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Review

Research Progress on Grassland Eco-Assets and Eco-Products and Its Implications for the Enhancement of Ecosystem Service Function of Karst Desertification Control

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Abstract: Grasslands in karst ecological fragile areas can effectively mitigate climate change, conserve biodiversity, maintain human well-being, and play a significant role in improving the health of regional ecosystems and farmers' livelihoods. Thus, the study of grassland ecological assets and ecological products comprehensively examines their effects on grassland ecosystem services based on the traditional paradigm. This procedure is crucial from a strategic perspective for rebuilding damaged grassland ecosystems in karst regions, strengthening the efficacy of desertification control, and encouraging sustainable economic growth. In this review, 143 pertinent works on grassland ecological assets and ecological products are numerically and qualitatively analyzed. The findings demonstrated the following: (i) After 2012, there was an exponential increase in the number of studies. The most frequently researched topics were ecological assets, functional enhancement, and service management contents, accounting for 82.09% of the total literature; the research regions were primarily distributed in Asia and North America. (ii) The research patterns were slowly diversifying and becoming more interdisciplinary. (iii) There are five key scientific issues to be addressed in the research on grassland ecosystems and we summarize the main developments and landmark achievements. (iv) There is an intrinsic relationship between grassland ecological assets, ecological products, and desertification control, and we propose insights into the enhancement of karst grassland ecosystem service functions based on three perspectives: fragile environment, trade-off synergy, and service management. This study provides valuable insights for the development of regional ecological livestock and the scientific promotion of integrated desertification control.

Keywords: structure optimization; function enhancement; ecological assets; service management; ecological products; supply capacity

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1. Introduction

The intensification of global climate change, depletion of non-renewable resources, population explosion, and food shortages are generating many problems, such as biodiversity loss, grassland degradation, desertification, and shrinking of human living spaces [1,2]. In the past decades, the Convention on Biological Diversity (CBD) and the United Nations Sustainable Development Goals (SDGs) have emphasized a recovery strategy for global degraded grasslands, highlighting the multiple functions of grasslands in delaying atmospheric warming and increasing soil carbon sinks and human livelihoods [3,4]. Grasslands, mainly consisting of the legume and the grass family, are one of the pioneer communities of plants that predate ecological restoration [5]. Meanwhile, grasslands are also one of the producers of ecosystem cycle processes and food chains, which can provide a variety of products and services for sustainable socio-economic development to guarantee human well-being [6,7]. However, globally, the grasslands at varying degrees of risk of degradation represent about 40% of the existing grasslands, mainly in tropical and subtropical humid climate zones [8–10]. The essence of the current contradiction between grassland ecosystem protection and human society is the contradiction between the basic research on grassland ecosystem service (GES) functions and the environmental fragility of the combination of grassland resource scarcity, value, and ownership of power [11]. Therefore, clarifying the connotation and extension of the concepts of ecological assets and ecological products is a necessary condition for promoting the restoration of ecologically fragile areas. Ecological assets (EAs) are ecosystems that provide welfare for human society within a certain time and space range and under technological conditions [12]. Ecological products (EPs) refer to the physical and intangible products produced through clean production, recycling, consumption reduction, and emission reduction [13]. Liu et al. [14] proposed that grassland EAs are all resources and ecological environments that can enhance human well-being and serve as a "stock" for the pastoralists' economic development. Additionally, Zhang et al. [15] proposed that the EPs of grasslands are the final services and products used and consumed by human beings as a kind of "flow" under the joint action of biological production and human labor and are divided into public and business products [16]. The EP supply capacity of grasslands is based on the relationship between EAs natural resource endowment stock (Figure 1). Assets and products are prerequisites for human societies to value natural resources and are also intermediates in exploring economic development and environmental protection in ecologically fragile areas, providing important insights for a proper understanding of the human–land relationship.

