetic exchange, bolstering ecosystem stability. Comprehensive networks protect more ecological sources and nodes, maintaining ecological diversity and improving overall functionality.

2）*Role of Ecological Flows in Linking Networks and Functions*

Ecological flows—including material, energy, information, and biological flows—serve as critical links between ecological networks and landscape functions. Ecological networks act as conduits for these flows, ensuring their smooth transmission and maximizing landscape functionality (Messager et al., 2023). For instance, river corridors transport water resources, balance hydrological processes, and provide migration paths for aquatic species, fulfilling water-related ecological services. Biological flows, such as seed dispersal and animal migration, sustain biodiversity, influencing ecological support and cultural aesthetic functions.

M. Planning and Design Strategies for Enhancing Rural Landscape Functions

1) *Landscape Pattern Optimization*

Rational planning of rural land use optimizes landscape patterns, enhancing heterogeneity and diversity to improve landscape functions (Balzan et al., 2018; Ortiz-Báez et al., 2021). For example, strategically allocating farmland, forests, grasslands, and water bodies to form mosaic structures increases edge effects, providing habitats and food resources for species (Fan & Xiao, 2020). Preserving natural ecological spaces in rural settlement planning and establishing green infrastructure networks further enhance ecological services (Hamel et al., 2022; Baró et al., 2020).

2) *Application of Ecological Engineering Technologies*

Ecological engineering technologies, such as ecological restoration, wetland construction, green roofs, and rain gardens, improve rural ecological environments and landscape functions. Restoring degraded land enhances soil fertility and ecological services. Constructed wetlands treat domestic wastewater, purify water, and provide habitats. Green roofs and rain gardens increase rainwater infiltration, reduce surface runoff, mitigate flooding, and beautify landscapes.

3) *Conservation and Utilization of Rural Cultural Landscapes*

Preserving and utilizing rural cultural landscapes helps inherit and promote rural culture, enhancing cultural and aesthetic functions. Efforts include protecting and restoring traditional villages and historical buildings to retain their unique character. Integrating rural tourism with cultural products, such as folk experiences and traditional crafts, transforms cultural landscapes into economic resources, driving rural economic development.

5. Experimental Design and Implementation

The optimization of rural ecological networks based on ecological civilization policies enhances ecological functions, landscape functionality, and socio-economic benefits. Optimizing landscape patterns significantly improves ecological connectivity and ecosystem service functions.

N. Study Area

The study selects representative rural areas in China as experimental samples, encompassing various terrains (plains, hills, mountains) and villages with different economic development levels.

O. Experimental Objectives

Quantify changes in rural landscape functions before and after ecological network optimization.

Analyze the impacts of different optimization strategies on biodiversity and ecosystem services.

P. Experimental Data and Analytical Methods

1) Data Collection

a) *Ecological and Landscape Data*

Remote Sensing: Landsat 8 imagery (30m resolution) for land-use type and change analysis.

GIS Data: Terrain, soil types, vegetation cover, and river distribution.

b) *Socio-Economic Data*

Village socio-economic status, population density, and income levels.

Ecosystem service data such as water resource utilization and carbon sequestration.

c) *Biodiversity Data*

Field surveys documenting species composition and abundance.

Infrared cameras tracking key species' activity.

2) Data Processing

a) *Ecological Source Identification*

Overlay analysis of multiple indicators (biodiversity index, ecosystem service importance).

Use of MSPA (Morphological Spatial Pattern Analysis) to identify ecological sources and core landscape patches.

b) *Ecological Corridor Construction*

Least-cost path (LCP) modeling for optimal corridor routing.

Circuit theory to simulate ecological flows and pinpoint critical connections.

c) *Landscape Function Evaluation*

Calculation of landscape metrics (e.g., patch density, connectivity index).

Integration of socio-economic indicators to assess optimization effectiveness.

Q. Experimental Process

1) *Baseline Assessment of Rural Ecological Networks*

Extract land-use data using GIS and remote sensing technologies.

Map the landscape pattern and compute baseline connectivity indices (e.g., IIC, PC).

Analyze the distribution and functionality of existing ecological sources and corridors.

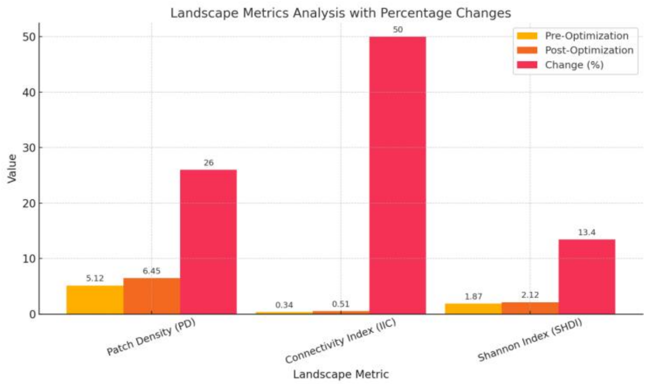

Fig.1. Landscape Pattern Analysis Diagram

2) *Ecological Network Optimization Strategies*

Plan new ecological corridors and nodes aligned with policy objectives.

Simulate various optimization scenarios (e.g., conservation priority, functionality enhancement, economic benefit maximization).

Compare the impacts of different scenarios on ecological connectivity and biodiversity.

3) *Implementation of Landscape Function Enhancement Practices*

Conduct ecological restoration projects, such as planting native vegetation and restoring degraded wetlands.

Optimize rural land-use structures and build multifunctional green infrastructure.

Introduce ecological buffer zones and artificial habitats at critical ecological nodes.

4) *Evaluation of Optimization Effects*

a) *Ecological Function Assessment*

Monitor the increase in species and population numbers.

