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Review

A Review of Ecosystem Service Trade-Offs/Synergies: Enlightenment for the Optimization of Forest Ecosystem Functions in Karst Desertification Control

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Abstract: Ecosystem services provide regulation, provisioning, support, and cultural benefits for human survival, but it needs to be clarified how the trade-off/synergy relationships can be used to optimize function. Based on the Web of Science (WOS) and China National Knowledge Infrastructure (CNKI) databases, we collected 254 articles on the ecosystem trade-offs/synergies and functional optimization. Through a systematic review of the literature, this paper summarized the research progress and landmark achievements from three aspects: trade-offs/synergies, functional optimization, and evaluation methods. The results indicated the following: (1) In terms of the number of articles published, there were no reports before 2005; from 2006 to 2022, the annual number of published papers increased from 1 to 72, showing an overall growth trend year by year. This mainly includes three stages: initial (1970–2005), slow development (2005–2014), and rapid development (2014–2022). (2) In terms of research areas, focus was placed mainly on Asia, North America, and Europe, accounting for 40.47%, 25.55%, and 15.07% of all regions, respectively. (3) In the future, it is necessary to focus on scientific issues such as the improvement of forest ecosystem functions, the trade-off/synergy relationships between services, the scale of spatiotemporal research, and the driving factors and evaluation methods for the management of rocky karst desertification. The aim is to provide a theoretical basis to optimize the forest ecosystem service functions.

Keywords: desertification control; ecosystem services; forests; functions; trade-offs/synergies

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1. Introduction

Ecosystem services, as the term of a scientific period, began in 1970 with the publication of the UN University's report on "Human Impact on the Global Environment" [1]. Since then, Costanza [2] has proposed that ecosystem services are benefits derived directly or indirectly by human beings from the ecosystem, which are used to maintain the natural environmental conditions and utilities on which human beings depend for survival and development. Since the concept was proposed, it has attracted extensive attention from the academic community, and ecosystem services have been classified. People have widely accepted the classification of ecosystem services established by the Millennium Ecosystem Assessment, which is divided into provision, regulation, support, and cultural services [3]. Various factors regulate the services, and there are differences and overlaps in handling different services. This leads to complex interrelationships between other ecosystem services [4], manifesting as synergies and trade-offs between mutual gains and losses.

Trade-offs, as a fundamental concept, first appeared in economics and were defined as opportunity costs. Where resources are scarce, an individual or group must give up a certain amount of additional scarce resources to obtain more of the scarce resources [5]. Begong believes that a "trade-off" is a relationship between two life history traits. Due to the imbalance in the distribution of resources, an increase in the payoff from one feature is associated with a decrease in the payoff from the other feature [6]. Synergy was first introduced by the German theoretical physicist Haken in 1971 [7]. He considered "synergy" as the joint action and collective behavior of the parts of a system that collaborate or cooperate, leading to a new structure and characteristics of the whole system. In 2005, the Millennium Ecosystem Assessment (MA) [3] defined ecosystem service trade-offs as follows: within a particular spatial and temporal scale, when the supply level of an ecosystem service is enhanced, it is at the cost of reducing the resilience of its ecosystem and the supply function of other ecosystem services. in contrast, a synergistic relationship is manifested as a joint increase or decrease in various service supply capabilities [8]. It is clear from this line of development that the study of ecosystem service trade-offs/synergies is still a hot topic for future research.

Karst desertification refers to the land degradation phenomenon caused by the disturbance and destruction of unreasonable human social and economic activities under the fragile karst environment in the subtropical zone, which is manifested by soil erosion, gradual rock exposure, land productivity degradation, and a desert-like landscape on the surface [9]. Karst landscapes are widely distributed around the world, covering 22 million km^2, accounting for 12–15% of the land area [10,11]. They are mainly distributed in the Mediterranean region, the east and central of North America, and southern China. Due to the fragile ecological environment and unreasonable human activities in these areas, karst desertification is a major problem, which threatens the security of ecological environment and restricts the development of the economy and society [9]. In order to reduce land degradation and promote ecological and economic development, scholars regard forest as the preferred goal of ecological restoration in this area [11,12]. The results of management over the years show that forests, as the main provider of ecosystem services, have the functions of water conservation, soil and water conservation, carbon sequestration, and climate change mitigation [13]. In particular, they play an irreplaceable role in managing karst desertification. However, as time has passed, the problems of forest ecosystems in karst rocky desertification areas have become more and more prominent such as the competition between communities, leading to a reduction in biodiversity and the weakening of service functions. To promote the sustainable development of forest ecosystems in karst desertification areas, it is necessary to review studies related to the trade-offs and synergies of forest ecosystem services.

In recent years, studies on ecosystem service trade-offs/synergies have mainly focused on watershed [14], wetland [15], and vulnerable functional areas [16], and have achieved good results. The karst rocky desertification forest ecosystem is an important part of the terrestrial ecosystem, but its trade-offs/synergies are rarely reported, which hinders the research on functional optimization strategies. In order to solve this problem, based on a systematic review of the literature, this study summarizes the progress and landmark achievements of global ecosystem service trade-offs/synergies. It summarizes the key scientific questions about the function of forest ecosystems in managing karst rocky desertification, the trade-off/synergy relationships, the spatial research scale, driving factors, and evaluation methods. It aims to enlighten future research directions on optimizing forest ecosystem service functions in stone desertification management and provide theoretical references to enhance its service supply capacity.

