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An Exploratory Study on Ecosystem Services in National Parks

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Abstract

National parks, as an important type of nature reserve, are crucial for maintaining the balance between human society and the natural system. The ecosystem service (ES) value of national parks holds significant guiding significance for the protection effectiveness and sustainable management of national parks. We summarize the relevant research achievements on the ESs of national parks from 2000 to the present, elaborating in detail on three aspects: ecosystem service assessment, trade-offs and synergies of ecosystem services, and driving factors of ecosystem service functions, and point out their shortcomings. The aim is to provide a reference for the sustainable development and scientific planning of national parks in China.

Keywords

Ecosystem Services, Trade-Offs and Synergies, National Parks, Nature Reserve

1. Introduction

National parks serve as vital protected areas that deliver multiple ecosystem services—including biodiversity conservation, water retention, and recreational and cultural services—playing a crucial role in maintaining regional ecological balance and enhancing human well-being [1]. Amidst the intensification of global climate change and increasing human activities, national parks are confronting unprecedented challenges to their ecological integrity and the stability of ecosystem services. In this context, how to scientifically quantify the supply capacity of ecosystem services in national parks, accurately assess their spatial heterogeneity and temporal dynamics, and thereby construct sustainable management and regulatory

mechanisms constitutes a pivotal challenge for achieving synergistic outcomes between ecological conservation and regional sustainable development. This review synthesizes research progress in this field from the year 2000 to 2024, systematically analyzing three key dimensions: ecosystem service assessment, trade-offs and synergies among ecosystem services, and driving factors of ecosystem service functions. It further explores emerging research trajectories in national park ecosystem services, aiming to provide a theoretical foundation for ecological conservation and high-quality sustainable development of China's national park system.

2. Literature Retrieval and Screening

This study takes the ecosystem services of national parks as the research object, comprehensively selecting two databases as literature sources: China National Knowledge Infrastructure (CNKI) and the Web of Science (WoS) core collection. In the Chinese literature search, CNKI was used as the data source with advanced search mode, setting the subject terms as "national park" containing "ecosystem services" or "national park" containing "ecosystem services", with the time range limited to January 1, 2000 to December 31, 2024, initially retrieving 852 relevant articles. For international literature search, the WoS core collection was used as the data source with advanced search mode, setting the search query as "(national park OR natural protection area) AND ecosystem services", with the time range limited to 2000-2024, initially retrieving 2,723 relevant articles. After preliminary literature retrieval, screening must be conducted according to the following criteria: 1) The research subject must explicitly focus on national parks or equivalent-level protected areas; 2) The research content must involve ecosystem service assessment, trade-offs/coordinations, or driving mechanisms; 3) The literature type must be research papers or reviews, excluding non-academic documents such as news reports and commentaries, full-text unavailable articles, and studies unrelated to the research region or containing duplicate content.

Notably, when determining search terms, we simultaneously incorporated "national parks" and "nature reserves", primarily based on the following considerations: 1) Historical evolution and literature continuity: As early core carriers of global ecological conservation, nature reserves have earlier-started ecosystem service research and more mature theoretical frameworks. National parks, as a new protected area model balancing conservation and sustainable utilization, derive their studies mainly from extensions and innovations of nature reserve theories. Moreover, since national park systems were established later than nature reserves both domestically and internationally, separately searching for national park literature could lead to missing early research data. Supplementing with nature reserve literature not only fully presents the research evolution from traditional conservation to collaborative utilization in this field but also fills temporal gaps in literature, ensuring comprehensive data coverage. 2) Commonality analysis of research subjects: Both share core conservation targets—ecosystems of significant

ecological value. Their core ecosystem services supply mechanisms and evaluation methods, such as water source conservation, biodiversity maintenance, and soil preservation, exhibit high overlap. This allows sharing technical frameworks and research methodologies, providing methodological references for national park studies. 3) Research Objectives: While national parks are characterized by "synergy between conservation and utilization" and nature reserves prioritize "strict protection", both share the core research objective of "quantifying ecosystem service values to support ecological conservation decisions". The findings from nature reserve studies can provide baseline references and comparative benchmarks for national park research, helping to reveal the unique service functions of national parks and identify optimization directions. In conclusion, this retrieval strategy not only conforms to the historical logic and data integrity requirements of academic research, but also can realize the effective complementarity of literature resources through common basis and goal association, laying a more comprehensive theoretical and empirical foundation for review research.