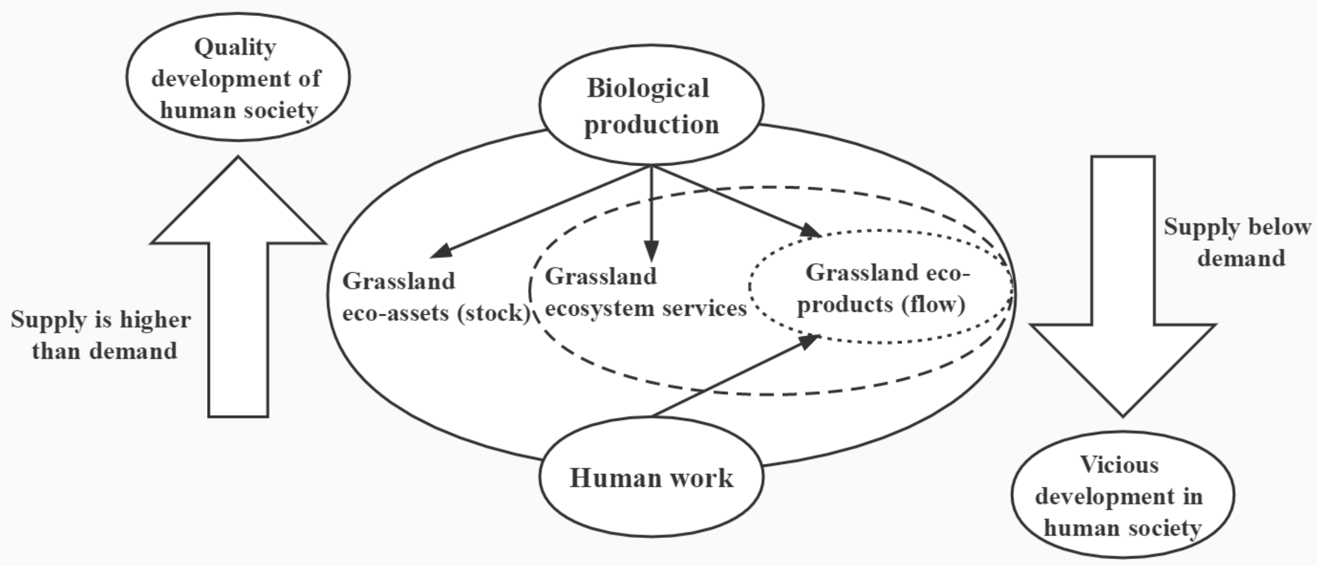

Figure 1. Relationship between grassland ecological assets, ecosystem services, and ecological products. Note: EAs contain ecosystem services, and ecosystem services contain EPs. When the supply and demand between natural ecosystem productivity and human society is an oversupply, society moves toward a virtuous cycle; on the contrary, society moves towards a vicious cycle.

Ecosystems and human health are being harmed by intensive fertilization and overgrazing practices in ecologically fragile areas [17]. As a result, the phenomenon of vulnerability is particularly common in karst ecosystems, which directly affects the restoration and conservation of degraded grasslands and sustainable socio-economic development [18]. Karst is due to the erosion process of soluble carbonate rocks by water flow, which forms a binary three-dimensional structure of surface–subsurface hydrological characteristics and a rich geomorphic landscape [19]. Global karst accounts for 1/5 of the land area, of which, the South China Karst (SCK) centered in Guizhou is the most widely distributed karst in a contiguous area, and its contribution to industry, agriculture, livestock, and safe water supplies for human life cannot be ignored [20,21]. However, the fragile natural environment and irrational human economic activities have led to social and environmental problems, such as soil erosion, vegetation degradation, increased rock outcrops, and increased poverty [22,23]. Curbing the expansion of rock desertification has quietly become a common problem in the world, and the Chinese government's plan to convert agricultural land into woodland and grassland provides a viable solution for the world [24]. SCK's desertification control has achieved significant results. At the same time, the process from "ecological cancer" (a special phenomenon of regional ecological imbalance caused by natural or human factors) to "green desert" (a phenomenon of large-scale and rapid artificial afforestation leading to a decrease in biodiversity and a decline in system function) is occuring. Although the rocky desertification control project has taken such measures as artificial afforestation and grassland planting, its species richness and ecosystem structure have suffered serious damage as a result of high-speed economic development. Examples include the emergence of the endangered *Primulina tabacum Hance*, the near-endangered *Castrodia elata*, the protected medicinal *Coptis chinensis*, and the invasive species *Ageratina adenophora* [25–27]. The fragmentation, and transferability of, and differences in, karst areas indirectly lead to the real dilemma of low yield, poor quality, and slow transformation of EPs [28]. Fundamentally, the relationship between EAs and EPs of grasslands under desertification control is that the supply is much smaller than the demand, and the high cost of farmers' input labor threatens their livelihoods [29]. Therefore, a clear understanding of the services and products that grasslands provide to human society is conducive to achieving ecological restoration. These services include the supply of raw materials, water purification, soil conservation, carbon sequestration, climate regulation, nutrient cycling, biodiversity conservation, and cultural aesthetics [30,31].

Currently, various forage planting combinations have been used to optimize the structure of grassland ecosystems and enrich the species diversity of soil communities [32,33]. By grazing at a reasonable level, soil erosion and farm poverty in karst areas can be effectively alleviated [34–36]. Effective trade-offs/synergies in the degree of human management are key to safeguarding the multifunctionality of grasslands and are very important to curbing land degradation and improving the quality of karst ecosystems, especially karst permanent grasslands (natural grasslands) [37,38]. However, there are few integrated studies on grassland ecosystem structure optimization, function enhancement, service management, EAs, and EPs. Therefore, this paper uses a systematic literature review approach. We aimed to (i) clarify the interrelationship between GES, EAs, and EPs, (ii) summarize the main developments and landmark achievements of grassland EAs and EPs, and (iii) extract five key scientific issues to be addressed at present. This paper helps to improve the scientific understanding of the components and functions of grassland ecosystems, so as to improve the quality and efficiency of grassland ecosystem ecological asset assessment and product supply capacity enhancement. It could provide decision-making guidelines for the scientific facilitation of integrated monitoring of desertification control and human welfare.

2. Materials and Methods

We used a systematic literature review (SLR) approach, which is a five-step cyclical process that incorporates program protocol, search, appraisal, synthesis, and report, with a characteristic methodology that is systematic, comprehensive, and reproducible [39]. This method has been utilized by researchers to both qualitatively and quantitatively analyze related research (Figure 2). The analytical approach of SLRs originated in the field of sanitation and nutrition evaluation and has proven to be applicable in a variety of fields such as mathematical modeling and geographical indications [40].