2. Materials and Methods

This study was based on platforms such as the CNKI (China National Knowledge Infrastructure) and the Foreign Journal Resource Service System of Guizhou Normal University Library (Web of Science) (http://lib.gznu.edu.cn/data/weibu/waiwen/waiwen.htm, accessed on 22 October 2022). The search period was the maximum time range of both databases, and the search time was up to 22 October 2022 (Figure 1). First, we searched the WOS database by entering "ecosystem service" and "trade-offs/synergy", and again by entering "forest ecosystems" and "function optimization." A total of 234 documents were retrieved. Second, the CNKI database was searched by entering "ecosystem service", "trade-offs/synergy", "forest ecosystems", and "function optimization", and a total of 399 Chinese documents were retrieved. After the manual screening, a total of 564 documents were obtained. Finally, the articles' titles, abstracts, and keywords were screened based on the research themes related to trade-offs/synergies and functional optimization of ecosystem services. Following this, we further combined the literature for ecosystem services, trade-offs/synergies among services, functional optimization, and assessment methods. After, the full text of the alternative literature was browsed, and a total of 254 articles were screened. Among them, 93 papers were obtained from the WOS database (92 articles and one conference paper), and 161 papers were obtained from the CNKI database (109 journal papers, 42 master's theses, five doctoral dissertations, and three conference papers).

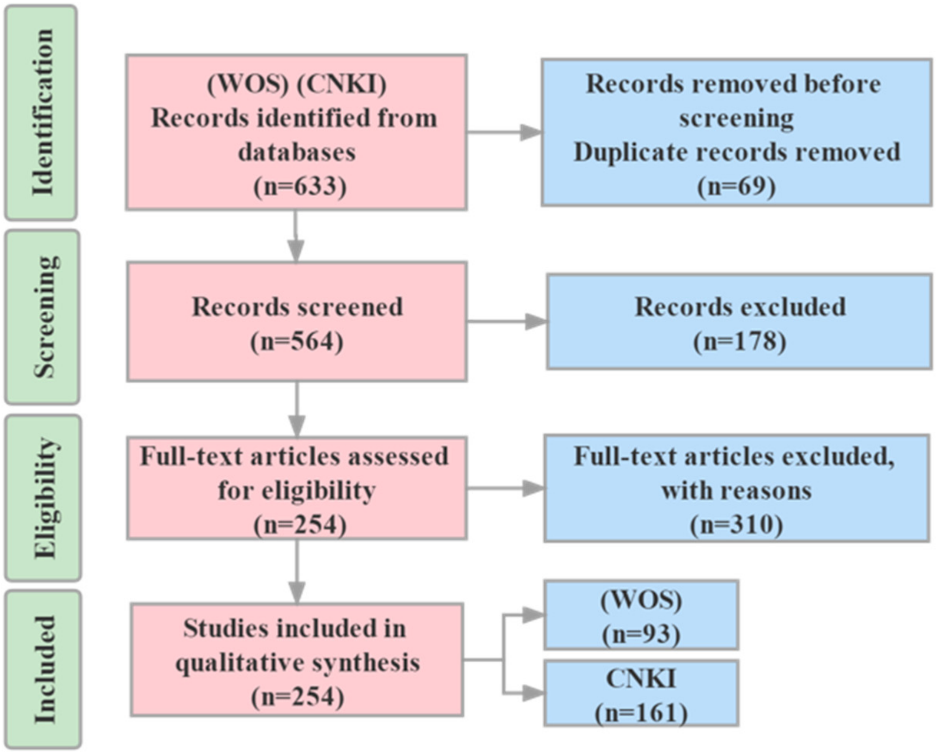

Figure 1. The process of the literature search.

3. Results

3.1. Annual Distribution of the Literature

From the annual distribution of the literature (Figure 2), the research related to ecosystem service trade-offs/synergies and functional optimization started in 2005 and reached its peak in 2022. This can be roughly divided into three stages. The first stage was from 2006 to 2014, when there were few studies on ecosystem service trade-offs/synergies and functional optimization, with only three literature articles in total; this was the starting stage. The second stage was from 2014 to 2018, and the literature showed a fluctuating growth trend, which was 16.3 times that of the first stage. In addition, there were already articles related to karst ecosystem research in this stage, but the number of types of literature was small; this is the development stage. The third phase was from 2017–2022, with a surge in the number of types of literature, 4.12 times more than in the second phase, but there were only 12 articles on the ecosystem service trade-offs/synergies and functional optimization of karst rocky desert ecosystem services. The overall trend shows that the number of articles on this topic will continue to grow.

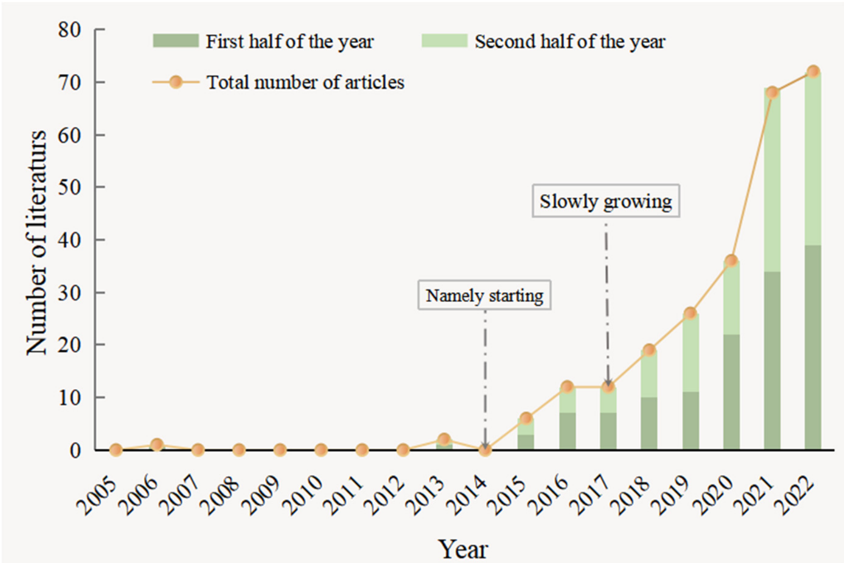

Figure 2. Annual distribution of the literature. The dark green is the first half of the year (January–June); the light green is the second half of the year (July–December).

