A Review on the Theory and Principle of the Division of "Production-Living-Ecology" Spaces

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Abstract From the concept of the "Production-Living-Ecology" Spaces, this paper sorts out the theoretical basis, division principles, and division methods of the "Production-Living-Ecology" Spaces, and then proposes future prospects for them. The integration of theory and practice of "Production-Living-Ecology" Spaces is currently in a stage of in-depth exploration and practical application. Future research should fully recognize the importance and necessity of theoretical research on "Production-Living-Ecology" Spaces under the new situation, and consolidate the theoretical foundation for research on the development and protection of territorial space in the new era.

Key words "Production-Living-Ecology" Spaces, Division methods, Territorial spatial planning, Ecological priority

0 Introduction

At the current stage in China, the rapid development of urbanization has, to some extent, caused increasingly tight local resource constraints and growing ecological pressures. Objectively, this has imposed serious pressure on the development and protection of China's territorial space. Therefore, the Central Committee of the Communist Party of China proposed the concept of scientifically delineating the three major spaces, namely, production, living, and ecology. This aims to optimize spatial structure and plan spatial layout by defining their boundaries, thereby providing theoretical support for scientifically formulating policies on the development and protection of territorial space. Since 2012, the Chinese government has continuously emphasized the importance of ecological civilization construction and spatial planning, and put forward the overall development layout of the "Five-sphere Integrated Plan". Subsequently issued relevant policies have progressively refined the concept and management measures for the "Production-Living-Ecology" Spaces. In November 2012, the report to the 18th CPC National Congress first proposed the goal of ecological civilization construction, emphasizing the integration of spatial planning and the importance of ecological protection. In 2013, the Third Plenary Session of the 18th CPC Central Committee further stressed the necessity of establishing a unified spatial planning system. In 2015, the *Overall Plan for Ecological Civilization System Reform* was issued, aiming to optimize spatial structure and proposing a spatial planning system with hierarchical management. In 2017, the Provincial Spatial Planning Pilot Program served as a concrete practice of relevant planning, designed to scientifically delineate "Production-Living-Ecology" Spaces, ensuring the sustainable development of "Production-Living-Ecology" Spaces In October 2022, the 20th National Congress emphasized the idea of ecological civilization as the fundamental principle to promote the construction of ecological civilization in the new era with high quality. Among them, the "two mountains theory", "beautiful China" and "clean and beautiful world" as guiding concepts, as well as the planning of the main functional areas as strategic arrangements, the scientific layout of "Production-Living-Ecology" Spaces and the high-level utilization of land and space resources as a whole, *etc.*, embody the spatial planning of the construction of ecological civilization in the new era and provide space for the construction of ecological civilization in the new era, to ensure the sustainable health of the ecological environment and the sustainability of human activities.

From a theoretical perspective, the relevant policy and institutional framework has been clarified; however, from an application perspective, the division theories and principles of "Production-Living-Ecology" Spaces still exhibit certain ambiguities. For example: diversity in connotative definitions; diversity in identification and classification methods; scale dependency in optimization development research; and complexity in internal operational mechanisms and management strategies. These factors present challenges in practical operations for delineating spatial boundaries

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and studying composite functions. Therefore, exploring the delineation theories, methods, and principles of "Production-Living-Ecology" Spaces adapted to territorial spatial planning will provide theoretical basis and foundational support for resolving issues in "Production-Living-Ecology" Spaces-related theory and practice, promoting ecological civilization construction and effective scientific spatial planning. Existing research has revealed the conceptual framework, characteristics, and influencing factors of "Production-Living-Ecology" Spaces, yet in-depth analysis of their spatial division theories and principles remains incomplete. This study, starting from the concept of "Production-Living-Ecology" Spaces, sorts out the theoretical foundations for their division, analyzes quantitative analysis techniques for division methods and division principles, and subsequently proposes prospects for "Production-Living-Ecology" Spaces.