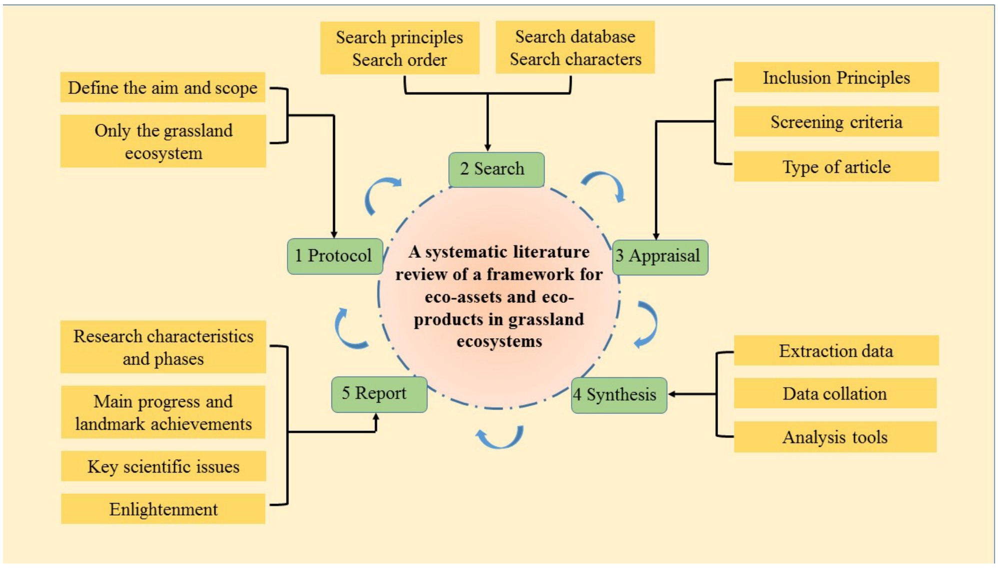

Figure 2. Technical route for the systematic literature review. The technical route is divided into a five-step, clockwise analysis cycle process from 1 to 5, including protocol, search, appraisal, synthesis, and report, and is completed by subroutines under each component.

2.1. Protocol

The protocol phase, using the China National Knowledge Infrastructure (CNKI) and Web of Science (WOS) databases for the literature search, developed a protocol to initiate a systematic literature review that is procedural, cross-disciplinary, and reproducible. The methodology's key aspect is the identification of study objectives, subjects, and boundaries, which helps researchers to validate scientific conjectures made prior to initiating the program [41]. The details of these conjectures were as follows: (1) the year of publication and the regional classification of the research; (2) the distribution of current hot topics; (3) the main developments and landmark achievements of the published literature; (4) the key scientific issues to be addressed in the future; and (5) the progress of research on EAs and EPs of grasslands for enhancing the ecosystem service function of karst desertification control.

2.2. Search

The search phase is shown in Table 1, and 4241 papers were obtained by entering the relevant search strings into the CNKI and WOS databases for primary searches according to the search order of title, abstract, and keywords. We inputted multiple terms related to grass, clicked the search window in the results for a secondary search, and excluded doctoral and master's theses by manual screening; a total of 488 papers were obtained.

2.3. Appraisal

During the evaluation phase, a full assessment of the 488 papers was performed to ensure the scientific validity and scope of the research. Clarification of the inclusion criteria, exclusion criteria, and type of evaluation allowed for further details and improved accuracy of the analysis. The inclusion criteria stipulated that (1) the search terms were present anywhere in the title, abstract, or keywords and (2) the content of the paper clarified the conceptual connotation of EAs, EPs, or services of grassland ecosystems.

The exclusion criteria included (1) duplicate papers; (2) publications with a weak impact; and (3) papers that could not be downloaded for reading.

Finally, based on the inclusion and exclusion criteria, 143 publications were used for SLR analysis. The content and number of all publications included service management (n = 28), structural optimization (n = 22), functional enhancement (n = 40), eco-assets (n = 51), and eco-products (n = 2). Qualitative and quantitative analysis of writings related to grassland ecological assets and ecological products. 85.31% of these literature were positive, 4.2% were negative, and 10.49% were neutral.

Table 1. Search databases and number of relevant papers on ecological assets and ecological products of grassland ecosystems. Retrieved 30 December 2022.

Literature Databases		**Primary Search Terms (in Title, Abstract, and Keywords)**	**Search within Results**	**No. of Initially Acquired Publications**	**No. of Final Publications**
CNKI and WOS	Retrieval string	"Ecosystem" AND "Structural optimization"	"Karst" and "Grassland" OR "Meadow" OR "Pasture" OR "Rangeland" OR "Steppe" OR "Prairie" OR "Savanna"	1658	181
		"Ecosystem" AND "Function enhancement"		817	84
		"Ecosystem" AND "Ecological assets" AND "Ecological products"		196	30
		"Ecosystem" AND "Ecological assets" AND "Services"		1199	129
		"Ecosystem" AND "Ecological products" AND "Services"		371	64
	Total			4241	488

2.4. Synthesis

During this phase, the analysis was carried out using tools such as Excel 2010, IBM SPSS Statistics 22.0, and Origin 2018, with a detailed delineation of themes, time period, and regional distribution. We concluded that grassland ecosystems are a source of abundant food and raw materials for human society. Our belief is that grassland ecosystem components, structures, and functions are crucial for human economic and social development. The focus on relationships, transformation mechanisms, and drivers of services, assets, and products is conducive to enhancing the systems' supply capacity and promoting the goals of the SLR.

2.5. Report

The main aim of the report phase is to analyze the results of the SLR and to establish the research framework for this article. Sections 3.1–3.3 discuss the trends over time, the proportion of research themes, and the distribution of the regions under study, respectively; Section 3.4 outlines the main developments and landmark achievements of the current research; Section 4.1 contains the key scientific issues to be addressed by future research; and Section 4.2 discusses the implications of the ecosystem service functions of grasslands for desertification control.

3. Results

3.1. Annual Distribution

Figure 3 shows the temporal distribution of the retrieved literature from 1994 to 2022 and examines the trend of the total grassland EAs and EPs literature volume according to the focus. Based on the distribution characteristics and landmark events, three research phases could be distinguished: the budding period, the development period, and the diversification period.