Measure changes in carbon storage, water retention, and soil conservation.

b) *Socio-Economic Benefit Evaluation*

Compare agricultural product quality and market benefits pre- and post-optimization.

Analyze changes in tourist numbers and tourism revenue.

c) *Aesthetic Function Assessment*

Conduct surveys of resident and visitor satisfaction with rural landscapes.

Measure participation rates in cultural activities and the utilization of public spaces.

R. Results Presentation and Analysis

1) *Data Statistics and Analysis*

Landscape Metrics Analysis:Use FRAGSTATS to calculate landscape metrics before and after optimization, such as LPI (Largest Patch Index) and SHDI (Shannon Diversity Index).Compare changes in landscape heterogeneity (see Table 1).

Table. 1.

Metric	Before Optimization	After Optimization	Change Rate
Patch Density (PD)	5.12	6.45	+26.0%
Connectivity Index (IIC)	0.34	0.51	+50.0%
Shannon Index (SHDI)	1.87	2.12	+13.4%

Ecosystem Service Improvements:Compare water quality improvements and soil erosion reduction (see Table 2).

Table. 1.

Service Function	Before Optimization	After Optimization	Improvement Rate
Water Quality (COD, mg/L)	8.6	4.3	-50.0%
Soil Erosion Reduction (tons)	1200	950	-21.0%

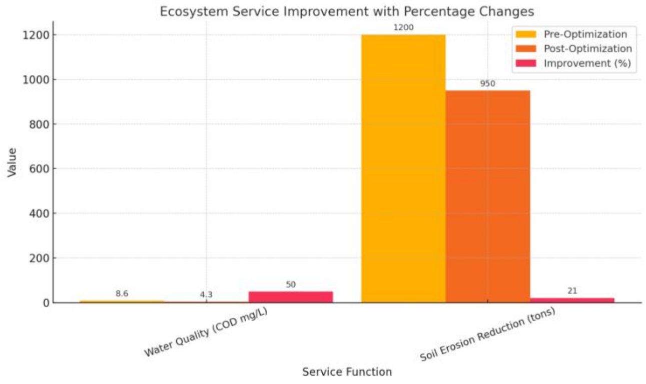

Fig.2. Ecosystem Service Improvement Graph

Socio–Economic Impacts:Increase in farmer income: +30%.Growth in tourist numbers: +45%.

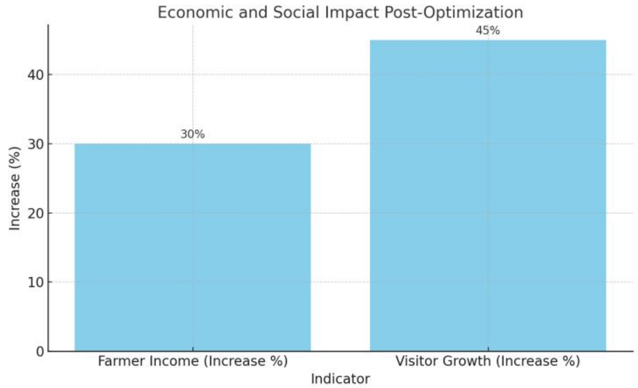

Fig.3. Economic and Social Impact Chart

6. Conclusion and Outlook

S. Main Conclusions

This study, through an analysis of research trends and practical applications in rural ecological landscape biodiversity and ecological network optimization, has drawn the following conclusions:

1) *Research Trends*

The focus of rural ecological landscape biodiversity research has shifted from the impacts of urbanization to sustainable development and human livelihoods.

Emerging trends include interdisciplinary integration, synergetic optimization of ecological networks and landscape functions, and the application of big data and new technologies.

2) *Ecological Network Optimization*

Effective rural ecological network optimization requires scientific identification of ecological sources, rational construction of corridors, and optimized node layout.

Measures based on ecological civilization policies significantly improve the structure of rural ecological networks.

3) *Landscape Function Enhancement*

Rural landscape functions can be enhanced through landscape pattern optimization, application of ecological engineering technologies, and conservation and utilization of rural cultural landscapes.

Case studies demonstrate that these measures significantly improve ecological services, production functions, and cultural and aesthetic values, thereby promoting rural sustainable development.

3) *Experimental Validation*

This experimental study confirms that ecological network optimization substantially enhances landscape connectivity and stability.Optimizing landscape functions not only strengthens ecosystem services but also stimulates economic growth and social engagement.Comprehensive optimization strategies align better with the goals of ecological civilization policies, offering valuable insights for broader application.

T. Limitations and Outlook

While this study has made certain advancements in optimizing rural ecological networks and enhancing landscape functions, it still presents some limitations. The quantitative analysis of ecological flows in the optimization process is insufficiently detailed, and precise simulation of ecological processes is lacking. In evaluating the effects of landscape function enhancement, some indicators lack robust quantification methods, introducing subjectivity. Additionally, the research primarily focuses on a single rural area, with limited exploration of the generalizability of models across different geographical regions and socio-economic conditions.

Future research should emphasize deeper interdisciplinary integration to explore the coupling relationships between ecological network structures and processes, improving the accuracy of ecological flow simulations. It is also necessary to refine the evaluation indicator system for landscape function enhancement effects, incorporating long-term monitoring and dynamic assessment. Comparative studies across regions should be conducted to identify optimization strategies suitable for various rural types, providing more targeted and practical scientific guidance for rural ecological civilization construction.

Furthermore, greater attention should be paid to public engagement and the comprehensive consideration of socio-economic factors, ensuring that optimization strategies align closely with the actual needs of rural areas. This approach will enable the realization of coordinated development across ecological, economic, and social dimensions.

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