3.2. Content Distribution of Documents

This paper classified and summarize all of the reviewed literature according to the classification method. It was also divided into studies related to ecosystem service trade-offs/synergies, the optimization of ecosystem service functions, and assessment methods according to the content of the studies. Ecosystem service trade-offs/synergies account for 61% of the literature, dominated by theoretical studies such as trade-offs/synergies, spatiotemporal characteristics, and relationship identification. In addition, in this literature, studies related to wetlands, oceans, watersheds, and fragile functional areas were dominant, and there were fewer studies on forest ecosystems in karst stone desert areas. The ecosystem service functional optimization literature accounts for 20%, which contains strategies for forest service functional optimization such as strategies for ecological corridor construction applied in northeast China, and ecological restoration and compensation strategies used in karst stone desertification areas in southern China. Assessment methods and other literature accounted for 11% and 8%, respectively, of which the assessment methods included both ecosystem services and trade-offs/synergies. The proportion of this literature indicates that the study of ecosystem service trade-offs/synergies is becoming more mature. However, the optimization of ecosystem service functions and assessment methods is still in the exploration and development stage.

3.3. Distribution of Research Institutions Publishing Documents

The regional distribution of the literature shows that China, the United States, and Germany dominate the research on ecosystem service trade-offs/synergies and functional optimization. The unique landscapes in China such as the northwest desert belt, fragile functional areas, and southern karst have attracted more Chinese scholars to study these areas and publish their research results. Thus, the overall number of publications was the highest. Next, developed countries such as Canada, France, Spain, Finland, Sweden, and Australia also had more relevant studies. In addition, Brazil, South Africa, Singapore, and other countries such as Iran had few studies. In terms of the overall publication volume, Asia had the highest number of publications, followed by North American states, Europe, Oceania, South American states, and Africa, accounting for 40.47%, 25.55%, 15.07%, 8.3%, 5.58%, and 5.03% of all regions, respectively. This correlated more significantly with each region's natural resources, social environment, policy support, and management experience.

The distribution of institutions publishing literature related to trade-offs/synergies and the functional optimization of ecosystem services was deciphered and analyzed. The acquired institutions were divided into four categories: higher education institutions, research institutions (centers), business units, and grassroots organizations, with percentages of 77.1%, 13.50%, 5.7%, and 3.5%, respectively. The rates showed that higher education institutions and research institutes (centers) have paid more attention to research related to trade-offs/synergies and the functional optimization of ecosystem services. However, due to the limited space of the figure, only institutions with a higher number of publications are marked in Figure 3.

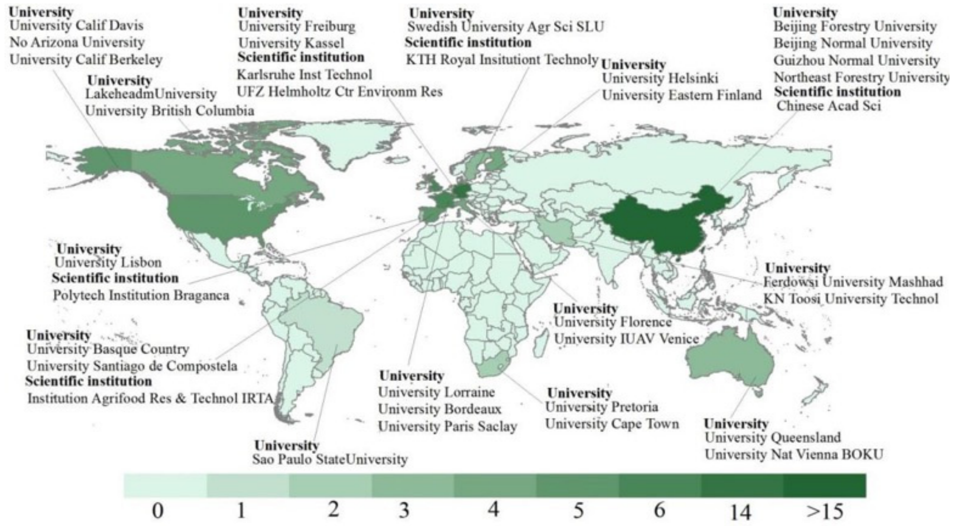

Figure 3. Distribution of countries and institutions studied in the literature. The different color bands and numbers at the bottom indicate the number of publications; the darker green the color, the higher the number of publications.

3.4. Research Stage Division

Ecosystem services appeared as a technical term in the Human Impact on the Global Environment report published by the United Nations University in 1970. Ecosystem service trade-offs/synergies emerged from the 2005 Millennium Ecosystem Assessment [3]. Ecosystem services are the basis, and an essential part, of the ecosystem service trade-off/synergy research. Thus, the first stage began in 1970 when ecosystem services were proposed. According to the research background of the changes in the theoretical studies, classification systems, and assessment methods, the development stages of ecosystem service trade-off/synergy and functional optimization were divided into the initial stage, the slow development stage, and the rapid development stage (Table 1).

Table 1. Division of the research stages.