1 Theoretical foundation and interrelationship of "Production-Living-Ecology" Spaces

1.1 Theoretical foundation The theoretical foundation of "Production-Living-Ecology" Spaces integrates knowledge from multiple disciplines such as geography, ecology, and urban planning. Geography provides the theoretical basis for spatial differentiation and spatial structure in delineating these spaces; through analyzing geographical characteristics and spatial relationships of territorial space, it will facilitate understanding of the distribution and evolution patterns of "Production-Living-Ecology" Spaces. Ecological principles emphasize the importance of ecological protection and ecosystem services, guiding the sustainable development of "Production-Living-Ecology" Spaces and advocating for maintaining ecosystem integrity and stability in planning. Urban planning focuses on optimizing the layout and functional coordination of "Production-Living-Ecology" Spaces; through rational planning and management, it promotes their harmonious coexistence. The comprehensive application of multidisciplinary approaches provides a solid scientific foundation for theoretical construction and practical implementation of "Production-Living-Ecology" Spaces. In actual spatial composition, "Production-Living-Ecology" Spaces often interpenetrate and intertwine, forming a complex multidimensional network.

1.2 Interrelationship Relevant scholars have conducted in-depth research on the connotation and interrelationships of "Production-Living-Ecology" Spaces. Liu Yansui *et al.* [1] regarded "Production-Living-Ecology" Spaces as an organic whole, asserting that interdependence and mutual constraints exist among them; Li Guangdong *et al.* [2] emphasize that ecological, production, and living spaces encompass biophysical processes, direct/indirect production, and satisfaction of spiritual-cultural needs, viewing them as products of synergistic coupling between natural systems and socioeconomic systems. Huang Jinchuan[3] *et al.* respectively define the dominant functions of production space, living space, and ecological space, pointing out the interaction mechanisms of the 'three major spaces' in regional ecological security. Zhang Hongqi and Zhu Yuanyuan *et al.* [4] refine "Production-Living-Ecology" Spaces into specific production land, living land, and ecological land based on land-use attributes. Liu Yan *et al.* [5] propose functional positioning for living space, production space, and ecological space by integrating Marxist ecological civilization spatial layout philosophy, while highlighting ecological space's foundational supporting role for production and living spaces. Although existing research reveals the multidimensional connotations of "Production-Living-Ecology" Spaces, exploration of their formation mechanisms remains insufficient, leading to conceptual interpretation differences. These preceding perspectives focus on integrating the intension and extension of "Production-Living-Ecology" Spaces within different theoretical frameworks to establish a more comprehensive and consistent "Production-Living-Ecology" Spaces theory, thereby laying a solid research foundation for this study.

The "Production-Living-Ecology" Spaces represent an integrated territorial spatial organization framework encompassing three dimensions: production, living, and ecology. This classification not only reflects the comprehensive objectives of territorial spatial management but also demonstrates the strategic significance of optimizing territorial spatial layout[6]. From the perspective of human-nature interaction, ecological spaces form the foundation for production and living spaces, serving as the "primary space" that provides ecological products and services[7]. Production and living spaces, meanwhile, are concentrated areas of human activity, respectively fulfilling functions related to economic production and daily life[8]. The health of ecological spaces directly impacts the sustainability of production and living spaces, while production and living activities must account for the protection and restoration of ecological spaces[9]. As societal recognition of the importance of ecological civilization deepens, human activities have begun to place greater emphasis on making positive contributions to ecological spaces. This shift aims to achieve a rational delineation of the "three functions" (production, living, ecology), thereby providing support for the formulation of territorial spatial planning[10].

2 Division principle of "Production-Living-Ecology" Spaces

2.1 Scientific and operational principles The combined use of qualitative and quantitative methods is essential for ensuring both scientific soundness and practical value in research on "Production-Living-Ecology" Spaces. Qualitative analysis helps uncover the socioeconomic complexities and underlying rationales behind "Production-Living-Ecology" Spaces planning, while quantitative analysis quantifies these phenomena through mathematical models and statistical tools, thereby providing more precise and comparable data. This integrated approach enables researchers to compre-

hensively understand land-use changes and conduct effective evaluations. For quantitative calculations, adherence to standardized research procedures and data processing protocols is critical for enhancing research quality. This includes ensuring data representativeness, accuracy, and completeness, as well as applying appropriate statistical methods during analysis. In constructing the indicator system, selected metrics must demonstrate operational practicability, feasible for implementation, and support effective real-time monitoring. Concurrently, data acquisition for these indicators should follow standardized and streamlined procedures, with all data being stable and reliable to facilitate comparative analyses across different time periods and regions.