First, the budding period was from 1994 to 2004 and was characterized by an average of no more than two articles per year, with the ecosystem process of "plant–animal–soil" interaction as the main focus [42,43]. Global climate change, fire, overgrazing, and species invasion (e.g, *Ageratina adenophora, Amaranthus spinosus* L. and *Bidens pilosa* L.) disrupt the nutrient cycles of carbon, nitrogen, and phosphorus in soils. This affects the functions of microbial communities, alters species diversity, and accelerates the degradation of soil and grassland ecosystems [44,45]. In order to alleviate the contradiction between high-speed economic development and limited ecological resources, macro-control and environmental protection are necessary.

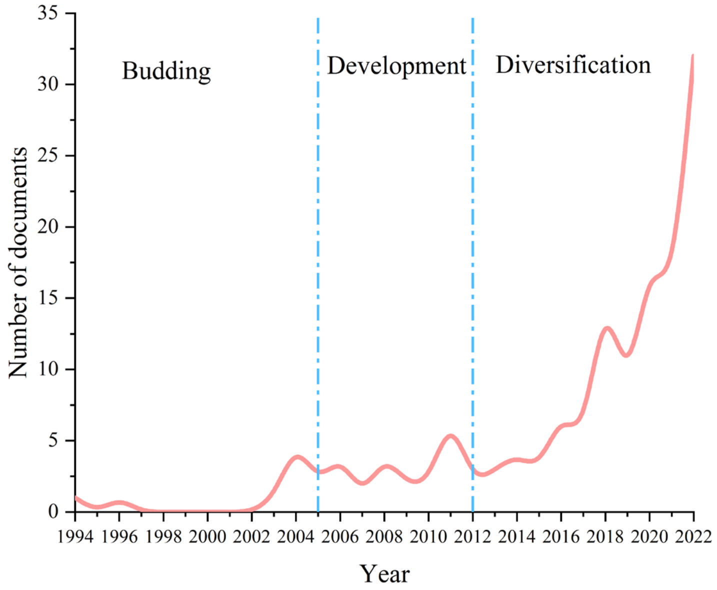

Figure 3. Annual distribution of published literature from 1994 to 2022.

The development period was from 2005 to 2011, with the UN-sponsored Millennium Ecosystem Assessment triggering a global scientific focus on restoring grassland ecosystems [46]. Structural optimization, functional enhancement, and ecological asset assessment of grassland ecosystems were the main concerns, with small fluctuations in the number of published papers. The researchers studied the various changes in microbial community structure, land use types, plant diversity conservation, and ecosystem service values. It has been shown that changing traditional grassland management patterns and improving grassland ecosystem services can help to ensure human food security, mitigate climate change, and enhance human welfare [47–49].

After 2012, the volume of published studies showed an exponential growth trend, and the United Nations focused on the restoration of different ecosystems in the next ten years [50]. In the context of global food security, biodiversity loss, and resource scarcity, aspects of service management, asset and product transformation, and ecological product supply capacity were the focus of the research in this period [51–54]. This period was characterized by studies on the diversity, intersectionality, and technological aspects of issues related to grassland ecosystems. Therefore, this period is known as the diversification phase. It was found that the sustainable development of animal husbandry was conducive to solving the livelihood problems of pastoralists and promoting the restoration of degraded grassland ecosystems.

In summary, the budding period focused on qualitative analyses of grassland ecosystem degradation. The data on system structure optimization and function enhancement support the shift from qualitative to quantitative assessments in the development period. The primary research in the diversification period highlighted the characteristics of the overall quality improvement path of regional ecosystems, the improvement of the supply capacity of high-quality EPs, and the management of ecosystem services.

3.2. Research Topic Distribution

This literature review classified and summarized the research contents of grassland EAs and EPs from the perspective of the structure, process, function, and services of ecosystems. We explored the research characteristics of structure optimization, function enhancement, service management, ecological asset assessment, and ecological product supply capacity improvement (Figure 4).

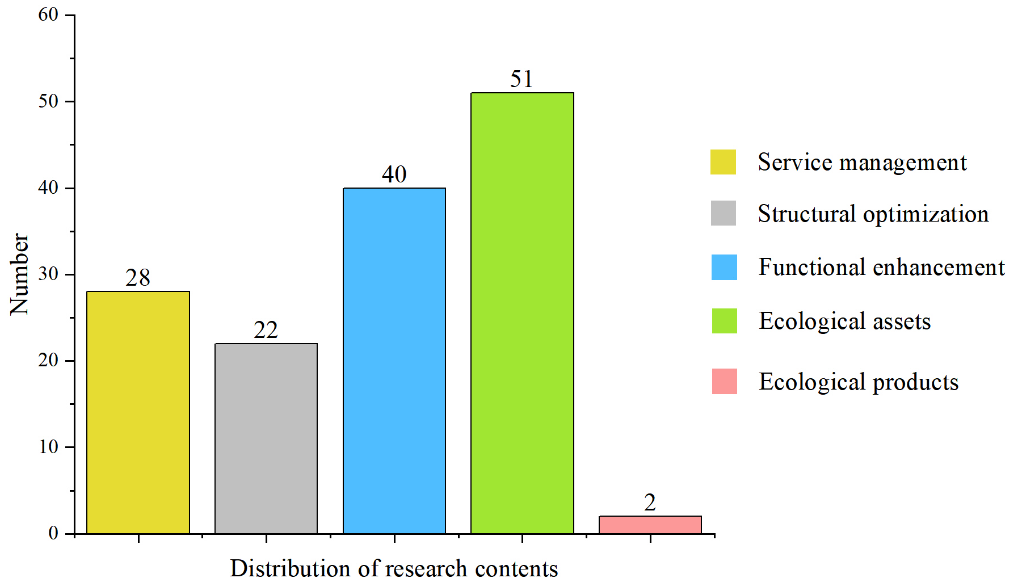

Figure 4. Thematic distribution of research literature.