Research Stages	Research Content	Background	Main Characteristics
Starting stage (1970–2005)	Conceptual and theoretical study of ecosystem services.	The relevant theoretical research was still at the beginning stage, and the depth of research was insufficient.	There were more qualitative studies, lacking systematic research and a single research method.
Slow growth stage (2005–2014)	The research methodology was diverse, using mainly statistical, spatial, model, and scenario analysis.	As the economy developed, attention begun to be paid to research related to trade-offs/synergies in ecosystem services and functional optimization.	The results were verified by the experiments, the classification system and evaluation method were gradually improved.

Table 1. *Cont.*

Research Stages	Research Content	Background	Main Characteristics
Rapid growth stage (2014–2022)	The mechanism of trade-offs/synergies and functional optimization of forest ecosystem services has been further clarified, and quantitative studies have gradually increased.	Ecosystem service trade-off/synergy research is developing rapidly, with an increasing number of cross-disciplinary studies and relatively mature technical approaches in China.	A variety of trade-off/synergy analysis methods. The research system presents a "pattern–process–service–sustainability" system.

3.5. Research Progress and Landmark Results

3.5.1. Ecosystem Service Trade-Off/Synergy

1. Spatial and temporal characteristics of ecosystem service trade-off/synergy

The trade-off/synergy among ecosystem services is spatial and temporal scale-dependent and nonlinear, and the trade-off and synergistic relationships of ecosystem services may change at different spatial and temporal scales [17]. Current studies on the time scale of the trade-offs and synergies of ecosystem services rarely use continuous time series and usually choose years with certain time intervals. For example, Niu et al. [18] analyzed the trade-off/synergistic relationships of ecosystem services in the Songhua River basin in China during 2000–2018. They concluded that there was a synergistic relationship between water harvesting, soil conservation, biodiversity, and carbon sequestration, and a trade-off relationship between broadleaf forests, coniferous forests, and crops. Schroder et al. [19] found a short-term trade-off and long-term synergistic relationship between national forest fire risk management (logging) and owl habitat protection and water quality regulation in the United States. Chen et al. [20] found an increasing trend in net primary productivity, water production, and soil retention capacity from 2000 to 2018 during their study in a karst watershed. Still, the ecosystem synergy in the region was poor, and the trade-offs were particularly pronounced in karst stone desertification areas.

At the spatial scale, Zhang et al. analyzed the trade-off/synergistic effects of forest ecosystem services in the Fuyu Mountain region. They found that the synergistic relationship between services was better on the south slope than on the north slope, and that the best synergistic relationship between services was found in the middle mountain deciduous broadleaf forest belt on the south slope. The worst synergistic relationship was found in the low mountain deciduous broadleaf forest belt on the north slope [21]. Han et al. studied the trade-off and synergistic relationships between ecosystem services and land use change in the karst region response, finding synergistic relationships between soil water yield and soil retention, soil water yield and carbon storage, and soil retention and carbon storage. In contrast, most of the relationships between other crops were trade-offs [22]. In summary, the trade-off/synergistic relationships among services showed significant differences at different temporal and spatial scales due to the natural recovery status and the selectivity of human use of the services.

2. Drivers of ecosystem service trade-off/synergy

The drivers of changes in the ecosystem service trade-offs and synergies are mainly divided into anthropogenic and natural factors [23]. As one of the typical fragile ecosystems in the world, the generation of trade-off/synergistic relationships between services in karst ecosystems mainly comes from the coupling effect of two significant factors: anthropogenic and natural. Scholars have studied the causes of the changes in the synergistic relationships of service trade-offs in karst ecosystems. For example, Han et al. suggested that climate is the leading natural factor for the transformation of service trade-off/synergistic relationships, which changes the temperature and precipitation intensity in karst regions through climate change, thus affecting the distribution pattern of plants, causing competition for species' ecological niches, and indirectly changing the relationship between services [24]. Chen et al. found that lithology is also one of the factors influencing the trade-off/synergistic relationships, and that karst areas dominated by dolomite and limestone, where limestone is more susceptible to dissolution by running water, have a poorer soil retention capacity. Therefore, the trade-off relationship between soil conservation and services such as water production is more significant in this region [25]. In addition, some scholars also believe that factors such as soil erosion [10], vegetation degradation [9], and reduced biodiversity [26] have a more significant impact on the trade-off/synergistic relationship between services. With the rapid development of society, the economy, and urbanization, many karst ecosystems such as agricultural land, forests, and wetlands have been occupied by human activities. This approach has not only changed the land use pattern and disrupted the material and energy balance of the karst soil–vegetation system [27], but also induced the reverse evolution of the soil–vegetation system. In addition, the supply capacity of karst ecosystem services will also be reduced, directly affecting the relationship between the benefits of the karst ecosystem [28]. In addition, to meet the needs of human survival and development, a large amount of scrub was reclaimed for cultivation, which contributed to the loss of organic carbon from the surface layer of karst limestone soils and the intensification of surface erosion, resulting in the weakening of soil carbon and nitrogen sequestration capacity, which affected the relationship between the services to some extent [29]. Thus, it is clear that human activities are a key factor in the structural and functional changes of karst ecosystems.

3. Synergistic relationship of forest ecosystem service trade-offs

Forest ecosystems provide vital ecological services to the Earth's ecological environment, and the conservation of biodiversity and the development of forest industries are necessary ecological safeguards [12]. Karst forests are a special type of forest ecosystem developed on karst landscapes in the context of forest climate conditions [30]. However, long-term anthropogenic disturbances have exacerbated the problem of stone desertification in karst regions, reducing the stability of existing forest structures and leaving them in a state of fragmentation or secondary degradation succession. This significantly reduces the capacity of karst forest ecosystems in terms of water containment, soil conservation, biodiversity, and ecological product supply [31], creating trade-offs or synergistic relationships among services (Figure 4).