3. Current State of Research on Ecosystem Services in National Parks

As the pinnacle of the protected area system, national parks are a critical vehicle for synergizing ecological conservation and sustainable development. Their ecosystem services have become a focus of research in ecology, geography, and related disciplines [2]. In recent years, research on ecosystem services in national parks has evolved significantly. The research content is shifting from qualitative to quantitative assessment and from evaluating single ecosystem service to investigating interrelationships among multiple services. Currently, the research scale is expanding from localized areas to encompass the spatial patterns of entire national parks, while the methodologies are increasingly integrating remote sensing, GIS, and modeling simulation techniques. A search of the CNKI database, using "national park" and "ecosystem service" as keywords, yielded approximately 576 relevant publications from 2000 to 2024. Correspondingly, a query of the Web of Science Core Collection with the search terms "national park" or "natural reserve" combined with "ecosystem service" returned about 1295 academic articles.

As shown in **Figure 1**, the annual publication output of research on ecosystem services in national parks in China remained below 10 articles between 2000 and 2014. Since the proposal of the national park system in 2013, the number of related publications has gradually increased. The period from 2019 to 2024 represents the peak of publication activity, with annual output exceeding 50 articles. Concurrently, the research dimensions have significantly diversified, with a growing number of publications appearing in leading Chinese journals such as *Acta Geographica Sinica*, *Acta Ecologica Sinica*, and *Environmental Science*. As illustrated in **Figure 2**, publications on ecosystem services in national parks indexed in the Web of Science Core Collection demonstrate a marked upward trajectory from 2000 to 2024. In particular, the annual output remained below 10 articles prior to 2010, followed

by a consistent increase that culminated in a peak of 178 publications in 2022, and a notable increase was also observed in studies focusing on the regulating services of national parks.

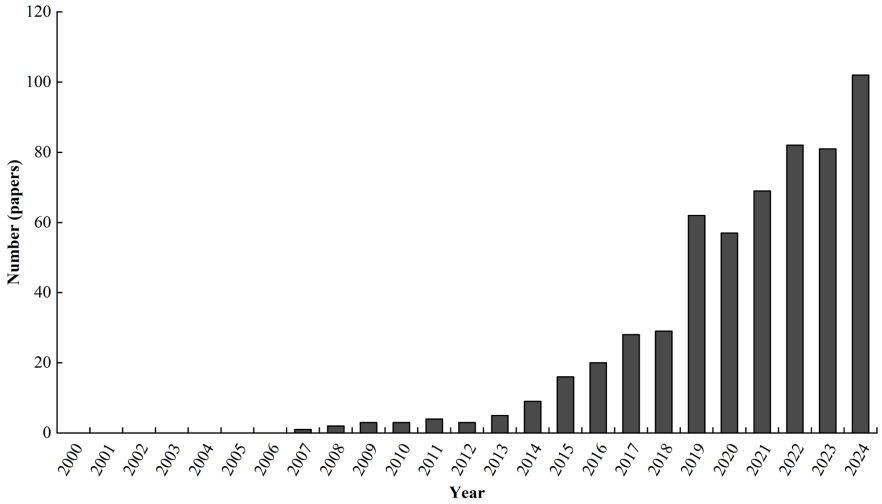

Figure 1. Changes in the number of articles in the CNKI database over the years.

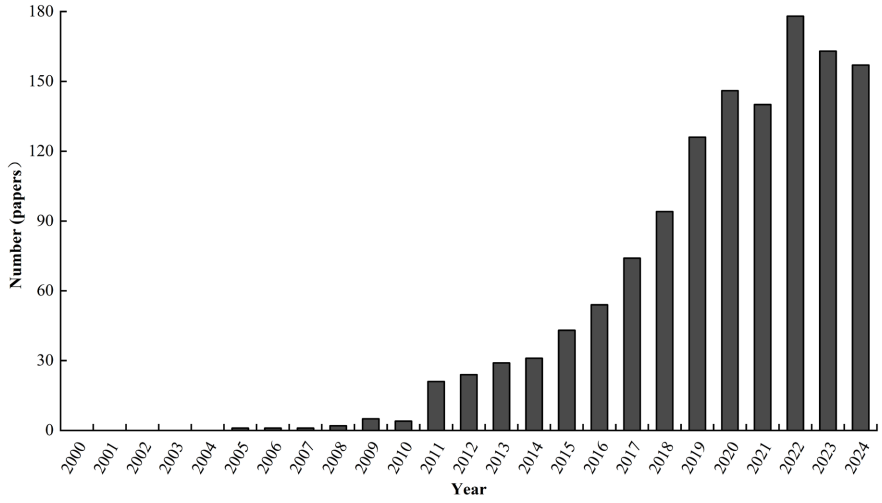

Figure 2. Changes in the number of documents on national park and ecosystem services in the Web of Science core database over the years.