The most researched themes were EAs, service management, and functional enhancement, which accounted for 82.09% of all papers. Among them, 34.93% were on EAs, 19.58% on service management, and 27.58% on functional enhancement. Because decision-makers and managers need to determine a list of regional ecological resources in order to provide data support for service management and improvement of degraded grassland ecosystems [55]. This shows that ecological asset assessment can change the status of grassland resources. It provides data monitoring for grazing time, technical regulation, and environmental protection red line delineation and regulates ecosystem service functional areas and management measures [56,57].

3.3. Study Area Distribution

Figure 5 shows the regional global distribution of grassland EAs and EPs studies. China had the highest number of published papers with 105 articles and 73.43 percent of the total. This reflects the importance of grassland EAs, EPs, and policy development in Asia. It also reflects the paradoxical phenomenon of changing dietary habits and inadequate regional supply in densely populated areas of Asia [58]. The United States of America followed China with 13 articles and 9.09 percent of the total. This reflects the significant downward trend in net primary productivity of grasslands in North America, which has the largest grassland area in the world. The phenomenon of grassland degradation has attracted the attention of researchers in the region [59]. Germany, France, and Italy accumulated more than three papers (two or less articles are not listed). The quantity here refers only to the regional distribution of the authors' affiliated countries.

3.4. Major Progress and Landmark Achievements

The world is facing the risk of the gradual degradation of grasslands. However, there are still challenges in the classification and value assessment of EAs, EPs, and ecosystem services. The mechanisms for grassland ecosystem structure optimization, function enhancement, service management, and product supply capacity enhancement have been seriously neglected. This review focused on the research themes of grassland ecosystem structure optimization, function enhancement, service management, EAs, and EPs. Figure 6 shows the framework for analyzing the literature on different topics.

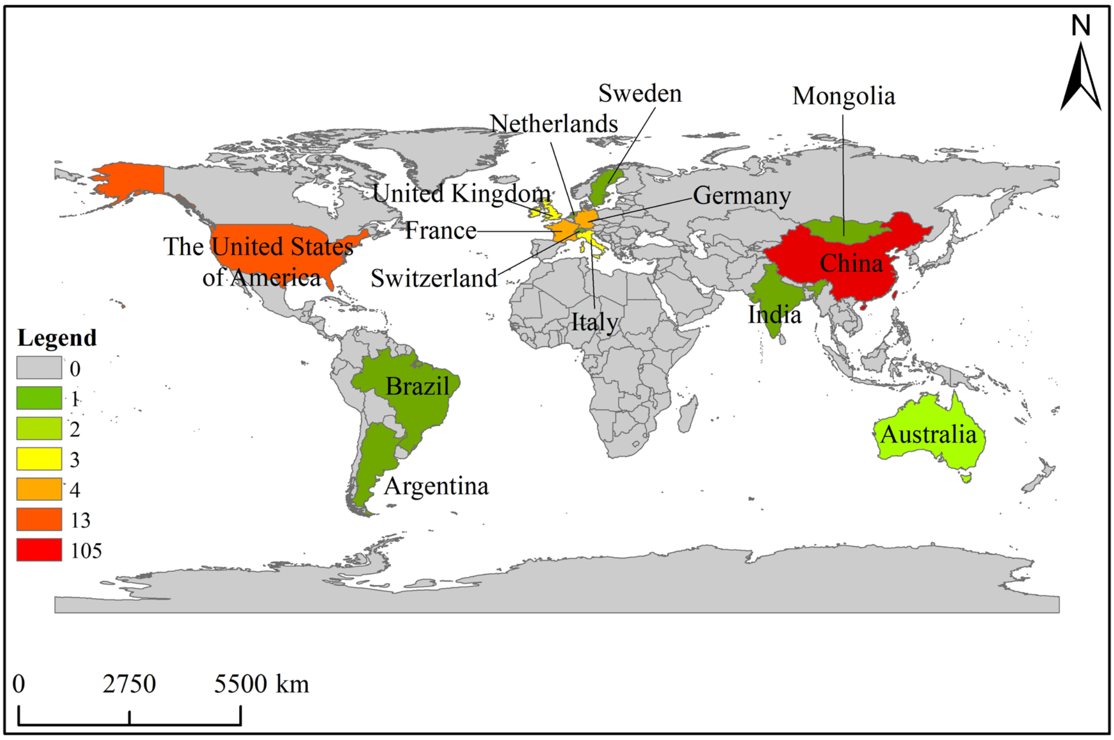

Figure 5. Regional distribution of the global number of published literature on eco-assets and eco-products of grassland ecosystems.