In recent years, some scholars have carried out studies related to the service relationships of karst forest ecosystems. For example, Wang et al. found that the relationship between the services in karst fallow forest areas (Grain for Green) was a trade-off between soil and water conservation and net primary productivity and water connotation, and a synergistic relationship between net primary productivity and water connotation [32]. Chen et al. found that the forest cover area in the karst area could enhance the forest's net primary productivity and soil erosion resistance. Still, expansion of the forest cover area will increase the uptake of water resources by vegetation, causing a decrease in surface water production service capacity so that the net primary productivity and water production form a trade-off relationship [33]. In turn, the trade-offs between services may impact the supply capacity of each service and hinder the ecological restoration process [9]. Therefore, based on the trade-offs between services, taking corresponding measures to optimize the service functions to maintain the structure and function of forest ecosystems is a critical way to achieve a "win–win" situation for economic development and ecological conservation [34].

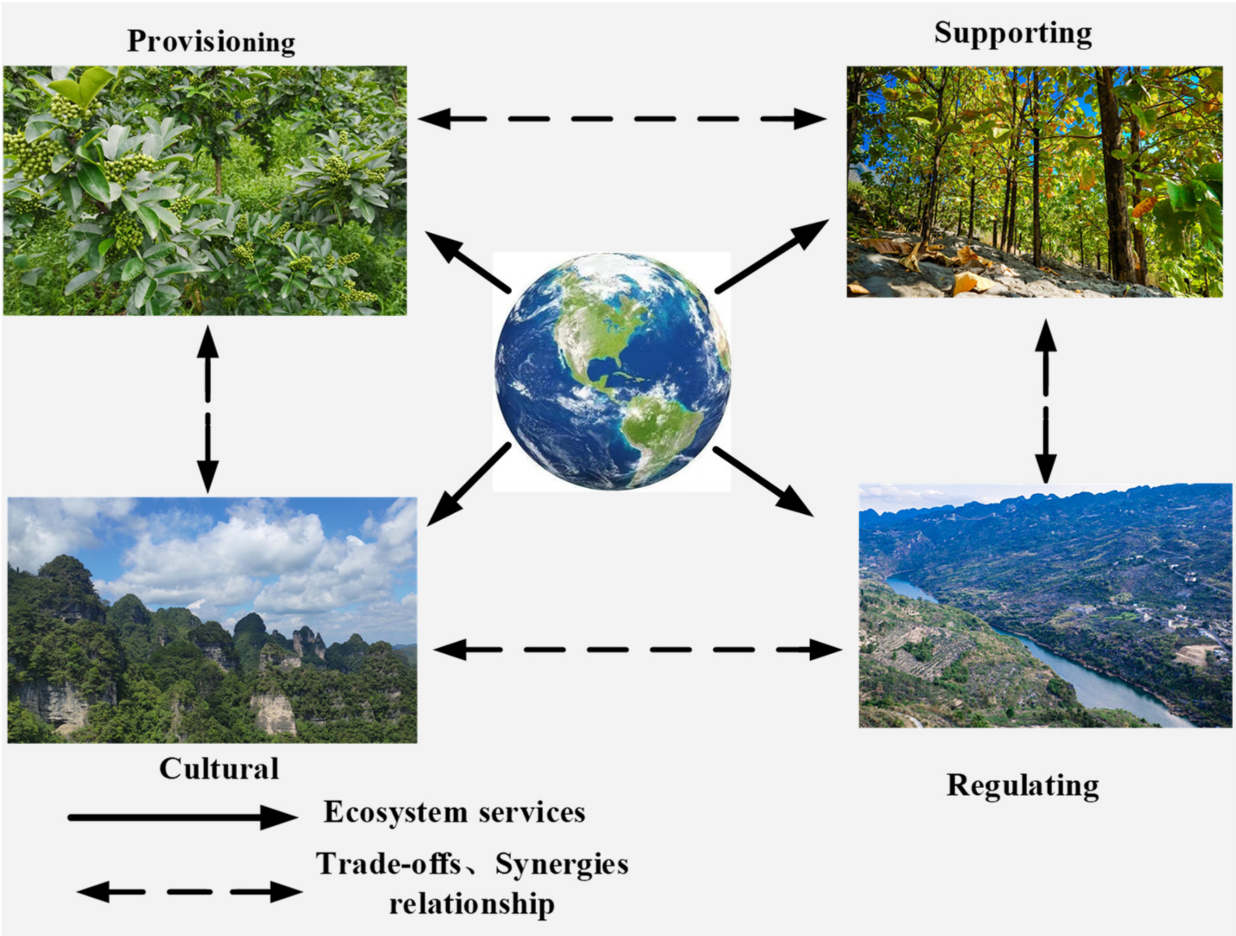

Figure 4. Trade-offs/synergies between forest ecosystem services.