3.1. Assessment of Ecosystem Services in National Parks

The quantitative assessment of ecosystem services aims to analyze the utility and economic value of ecosystem services in national parks through quantitative methods, thereby providing a scientific basis for effective ecosystem management and the formulation of ecological conservation strategies [1]. The typical case studies of ecosystem service assessment in national parks are presented in **Table 1**. Cao *et al.* [3] employed market valuation methods and the InVEST model to evaluate ecosystem service values in Wuyishan National Park from 1990 to 2020, revealing an overall downward fluctuation trend in these services across the region. Using

the InVEST model and Land Use and Land Cover Change (LUCC) data, Choudhary *et al.* [4] found that from 2009 to 2015, the area of bird habitats in India's Keoladeo National Park decreased from 18.28 km^2 to 11.13 km^2 due to land cover degradation and invasive species, revealing a significant deterioration in habitat quality. Pache *et al.* [5] estimated the economic value of carbon sequestration in Romania's national forests over the next decade to be approximately $1.7 million, which provides a basis for carbon trading policies and setting conservation priorities. The ecosystem service assessment study of Qianjiangyuan National Park [6] in China found that the material quantity of soil conservation, carbon sequestration, oxygen release and habitat quality services has been increasing continuously in the past 30 years, and the overall ecosystem services showed a spatial pattern of high in western China and low in eastern China. However, these case studies have predominantly focused on assessing the use values of national park ecosystem services, such as provisioning and regulating services [7]. With growing emphasis on the diverse functional demands for national parks, scholarly attention is increasingly shifting toward *evaluating* non-use values, particularly cultural services. Research has shown that perceptions [8], policy preferences [9], and willingness to pay [10] vary significantly across different beneficiary groups—including local residents, tourists, and students—which directly influences both the valuation of ecosystem services and their integration into national park management decisions.

Table 1. Typical cases of ecosystem services research in national parks.

National Park	Research Method	Core Ecosystem Services	Findings
Wuyi Mountain National Park, China [3]	Value assessment, InVEST model	Product supply, water conservation, soil conservation, carbon storage, biodiversity	The proportion of each function of ecosystem services changes dynamically, which is greatly affected by the output and value of soil conservation, carbon storage, water conservation and other parts
Keoladeo National Park, India [4]	InVEST model	Habitat quality	Between 2009 and 2015, habitat was reduced and habitat quality decreased significantly
Retezat National Park, Romania [5]	Value assessment	Carbon sequestration	Quantifying carbon sink value to support conservation decisions
Qianjiangyuan National Park, China [6]	InVEST model	Water supply, soil conservation, carbon sequestration and oxygen release, habitat Quality	Ecosystem services have generally increased over the past 30 years
Liaohe Estuary National Park, China [7]	MaxEnt model	Cultural services	The supply of cultural services in ecosystem category is greater than that in service flow within the region

3.2. Research on Trade-Offs of Ecosystem Services in National Parks

As a quintessential form of protected area, national parks play a critical role in the protected area system, with national parks as its cornerstone, which makes their ongoing conservation and management particularly crucial. Currently, the role of ecosystem services in national park management and decision-making is becoming increasingly prominent, making their integration into planning and policy processes an imperative [1]. However, national parks have limitations in coordinating ecological protection and the distribution of human interests. They involve multiple stakeholders, making relevant governance a complex trade-off process. At present, the research on the trade-offs between ecosystem services in national parks mainly focuses on two aspects. One is to examine the interrelationships between paired or multiple ecosystem services within national parks [11] [12], and the other is to focus on the perceptions and preferences of stakeholders regarding ecosystem services [13] [14]. Existing research has mostly concentrated on identifying and analyzing the interrelationships between services, while insufficient attention has been paid to the driving mechanisms underlying these trade-offs. In addition, current decision-making research remains predominantly confined to tourist perspective. Future research should expand to a broader range of stakeholders to scientifically determine service priorities and enhance the comprehensiveness and effectiveness of management.