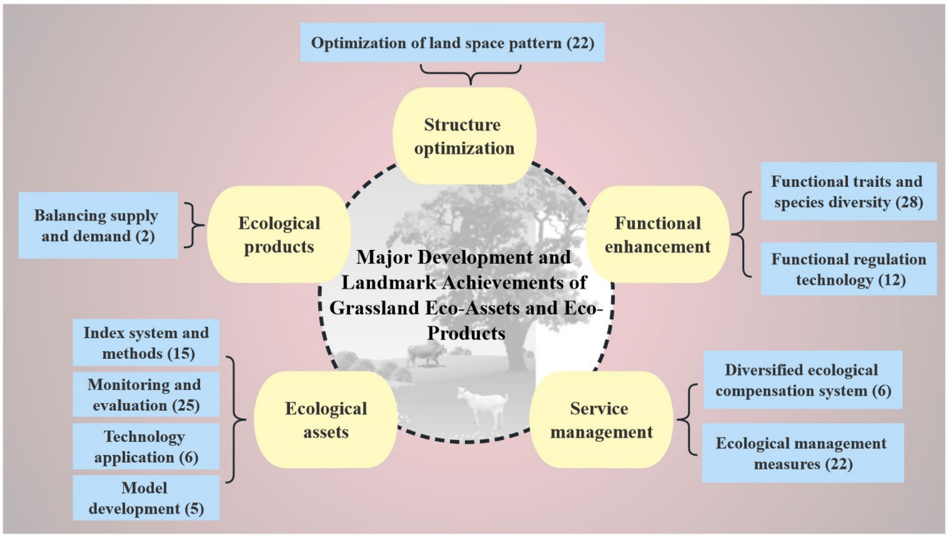

Figure 6. The frame diagram of eco-assets and eco-products of grassland ecosystems. (Note: The numbers in the graph indicate the amount of studies on that research topic).

3.4.1. Structure Optimization

The number of studies on the topic of structural optimization was 22. The earliest paper addressed the problem of diminished system productivity in the interlocking agricultural and pastoral areas of Altai, Xinjiang [60]. With the blurring of the boundaries of different ecosystems, analyzing the optimal allocation of EAs has gradually become the mainstream approach to ecosystem structural optimization. Currently, the spatial and temporal evolution of EAs is mediated by land use patterns, which reveal the indirect effects of climate change and human activities. This results in a general downward trend in the value of ecosystem services [61]. For example, to analyze the effects of population density on ecosystem structure and service values, Fei et al. [62] used a density estimation method. The results showed that population density was negatively correlated with ecosystem services, except for agricultural ecosystems. Thus, regional microhabitat differences and changes in population density show significant variability effects on ecosystems. Ecological restoration is the process of restoring dying ecosystems by returning farmland to forests and grasslands. This is a reasonable measure that will enable us to compensate for the environmental shortcomings and achieve the goal of optimizing the overall structural design. Li et al. [63] used spatial analysis to determine the spatial pattern of regional ecological assets. They clarified that the main drivers of asset change are the climate, population, land use, and urbanization process [64,65]. In summary, clarifying the main controlling factors of regional asset changes is conducive to the structural optimization of different ecosystems. It has provided data references and a scientific basis for ecological environment reconstruction.

3.4.2. Functional Enhancement

(1) Functional traits and species diversity

The theme of plant functional traits and species diversity contains 28 articles. In ecology, targeting the “soil microbial community–plant functional traits–species diversity” framework has been shown to be effective in improving ecosystem services. For example, a meta-analysis based on the exploration of mixed legume plantings in grasslands showed that net primary productivity (NPP) was significantly increased in grasslands with different soil environments. Studies have shown that legume forages may replace inorganic N fertilizers in the future, reducing damage to soil microbial communities from industrial fertilizers, and providing high-quality forage for livestock [42,66]. A study on the effect of optimal mowing time on the functional traits of community plants indicated that appropriate mowing frequency, time, and stubble retention height are beneficial to improving grass yield and quality [67]. Grazing and construction of vegetation barriers in sandy areas directly altered the contribution of the vegetation community and the physicochemical properties of the soil and protected biodiversity in ecologically fragile areas. For example, the intercropping of *Elymus nutans*, *Avena sativa,* and *Salix cupularis* [45,68]. Thus, the above three studies have demonstrated approaches for the improvement of the ecological service functions of grasslands and the effective restoration of ecosystem quality.

(2) Functional regulation technology

There were 12 papers on the topic of functional regulation techniques. Ecological problems have increased in recent years, with frequent fires and overgrazing activities destabilizing the structure of local grassland ecosystems [69], reducing plant community richness, and altering regional microhabitats. The decline in forage quality and the decrease in yield has led to a reduction in forage competitiveness. Therefore, the introduction of new species is an essential tool to maintain biodiversity and ecosystem stability [70]. For example, in studies of new species introductions, *Miscanthus* was found to be a relatively harmless forage grass in European regions, with high ecological and economic benefit in response to different hydrothermal conditions [71]. Thus, for future biodiversity conservation, this grass could be an effective option. At the same time, in order to prevent the disappearance of effective species in the future, it is necessary to establish a germplasm repository based on the requirements of genetic diversity. Thus, we need to clarify the different required materials, principles, and technical indicators, predict the current technical construction difficulties, and determine how to reasonably reduce input costs [72]. Using a quantitative analysis model based on Near-Infrared Spectroscopy (NIRS) technology to detect crude protein (CP) [73], high-quality grass species for breeding programs could be quickly and efficiently screened. However, it is important to combat the threat of invasive species (e.g., *Eupatorium odoratum* L., *Bidens pilosa* L., and *Avena fatua* L.) to grassland ecosystems and develop long-term monitoring and removal [74]. In addition, we should pay attention to the seasonal scarcity of feed and choose appropriate additives to improve the storage technology of silage feed. In order to obtain stable, safe, and high-quality feed [75].

3.4.3. Service Management

(1) Ecological management measures

The theme of ecological management measures was covered in 6 articles. The focus was on the macroscopic perspective of the relationship between regional EAs and ecological product inputs and outputs. The supply of natural ecosystems cannot meet the higher consumption needs of humans; therefore, in the future, an ecological product supply mechanism based on the public–private partnership (PPP) model should be established [76]. Studying the relationship between the economy and ecological environment in different regions is characterized by analyzing the degree of coupling and coordination between ecosystem service functions and supply capacity. At the same time, long-term integrated experimental network sites and forest–shrub–grass grazing crossover systems need to be established to improve ecosystem stability and supply capacity [77,78]. The politics of grass-based agriculture and livestock production, and the stability and resilience of the system vary from region to region. However, from the perspective of market analysis of ecological product supply and operation mechanisms, environmental management measures based on integration can play a significant role in alleviating the contradiction between the ecological environment and rapid economic development.