3.5.2. Optimization of Ecosystem Service Functions

4. Ecological compensation

Ecological compensation and payment are differentiated regulation strategies for the interaction between ecosystem services and human welfare, which should be adapted to the current ecological environment and social and economic system. As a mechanism to stimulate ecological construction and environmental protection, ecological compensation can realize the effect of internalizing the external ecological benefits [35]. Through the analysis of the spatial flow of supply, demand, and trade-offs, the key benefits and losses of ecosystem services are obtained, and the conditional payment transaction from service users to service providers is facilitated [36]. In general, a combination of remote sensing data and location-based observations is used to measure the profit and loss of supply, regulation, support, and cultural services. Complementary compensation strategies have been developed based on matching supply, demand, and trade-offs/synergies of ecosystem services. For example, Sun analyzed ecosystem service processes in crucial ecological function areas in Xinjiang. According to the total value of ecosystem services, all counties in the autonomous region can be divided into three compensation levels: priority compensation, secondary compensation, and potential compensation areas [37]. Thus, the efficiency of the ecological compensation mechanism can be improved. It was more difficult to compensate for the particular habitat of the karst desert region, and further funds were used. However, certain shortcomings in financial compensation can result in poor compensation outcomes. As a result, alternative ways to precisely refine and structure economic compensation methods exist such as improving the ecosystem structure stabilization and enhancing ecosystem service functions.

5. Enhance forest ecosystem service functions based on site conditions

A fragile ecological environment, fragmented surface morphology, and severe soil erosion and desertification characterize karst regions. The essence is the destruction of the ecosystem structure, which leads to a decline in and loss of ecosystem functions [38]. Given the uneven spatial distribution of forest ecosystem services and the selectivity of human use, the ecosystem service cascade framework was developed to increase the stability of the forest ecosystem structure, improve the function of forest ecosystem services, and promote regional synergies (Figure 5). According to the trade-off/synergy differentiation of the services, some scholars have proposed that plant communities can be adjusted and configured through functional groups to enhance the overall ecosystem service capacity [39]. Chen [40] offered optimal control strategies for the forest, irrigation, and grass communities in different rock desertification classes, considering the growth traits, adaptation strategies, ecological niches, and functional group types of tree species. Zhang [12] constructed a model for the ecological restoration of forests of different stone desertification classes with species adaptation strategies and ecological service functions. Zhang [41] proposed plant community optimization techniques by studying the plant species diversity, leaf functional traits of established species in plant communities, spatial patterns of plant communities, and interspecific correlations in the rocky desertification succession of different grades. Yu [39] took the upper reaches of the Chishui River as the study area, divided 32 water resource conservation forest tree species into seven water resource conservation function groups, and proposed optimization and adjustment strategies for the different function groups on this basis. Therefore, the conservation strategies for forest ecosystems in karst areas should be more targeted and specific.

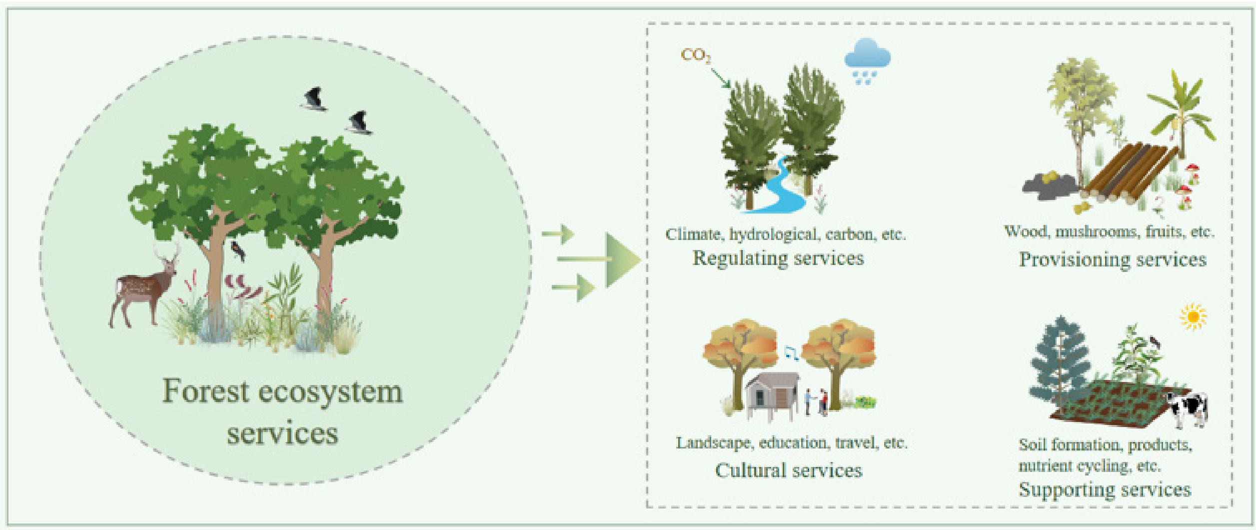

Figure 5. Forest ecosystem services.

3.5.3. Assessment Methods

Ecosystem service assessment is a complex process that needs to be refined and quantified. Currently, the main ecosystem service assessment methods include economical methods, plant functional traits, biophysical models, energy value conversion techniques [42], quality methods [43], modeling methods, and value quantity methods [44].

Several scholars have explored the spatial and temporal characteristics and the relationship between trade-offs and synergies of the forest ecosystem services. From the research perspective, the content mainly involves the expression form, dynamic change, scale effect, and scenario simulation of ecosystem service trade-off/synergy relationships [45]. The research scale includes country, region, and river basin [46]. The main research methods are statistical analysis [47], spatial analysis [48], scenario analysis [49], and service mobility analysis [50,51] (Table 2).

Table 2. Research methods of ecosystem service trade-offs/synergies.

	Research Method	Principles
Ecosystem service trade-off/ synergy research methods	Statistical methods	Mathematical models are used to study the quantitative relationships among various forest ecosystem services.
	Spatial analysis methods	GIS, spatial statistics, and other methods are used to characterize the spatial patterns of forest ecosystem service trade-offs at specific spatial and temporal scales.
	Scenario analysis methods	Spatial mapping and regression analysis are used to analyze the dynamics of forest ecosystem service trade-offs and seek optimal scenarios.
	Service mobility analysis	"Source" and "sink" regions are identified by analyzing single ecosystem service supply, transport, and utilization processes. The impact of human activities on the supply and demand of forest ecosystem services is measured.