2.2 Holistic and hierarchical principles "Production-Living-Ecology" Spaces emphasize the multifunctionality of land use and the holistic coordination of multi-attribute spaces. The holistic principle requires considering the interactions and interdependencies within "Production-Living-Ecology" Spaces as an organic whole during planning and management, ensuring harmonious coexistence among the three dimensions. The hierarchical principle addresses the tiered relationships between functions within "Production-Living-Ecology" Spaces, as well as the manifestation forms and management requirements of these functions across different spatial scales. The intrinsic attributes of territorial space demand that decision-makers holistically balance diverse spatial needs, necessitating adherence to both the holistic principle regarding the research subject and the hierarchical principle throughout the research process. Consequently, when establishing an evaluation framework for "Production-Living-Ecology" Spaces, corresponding indicator systems should be developed for distinct assessment objectives and targets to ensure the objectivity and impartiality of evaluation outcomes.

2.3 Principle of suiting measures to local conditions When constructing the suitability evaluation indicator system for "Production-Living-Ecology" Spaces, regional diversity must indeed be considered. Each area possesses its unique natural conditions, resource endowments, economic development status, and land resource conditions. These factors collectively determine region-specific demands and constraints; therefore, when formulating suitability evaluation criteria for "Production-Living-Ecology" Spaces, strategies must be flexibly adjusted based on actual circumstances to fully leverage local advantages, mitigate weaknesses, and avoid a "one-size-fits-all" approach. To ensure the scientific soundness and rationality of the "Production-Living-Ecology" Spaces suitability evaluation system, in-depth field investigations and data analysis of empirical areas remain essential. This enables accurate identification of key regional characteristics and potential issues, ensuring selected indicators not only comprehensively reflect local realities but also effectively guide sustainable regional development.

2.4 Sustainable development During the implementation of territorial spatial planning and the oversight of land use regulation, the principle of balancing development with protection, and regulation with efficiency, is emphasized. Protection is not only a prerequisite for development but must also ensure that ecological conservation consistently takes precedence. This is fundamental for maintaining the supply limits of natural resources, ensuring food security, and safeguarding ecological and environmental safety. By conducting a comprehensive evaluation of development suitability, agricultural capacity, and ecological functionality, the dominant function of land parcels is identified on this basis. Adhering to the principle of sustainable development in the exploitation and protection of land and resources helps balance economic activities with environmental conservation. This ensures the effective protection of natural assets within the region while accommodating the needs of social and economic development.

3 Division methods of "Production-Living-Ecology" Spaces

3.1 Division of living spaces Existing research on dividing living spaces primarily relies on classification systems and the interpretation of medium-to-high resolution remote sensing imagery, or categorizes land based on current land-use data. While feasible, this approach has limitations in simply merging land types through hierarchical classification[11]. Living spaces encompass not only residential areas but also zones providing service consumption, work-study activities, and leisure and entertainment. During China's rapid urban-rural transformation, the multifunctionality of rural living spaces and the diversity of urban living spaces necessitate more precise and efficient spatially explicit extraction methods.

3.1.1 Division based on nighttime light data. Given the limitations of traditional classification methods in capturing spatial dynamics and multifunctional integration, high-temporal-resolution nighttime light data offers an effective supplementary approach and breakthrough solution. The advent of nighttime light data has opened new research avenues for urban expansion studies[12]. DMSP-OLS stable nighttime light imagery and NPP-VIIRS monthly composite nighttime light imagery stand as the most widely utilized data sources for reflecting urban development dynamics and documenting human activities[13]. These datasets enable estimation of key indicators including: gross domestic product (GDP) and population; energy consumption; carbon dioxide emissions; gas flaring monitoring; fisheries surveillance[14]. Scholars have used nighttime light data to extract urban built-up areas, for example, EWING R *et al.* used nighttime light data to extract urban built-up areas in their research in 1997[15]. After the opening of NPP-VIIRS data, with the in-depth study of nighttime light data, it has made great contributions to the updating of national basic geographic information database and the monitoring of geographic conditions[16]. Nighttime light data has the characteristics of timely updating, which has great advantages for geographic national con-

ditions monitoring[17]. The combination of nighttime light data and medium and high resolution remote sensing data provides reliable data support for more refined quantitative research[18].