(2) Diversified ecological compensation system

A diversified ecological compensation system was the theme of 22 papers. Currently, ecosystem degradation and biodiversity loss are common. The "ecological protection red line" delineates ecologically essential and environmentally sensitive areas and seeks a long-term mechanism for simultaneous socio-economic development and ecological protection [79]. GES and local farmers' livelihoods are essential components of the sustainable management of socio-ecological systems [80]. Currently, it is necessary to pay more attention to the ecological and production functions of ecosystems, while also not neglecting the livelihood functions of farmers and vulnerable environmental areas. Therefore, grassland ecological compensation mechanism research should be based on environmental performance, income impact, and policy satisfaction as the indices to develop the grassland ecological compensation policy [81,82]. Only then, can we change grassland utilization and the ecological environment.

3.4.4. Ecological Assets

(1) Index system and methods

There were 15 articles on ecosystem service value assessment index systems and methods. In the past, ecological asset valuation was aimed at constructing an index system for the evaluation of ecosystem quality and area, and at monitoring biodiversity loss and the sustainable provision of ecosystem services [83]. For example, a set of 13 valuation indicators was initially developed using the forest indicator system and model to account for the value of grassland ecosystem services. With technological innovation, spatial analysis methods with a range of costs and computation times have been generated based on differences in scale, the difficulty of data acquisition, and research objectives [84]. Spatial analysis was used to study the spatial and temporal changes in landscape patterns for alpine, semi-arid, or ecologically hostile areas and to explore the impact mechanisms for improving ecosystem service functions and managing the development of agro-pastoral industries [85,86].

At present, the statement "green water and green mountains are the silver mountain of gold" points out that natural ecosystems contain enormous ecological and economic benefits. Incorporating the value of EAs into the social and market economic assessment system is necessary for society to attach more importance to the construction of an ecological civilization. In order to motivate institutional innovation in the ecological civilization construction, accounting methods such as green national economic accounting, national balance sheets, and account inventories of natural resource asset assessment frameworks have been developed [87–89]. For example, the integrated modeling framework integrates ecosystem services and landscape patterns into element, model, and data layers to explore practical solutions for regional ecosystem management [90]. The conceptual framework of "ecological assets–gross ecosystem product–green appreciation transformation–ecological compensation policy formulation" has made outstanding contributions to the process of ecological civilization construction. The gross ecosystem product (GEP) and ecological asset accounting are the basis for converting ecological benefits into economic benefits [91].

Simple and efficient valuation accounting methods were first identified by analyzing the ecological asset valuation objects and value categories [92]. The valuation methods were divided into three categories: direct market, alternative, and simulated market methods [93]. As shown in Tables 2 and 3, ecosystem service value assessment methods have their advantages and disadvantages. When comparing the scientific accuracy, objectivity, applicability, and credibility of the methods, the ranking is direct market method > alternative market method > simulated market method > energy valuation method.

Table 2. Advantages and disadvantages of different methods of accounting for ecosystem service value.

Evaluation Indicator	Method Type	Method	Equation	Formula Meaning	Advantages	Disadvantages	Reference
Organic matter production function	Direct market method	Market value method	$V_1 = \sum(m_i \times p_i)$	V_1 is the product value in CNY; m_i is the output of product category i in t; and P1 is the unit price of product category i in CNY·t^{-1}.	Evaluation is objective, with real-time data providing value and credibility.	Market prices follow the "supply and demand" law of economic development and are highly volatile; the data must be comprehensive and large in size.	[94]
Entertainment and leisure functions		Expense method	$V = V_1 + V_2$ $V_1 = \sum\limits_{i=1} P_i \times Q_i$ $V_2 = F + T + Q$	V is the cultural recreation value of the study area; V_1 is the research and cultural value; P_i is the average research value per unit area of ecosystem; and Q_i is the unit ecosystem area. V_2 is the recreational leisure value; F is the travel cost expenditure replaced by tourism income; T is the travel time value; and Q is other expenses.	The ecological value of cultural tourism areas can be directly quantified.	The method is limited and can only estimate the value of ecotourism areas.	[95]
Environmental purification function		Recovery and protection cost method	$V_a = \sum\limits_{i=1}^{n} X_i \times A_i \times P_i$	V_a is the value of the ecosystem's ability to absorb or deter pollutants; X_i is the capacity of the ecosystem to absorb pollutant i; A_i is the area of the ecosystem to absorb pollutants; P_i is the cost of treatment of pollutant i.	Ecological value can be quantified in terms of ecological restoration costs or protection costs.	Estimates are low, and the loss in value of ecosystem services that have been destroyed cannot be accurately estimated.	[96]