4. Discussion

4.1. Trade-Offs/Synergies and Functional Optimization of Annual Posting Volume Differences

The number of publications related to ecosystem service trade-offs/synergies and functional optimization is increasing rapidly with annual changes (Figure 2). For the forestry sector, this is both a challenge and an opportunity. Since the rise in ecosystem service trade-off/synergy research, the number of published articles has been increasing, accounting for 74.4% of the total articles published, which will continue to grow in the future. Studies on the trade-off/synergy relationships are mainly related to river basins, watersheds, and mountains. There needs to be more relevant studies on forests, as there is currently a lack of articles on karst stone desertification forests. It is speculated that the complex environment of karst desertification zones, with significant differences in different karst environments (canyons, depressions, rocky slopes, rocky forests, rocky troughs) [11], is more difficult for scholars to study, resulting in a low number of publications in these areas. Regarding functional optimization, there are relatively few studies on forest ecosystem service functions, accounting for only 25.6%. The current studies on functional optimization focus on the optimization of single services or the optimization of overall services, and there needs to be more studies on the optimization of services based on trade-off relationships. It is assumed that the concept and connotation of functional optimization need to be clearly defined [52], leading scholars to ignore the trade-offs between services in studying the functional optimization strategies in forest ecosystems. The characteristics of trade-off relationships and the driving mechanisms need to be better understood. The optimization methods for transforming trade-off relationships into synergistic relationships cannot be easily explored.

4.2. Differences in the Distribution of Study Areas

Regional differences in the natural conditions and social situations have led to the uneven development of research on ecosystem trade-offs/synergies and functional optimization (Figure 4). Regarding the number of publications, Asia has the highest number, with 40.47% of the total. Among the countries in Asia, China had the highest number of publications, with a total share of 86.97%, which may be related to the attention of national policies and research institutions [53], and possibly the use of the CNKI database. The emergence of a series of global problems such as resource and environmental degradation has made people deeply aware of the importance of the sustainable development of ecosystems [54,55]. As a result, there is a growing interest in the benefits provided by ecosystems, and the number of publications is increasing. South America had the second highest number of publications, with a total share of 25.55%. The region is advanced in education, science, and technology, but may have focused its research horizon on ecosystem function, biodiversity, and other related aspects, with less research on trade-offs/synergies and functional optimization. The lowest number of publications was found in Africa, accounting for 5.03% of the total number of publications. Compared with the Asian region, this region is poor in resources and lagging in education, science, and technology. More attention should be paid to the research on ecosystem trade-offs/synergies and functional optimization, and there were fewer relevant studies.

4.3. Key Scientific Questions to Be Addressed

1. Severe soil erosion, weak stability of vegetation communities, and deteriorating ecosystems in karst stone desertification areas. Karst systems have a unique, binary, three-dimensional spatial structure. However, due to their structural peculiarities, this exacerbates the water and soil leakage condition, making the soil layer in the area thin, causing challenges in retaining nutrients, along with a poor soil quality. In addition, to meet people's survival and development needs, the original vegetation in karst rocky desertification areas has been destroyed, so the existing forests are mostly planted and secondary forests. However, most planted and secondary forests have simple structures, poor biodiversity, low primary productivity, and poor soil and water retention functions. The vegetation shows a tendency to retreat, reducing the stability of the forest ecosystems [56] (Figure 6).

(a)

(b)

Figure 6. (**a**) Degradation of vegetation in karst desertification; (**b**) karst rocky desert landscape.

2. Karst stone desertification forest ecosystem services present trade-off/synergy relationships. This region has cultivated large areas of mature and overgrown forests using methods such as closed forestry and plantation, which have reached a certain high level of service capacity in terms of water content, net primary productivity, species diversity, and material production. However, the bias in human demand for forest ecosystem services and the tendency of forest communities to compete for ecological niche occupation [48] has led to trade-off/synergy relationships among services. Thus far, there are fewer studies on the trade-off/synergy of karst forest ecosystem services. During future research, understanding ecosystem services such as the water content and net primary productivity of karst forests should be enhanced to clarify the trade-off/synergistic relationships among services.

3. The spatial scale of forest ecosystem service trade-off/synergy studies is limited to large scales or single factors. Due to the successful development of 3S (remote sensing, geographic information systems, and global positioning systems) technologies, based on their ability to access spatial data quickly, the existing results of ecosystem service trade-offs/synergies are large-scale studies such as watersheds [57] and functional areas [58].

However, these studies typically use a single research scale, and the results cannot be verified. Especially in karst areas, the topographic conditions are complex, with numerous plateau mountains, peaks, and valleys, and the information identified by remote sensing needs to reflect the actual conditions. Therefore, in the future, we should strengthen the research on a small scale and obtain experimental data through the combination of field monitoring and 3S technology to clarify the process and mechanism of each ecosystem service.

4. The unclear trade-off/synergistic driving mechanisms of karst forest ecosystem services. The influences on ecosystem services arise from natural and socioeconomic systems, covering topography, soil, biology, climate, land use, socioeconomics, and human activities [59]. Due to regional differences in development, the uneven regional distribution, and diversification of socioeconomic factors such as population, education, social class, policies and regulations, religion and culture, urbanization, and economic level, local people develop preferences for ecosystem services. Additionally, in the selection process, they indirectly or directly influence ecosystem services, creating trade-off/synergistic relationships. Therefore, in the future, it is essential to explore what factors play a dominant role at the spatial and temporal scales, the relevance of driving mechanisms at the spatial and temporal scales, and to clarify the coupling of various factors at different spatial and temporal scales [60].