3.1.2 Division based on urban-rural construction land extraction. In the field of urban-rural construction land extraction, the application of DMSP-OLS remote sensing imagery has become quite mature. Its stable nighttime light data is particularly effective for distinguishing built-up areas from non-built-up areas[19]. A notable characteristic of the data is the existence of a transition zone with rapidly increasing radiation values at the edges of built-up areas. Within this, the growth rate of radiation values in the transition zone between urban built-up areas and built-up core areas far exceeds that between built-up areas and non-built-up areas[20]. This indicates that transition zones are more easily identified in NPP-VIIRS data[21]. To optimize the extraction process of regional construction land, logarithmic transformation processing is adopted to adjust the growth rate of spectral values. This mitigates the influence of transition zones while simultaneously enhancing their distinctive features. Such processing also helps narrow the distribution range of spectral values, thereby simplifying interpretation and analytical work. This makes NPP-VIIRS data an effective tool for extracting regional construction land[22]. Furthermore, compared to the lower-resolution DMSP-OLS data, NPP-VIIRS data provides higher spatial detail. This further improves the accuracy and practicality of regional construction land extraction[23].

3.2 Division of production spaces Production space includes industrial, logistics warehousing, transportation facilities, public facilities and other land use space. According to the allocation and utilization of land space, management characteristics and coverage characteristics, production space involves many levels and fields, including but not limited to land use types related to industrial production and economic activities, theoretical construction of rural production space system, and practical application of land space optimization. These studies are of great significance for promoting regional sustainable development. The research on identification and optimization of production space focuses on identifying the current spatial structure, pattern and problems, and optimizing the layout of future production space in order to achieve balanced and sustainable development of space. This research method is more comprehensive and has become an important subject of academic frontier and territorial spatial planning[24]. At present, the main division methods of production space focus on three aspects.

3.2.1 Production space analysis and evaluation method. Using GIS and remote sensing technology, the data of production space are acquired and processed with high precision and efficiency, and the distribution characteristics, evolution laws and their relationships of production space are further revealed. Through the construction of comprehensive evaluation index system, the development level, coordination degree and sustainability of production space are evaluated, which provides a scientific basis for optimization decision-making.

3.2.2 Production space optimization decision-making technology. Based on multi-objective decision analysis, spatial optimization model and other methods, the production space is optimized in terms of functional zoning, land use layout and resource allocation. Considering the complexity and dynamics of the production space, uncertainty analysis and risk assessment should be integrated into the decision-making process to improve the robustness and adaptability of the optimization scheme.

3.2.3 Production space planning and control. Through the formulation of territorial space planning, the development goals, positioning, layout and control requirements of production space are defined, and the rational allocation and efficient utilization of various space resources are guided. Establish a space control system to strictly supervise the development intensity, use conversion and ecological protection of production space, so as to ensure the implementation of the optimization scheme. Future research trends may pay more attention to interdisciplinary integration, combined with GIS, big data analysis, artificial intelligence and other advanced technologies, in order to achieve intelligent and refined division of production space.

In the future, we need to further improve the theoretical system of production space division. Firstly, we should explore more scientific and reasonable production space optimization methods to provide strong support for the high-quality development of China's territorial space. Secondly, we should strengthen interdisciplinary cooperation, especially interdisciplinary cooperation and exchanges, and learn from the theories and methods of other disciplines to provide a broader vision and ideas for the study of production space division; Finally, in promoting the integration of policy and practice, we should strengthen the research on the formulation and implementation of production space division policy, promote the deep integration of policy and practice, and promote the intensive and efficient production space.

3.3 Division of ecological spaces Ecological space is an important carrier for systematically implementing Xi Jinping's ecological civilization concept, and also a key area for carrying out all-region, all-element territorial spatial governance. Ecological space aims to fulfill the primary function of providing ecological services or ecological products, safeguarding national ecological security, and strengthening ecological civilization construction. The continuous deepening of ecological space demarcation methods has achieved significant progress in multiple aspects including theoretical construction, technical approaches, and practical applications, playing an important role in promoting regional sustainable development. Based on ecological function zoning, relevant scholars have proposed effective ecological space zoning methods and constructed evaluation index systems incorporating multiple factors such as ecosystem services, ecological sensitivity, ecological quality, and ecological health[25]. Meanwhile, threshold selection is also one of the research focal points, emphasizing the need to fully consider policy objectives, resident demands, and sustainable de-

velopment requirements[26].