3.3. Research on Driving Factors of Ecosystem Service Functions in National Parks

The precise identification and analysis of the driving factors affecting ecosystem service functions in national parks serves as a critical prerequisite for their scientific management and value optimization, and has become a focus of research in contemporary ecological and geographical research. Existing research mainly focuses on three types of influencing factors: land use change, climate change, and biodiversity. In terms of biodiversity, most research holds that biodiversity plays a fundamental role in ecosystem services [15], and it has been found that areas with high biodiversity in national parks often overlap spatially with services such as recreation [16]. Some research has also indicated that species richness is positively correlated with the total amount of multiple ecosystem services, while its relationship with a single ecosystem service is associated with the regulation of ecosystem types [17]. Regarding land use, numerous research [4] [18] [19] has demonstrated that changes in land use types and landscape patterns driven by human activities exert an impact on the ecosystem services of national parks. For instance, wetlands, inland waters, and shrublands in Doñana National Park (Spain) exhibit higher ecosystem service values and greater diversity of ecosystem services [20]. In contrast, relevant research on Bale Mountains National Park (Ethiopia) [19] and Doñana National Park (Spain) [20] has shown that, except for urban and agricultural lands, other land cover types have generally decreased, accompanied by

habitat fragmentation and patch shrinkage—factors that lead to the weakening of supply and regulation ecosystem services. In the context of climate change, numerous research has identified the negative effects of climate change on the ecosystem services of national parks by altering hydrothermal patterns and triggering extreme events (e.g., wildfires, droughts) [21]-[23]; increased temperature and humidity may exert a positive impact on the improvement of national park ecosystem services by promoting vegetation restoration [24] [25]. In addition, some research has found that topographic and socio-economic factors also influence changes in the ecosystem services of national parks [26] [27].

Although current research on the influencing factors of national park ecosystem services has achieved certain results, most studies still largely remain at the stage of describing the correlation between a single factor and services. There is insufficient research on the nonlinear mechanisms of multi-factor interaction, the scale effect of driving processes, and the laws of spatial heterogeneity. Future research needs to strengthen mechanistic analysis and dynamic simulation to reveal the causal chains in complex social-ecological systems, thereby providing more solid scientific support for the precise protection and adaptive management of national parks.

4. Key Technologies for National Park Ecosystem Service Research

Currently, research on national park ecosystem services mainly focuses on two aspects: ecosystem service assessment, trade-off and synergy effects. Among them, the key technology for ecosystem service assessment is primarily the value assessment method, which directly or indirectly evaluates service value through monetization. It has the advantage of simple operation, but has limitations such as low spatial resolution and difficulty in reflecting the spatial heterogeneity of national park ecosystem services [28]. In contrast, biophysical assessment methods—particularly emergy analysis and modeling approaches—have gained growing recognition in recent years. Among them, model methods represented by the InVEST and SolVES models integrate spatial modeling tools of remote sensing and GIS technologies. They can quantify the biophysical amount of ecosystem services, simulate their spatial-temporal dynamics and the trade-off relationships between services [29] [30], and thus are widely applied. Due to the large spatial scale and strong spatial heterogeneity of national parks, the ecological model method has obvious advantages in large-scale assessment. It helps realize comparative analysis of multi-period and multi-type ecosystem services, optimize vegetation configuration, and provide an important basis for national park resource management, dynamic monitoring, and planning decisions [31].

Three primary methodologies are commonly used for analyzing trade-offs and synergies among ecosystem services: First, the cold and hot spot analysis method based on spatial overlay, which identifies and spatially superimposes cold and hot spot areas of individual services to assess inter-service spatial relationships [32]

[33]. Second, the ecosystem service bundle identification approach integrating multivariate statistics and spatial clustering, which classifies regions into several internally consistent service combination types based on spatial heterogeneity in service supply levels [34]. Third, correlation analysis and ecosystem service trade-off degree modeling grounded in mathematical statistics, which quantify the direction and strength of inter-dependencies through correlation coefficients or fitted slopes [3] [35]. While the first two methods effectively reveal spatial patterns of service relationships, they face challenges in achieving global quantification; conversely, statistical analysis methods enable global relationship quantification but lack spatial explicitness. Consequently, integrating multi-source data and developing a unified spatiotemporal analytical framework based on existing methodologies has emerged as a critical research priority requiring further development in national park ecosystem service trade-off and synergy studies.