5. Given the multitude of ecosystem service assessment methods, there needs to be more certainty in the results of trade-off/synergy studies among karst forest ecosystem services. Ecosystem service assessment involves many aspects including forestry, econometrics, management, and ecology. There are more indicators of each service function and complex mechanisms of the action process. Additionally, there are significant differences among regions, research scales, and assessment methods. Especially in karst stone desertification areas, the ecological environment is special, and multiple processes can be selected for comparative studies to enhance the scientific nature of the research methods.

4.4. Enlightenment on the Optimization of Forest Ecosystem Service Functions for Karst Desertification Control

Good social, economic, and ecological benefits have been achieved in participating forest ecosystems in managing karst rock desertification [61]. However, the fragility of the karst rock desertification ecological environment [62] makes the forest ecosystem in this area less able to resist external disturbances and less stable [63]. Once unreasonable human activities occur and exacerbate the fragility of stone desertification habitats, they will change the forest ecosystem's structural configuration and species composition [64] and affect the service provisioning capacity and trade-off/synergistic relationships. Therefore, the work summarized and reviewed in this paper on the above ecosystem trade-off/synergy and functional optimization was synthesized. Insights into the optimization of forest ecosystem service functions in karst rock desertification management were provided regarding the forest ecosystem structure–function and trade-off relationships among services.

For the ecological structure–function, the karst stone desertification area has a shallow soil layer, discontinuous soil, high rock exposure rate, and rich soil calcium and magnesium content [56]. The suitability for small habitats should be considered when selecting restoration species, and drought-tolerant, calcium-loving, rocky, fast-growing, widely applicable, ecologically and economically valuable trees, bushes, vines, and grasses should be selected for ecological restoration such as species of any bean, cedar, and lady's mantle [65]. Second, we should adjust the cultivation methods of natural forests and plantations, which are sound ecological construction systems and natural gene pools with strong regulation and restoration abilities. The conservation of natural forests is mainly based on "no access to protected forest areas" measures to preserve their species and genetic diversity and maintain the community structure and function [66]. For natural secondary forests in poor health, we adopted the measure of "managing the forest closed and adjusting the structure of the trees", and promoted better plant growth through artificial support measures such as replanting, nurturing, and inter-logging. For the planted plantations in natural forest areas, measures that support a "change of management approaches while protecting the forest in culturing" were adopted. Through the nurturing of mixed conifer and broadleaf forests, and the regular replanting of native species, we can induce succession in native forests and optimize the community structure and function [31]. Regarding the trade-offs between services, the trade-offs between forest ecosystem services in karst stone desertification areas resulted from a combination of natural and human factors.

Due to the poor soil in this area, plants compete with other species spatially to occupy more ecological niches during growth, leading to trade-off relationships between some services such as water connotation and soil conservation, nutrient netting, etc. [67]. Natural restoration or scientific fertilization can enhance soil quality in the stone desertification area and promote the balance of nutrient supply and demand. In addition, the appropriate stand density and planting depth need to be determined during planting to provide a wider space for plants to grow. The competition between plants for ecological niches should be reduced and the service capacity of water connotation and carbon sequestration and oxygen release should be improved while optimizing their trade-off relationship. The most important point is to reduce human interference in the forest ecosystem in stone desertification areas. The impact on the service function can be minimized by prohibiting deforestation, stepping on the protected forest area, reclaiming scrubland for cultivation, and planning the land for urban construction and highway construction in a reasonable way, in order to maintain the original state of the service function and reduce the formation of trade-off relationships.

5. Conclusions

This paper conducted a literature search for the trade-offs/synergies and functional optimization of forest ecosystem services through two databases, the Web of Science and CNKI. This study analyzed and reviewed 254 selected papers. The following conclusions were drawn. (1) The number of publications has shown a rapid growth trend since 2014, and the research process has gone through three stages: start (1970–2005), slow development (2005–2014), and rapid development (2014–2022). (2) Research regions are mainly concentrated in Asia, North America, and Europe, accounting for 40.47%, 25.55%, and 15.07% of all regions, respectively. (3) In the research, the content trade-off/synergy relationships were the most abundant, accounting for 61% of the total, followed by functional optimization and assessment methods, accounting for 20% and 11% of the total, respectively. (4) The following are future scientific questions to focus on and ideas for solutions: ① Given the severe soil erosion, weak stability of vegetation communities, and deteriorating ecosystems in karst stone desertification areas, a combination of forest sealing and artificial planting could enhance the vegetation cover, strengthen the ability to fix soil and retain water, and improve the system's stability. ② Given that karst stone desertification forest ecosystem services present trade-off/synergistic relationships, the reasons for the formation of inter-service trade-offs can be explored, and the trade-offs can be mitigated by enhancing the capacity of individual and multiple services. ③ Given that the spatial scale of forest ecosystem service trade-off/synergy studies is limited to large scales or single factors, the diversity of research dimensions should be increased, and a combination of remote sensing images and field monitoring should be used for research and validation. ④ Given the unclear trade-off/synergistic driving mechanisms of karst forest ecosystem services, the human-made and natural factors that cause trade-offs between services should be fully explored, and their specific drivers should be identified. ⑤ Given the multitude of ecosystem service assessment methods, there is a problem of uncertainty in the results of trade-off/synergy studies among karst forest ecosystem services. The research should be conducted using methods applicable to small watersheds such as habitat monitoring and analysis to enhance the scientific validity of the research results.

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