3.3.1 Research method permeability. Quantitative analysis methods are applied to different ecological themes. For instance, in ecological space value assessment, mathematical statistics, contingent valuation, and iconography are adopted; in research on ecological space and resident well-being, behavioral analysis and GIS spatial analysis are utilized; in studies of ecological space patterns, remote sensing analysis and big data analysis are employed. These research methods encompass multiple domains including data analysis, model construction, social surveys, and psychological perception. In conceptual research on ecological space and ecological land, although certain achievements have been made in aspects such as definition, logical relationship analysis, and research progress, limitations and shortcomings still exist[27]. Currently, unified understanding regarding the connotations of ecological space and ecological land has not been reached, and their identification methods and classification systems require further improvement. Moreover, previous research primarily focused on urban areas, relatively neglecting rural ecological development demands. Therefore, in terms of research methodology, quantitative analysis, particularly spatial analysis and optimization models, are more frequently used, while qualitative analysis, especially methods like psychological perception and social surveys, are less applied[28].

3.3.2 Progress in technological research. In order to improve the accuracy and practicability of ecological space division, various data sources and analysis tools are being integrated, including remote sensing images, GIS analysis, ecological models and so on. The application of these technologies will help to achieve precise management and sustainable use of ecological space. With the development of ecological space classification, researchers are trying to build a more complex and comprehensive ecological space classification system to meet the needs of construction of ecological civilization and sustainable development. With the progress of technology and the development of theory, the future ecological space division will pay more attention to the integrity and functionality of the ecosystem, as well as the spatial planning concept of harmonious coexistence between man and nature[29].

Future research needs to focus not only on the static classification of ecological space but also consider the dynamic changes of ecological space, the spatial differentiation of ecological service functions, and the interactions between ecological space and other spatial types (such as production space and living space). For instance, research on the identification and optimization of "Production-Living-Ecology" Spaces has achieved phased results. Researchers are committed to improving quantitative identification methods and technical systems, and exploring the dynamic evolution and driving mechanisms of ecological space. Additionally, an analysis framework for identifying and optimizing "Production-Living-Ecological" Spaces based on resident behavior has been proposed. This method emphasizes the importance of resident behavior in spatial planning, providing a "people-oriented" theoretical framework for territorial spatial planning[30].

4 Prospects

At present, the Third Plenary Session of the 20th CPC Central Committee has further deployed the deepening of ecological civilization system reform, proposing seven "focal points." Among these, the fifth "focal point" explicitly requires focusing on building a Beautiful China, accelerating the comprehensive green transformation of economic and social development, improving the ecological environment governance system, advancing ecological priority, conservation, intensification, and green low-carbon development, and promoting harmonious coexistence between humans and nature. Therefore, strengthening and optimizing theoretical and methodological research on "Production-Living-Ecology" Spaces becomes particularly crucial. "Production-Living-Ecology" Spaces constitute key components of integrated urban-rural development. To ensure their harmonious coexistence and efficient utilization, establishing a robust theoretical foundation and methodological framework is imperative. Future practical applications of "Production-Living-Ecology" Spaces will primarily target five aspects: (i) Refined management and regulation strategies: researching how to achieve efficient utilization of these spaces and continuous ecological improvement through precision management and policy regulation; (ii) Application of spatial data analysis technologies: utilizing GIS, remote sensing, and other spatial data analysis technologies to more accurately assess changes in these spaces, providing scientific basis for decision-making; (iii) Ecological compensation mechanisms: exploring the establishment of ecological compensation mechanisms to incentivize local governments and communities to protect and restore ecological spaces; (iv) Interaction between resident behavior and these spaces: studying how resident behaviors influence the formation and evolution of these spaces, and how behavioral changes can optimize them; (v) Case studies and empirical analysis: conducting in-depth analysis of management experiences in specific regions to extract replicable models and strategies.

This study outlines four major division principles and the division methods for three types of spaces, along with their respective emphases. This holds certain significance for strengthening the integrated development concept of "Production-Living-Ecology", improving the mechanism for integrated protection and systematic management of "mountain- river-forest-farmland-lake-grassland-desert", and particularly carries important fundamental significance for establishing a high-quality territorial space planning system.

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