Furthermore, a deep understanding of the driving mechanisms of ecosystem services forms a crucial foundation for developing effective environmental policies. However, traditional linear models exhibit significant limitations in characterizing complex nonlinear interactions among driving factors. Recent advancements in machine learning have opened new avenues for deciphering such intricate mechanisms. For instance, Du *et al.* [36] employed LightGBM to investigate factors influencing water conservation functions in Hainan Tropical Rainforest National Park, revealing that dual impacts from natural elements (primarily precipitation and evaporation) and human activities (mainly land use patterns) drive these changes. Gao *et al.* [26], through self-organizing feature mapping networks (SOM), identified cultural service clusters in Wuyishan National Park (Fujian region) and explored their drivers, finding natural factors to be key determinants of aesthetic, recreational, and combined aesthetic-healthcare service clusters. These studies demonstrate that applying machine learning models like MC-EBM, XGBoost-SHAP, or random forests to ecosystem service research can transcend conventional correlation analysis. By uncovering critical thresholds and nonlinear patterns behind driving factors, they provide robust scientific support for establishing threshold-based precision ecological management strategies.

5. Research Prospects of National Park Ecosystem Services

The current main research direction involves using technologies such as 3S, long-term positioning observation, and multi-source data fusion to quantitatively identify the trade-off and synergy effects among national park ecosystem services is the current main research direction. However, national park ecosystems are characterized by large spatial scales, complex structures, and diverse ecosystem services. How to construct a systematic assessment model, clarify the mechanism of interaction among multiple services, and maximize ecological benefits remains a key and difficult issue in this field of research.

Currently, research on national park ecosystem services is in the ascendant, and future research needs to be strengthened in the following aspects:

1) Existing studies mostly focus on the assessment of the value of a single or a few types of ecosystem services, and there is a lack of systematic analysis of the interaction mechanisms among services. Therefore, future research should strengthen in-depth studies on the ecological processes and service formation mechanisms of national parks to clarify the internal driving factors of trade-offs and synergies among different services, thereby providing theoretical support for optimizing management strategies.

2) National parks not only have the function of biodiversity conservation but also provide multiple ecosystem service functions such as climate regulation, water conservation, and cultural services. In the future, comprehensive research on multi-functional synergy should be strengthened, with particular attention to the balance between protection and utilization, to promote the construction of a national park planning system based on the synergistic improvement of ecosystem services.

3) In terms of research scale, most current studies are limited to a single national park or local region, and there is a lack of cross-regional and multi-scale comprehensive comparative analysis. National parks' ecosystem services have obvious scale effects; therefore, research on ecosystem services at different spatial scales should be strengthened to clarify the impact of scale conversion on service trade-off relationships and enhance the promotion and applicability of research results.

4) National parks' ecosystem services are jointly affected by multiple natural and human factors such as climate change, land use, and vegetation types. Currently, research on the coupling mechanism of these multi-factors is insufficient. In the future, simulation and prediction of the dynamic evolution process of ecosystem services driven by multi-factors should be strengthened to improve the ability to analyze the mechanism of service trade-off relationships in complex ecosystems.

6. Discussion

In recent years, the integrated regulation of ecosystem services in national parks has become a consensus in management. However, current research findings still have certain limitations in guiding practical park management. Existing analyses predominantly draw from foreign theoretical frameworks, which lack compatibility with China's domestic park management practices, potentially triggering new conflicts between conservation and development. Moreover, studies tend to focus on evaluating single service types or identifying static relationships, while neglecting the dynamic mechanisms of trade-offs among multiple services. This leaves managers unable to predict how specific decisions might trigger chain reactions across multiple ecosystem services or foresee long-term ecological consequences, introducing significant uncertainty and risks into management decisions. Additionally, the interactions among ecosystem services represent only a part of the complex ecological processes in national parks. Future efforts should further integrate these trade-off mechanisms with deeper ecological issues like biodiversity

conservation and climate adaptation to synergistically enhance comprehensive ecological benefits. Therefore, subsequent research should strengthen studies on the driving mechanisms of trade-off synergies among ecosystem services, while developing analytical methods tailored to China's national parks. This will help clarify pathways for synergistic enhancement and trade-off optimization among services, providing a foundation for spatial planning and management decisions that promote the coordinated development of ecological protection and regional growth.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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