Table 2. *Cont.*

Evaluation Indicator	Method Type	Method	Equation	Formula Meaning	Advantages	Disadvantages	Reference
Soil conservation function	Alternative market approach	Opportunity cost method	$V = \sum_{i=1}^{n} S_i \times F_i$ $F = \sum\limits_{i-1} S_i \div T$	In the first formula, V is the value of ecosystem soil fixation; i is the different ecosystems; S_i is the opportunity cost of soil erosion per unit area of ecosystem type i; and F_i is the area of abandoned land of ecosystem type i. In the second formula, F is the area of abandoned land; L is the total reduction in soil erosion for ecosystem type i; and T is the average thickness of surface soil in the study area.	A more comprehensive way to calculate the ecological home value of ecological resources.	Cannot account for the value of scarce resources.	[97]
Water-supporting function		Alternative engineering method	$V = P \times K \times R \times C$	V is the value of cultured water, in CNY·m^{-2}·a^{-1}; P is the amount of precipitation, in mm; K is the ratio of flow-producing precipitation to total precipitation, a constant; R is the coefficient of runoff reduction benefit, a constant; and C is the cost invested in the construction of 1 m^{-3} reservoir construction.	Approximates the value of damaged ecosystems.	The cost of alternative work makes it difficult to fully value the multiple functional benefits of ecosystems.	[98]
Carbon sequestration		Shadow engineering method	$V = NPP \times (1.2 \times P + 1.62 \times Q)$	V is the value of carbon sequestration, in CNY; P is the price of industrial oxygen production, in CNY·g^{-1}·c^{-1}; and Q is the fixed price of CO_2, in CNY·g^{-1}·c^{-1}.	Use alternative market techniques to find market prices for common public goods.	The selection of shadow prices is highly subjective and uncertain, and the prices of the selected commodities fluctuate significantly.	[99]
Biodiversity maintenance function	Simulated market method	Conditional value method (CVM)	$V = P \times P_a$	V is the value of biodiversity, in USD; P is the number of people that are willing to pay, in units; and P_a is the average price, in CNY.	For non-use (non-market) types of ecosystem services, the economic value of consulting public goods from a consumer's perspective is estimated scientifically and rationally.	The ambiguity in consumer awareness creates preference problems that are difficult to solve.	[100]

Table 3. Energy value theory method.

Scope of Application	Method	Advantages	Disadvantages	Reference
Calculation of the value of various types of services	Energy value theory method	Calculation of different categories and different natures of EAs; the establishment of a unified standard solar radiation energy calculation formula; the flexible use of different energy value conversion rates; the elimination of objective factors; and thus, it has broader application prospects.	Current scientific and technological developments limit the widespread use of this method.	[101]

(2) Monitoring and evaluation

There were 25 papers on monitoring and assessment topics, including 18 ecosystem-wide studies and 7 single-system or single-service function studies. These studies showed that the scope of research on EA value monitoring and assessment is divided into four main categories: global scale, regional scale, watershed scale, and sample plot scale. This classification only characterizes the relative size relationship of the different problems and objects.

Overall ecosystem: London et al. [6] initiated a study of global and regional ecological asset valuation. Focusing on climate change issues and the impact of large-scale human production activities on ecology can help alleviate conflicts between humans and the environment and alleviate environmental degradation. The research has focused on the effects of different types of ecosystem structure, quality, and area on ecosystem function. Srikanta et al. [102] used the elasticity coefficient (CE) and sensitivity coefficient (CS) to analyze the spatio-temporal variation in ecosystem service value (ESV). The results indicated that anthropogenic and rational landscape planning and optimization of territorial spatial resources benefit sustainable future economic development. For example, spatio-temporal variation in dryland ecosystems resulted in regional hot and cold spots of ecosystem services [103,104]. Accurately tracking changes in forest, cropland, and grassland areas can provide data to support decisions by ecological conservation managers.

Single-ecosystem and single-service functions: The existing research has increasingly focused on the synergistic relationship between the functional composition of regional single ecosystems, production management practices, and the value transfer and trade-offs of service functions [105,106]. This is a key insight for the maximization of the value of a single ecosystem. For a single grassland ecosystem, for example, Chinese scientists conducted ecological asset accounting. Through numerous expert questionnaires, analytic hierarchy processes (AHP), and induction methods, they established equivalent factors for different service functions and roughly derived ecological asset values for different grassland types across the country [107]. Using local farm yields, a revised model based on biomass calculations allowed for the estimation of ecosystem service values of forests, grasslands, and croplands. However, this accounting approach ignores the heterogeneous influence of geographically differentiated characteristics and climatic conditions on the value of ecological services. The range of static values of a single ecosystem function for water purification, soil conservation, and biodiversity as criteria for good or low ecosystem quality is questionable [108–110]. Wu et al. [111] used the precipitation storage method to estimate the interannual variation in water content in forest and grassland ecosystems in the Three Rivers Source Area. They clarified that the contribution of the improvement of water purification service function after the implementation of ecological projects was about 23.98%. Xiao et al. [112] used the soil loss equation model (USLE) to measure the soil conservation function of woodland, grassland, swamp, and farmland ecosystems on the Tibetan Plateau. They classified the soil conservation function into soil nutrient retention, wasteland reduction, and sedimentation reduction. The focus of more recent research has been on the simple summation of the values of various ecosystems. The mechanism of ecological asset transfer between different regions, landscape types, and functions is unclear, which directly affects the supply capacity of ecosystem services.

The conversion of ecological assets from quantified to unquantified is carried out to assess the overall index or grade of government performance and to provide data support for ecological compensation policies. Recent research has focused on the expanded index and ranking of total ecological assets to accurately compensate for weaknesses in ecologically vulnerable areas and to establish a complete compensation mechanism [113]. For example, Bo et al. [114] conducted an accounting of the comprehensive index of ecological assets in the Hinggan League, Inner Mongolia. They created a physical volume change table and a profit and loss table that showed that improving the quality of forests, grasslands, and wetlands promoted a virtuous cycle of ecosystem development. You et al. [55] examined a comprehensive index of county EAs, a liability account, and a profit and loss account to effectively reflect changes in ecosystem quality and delineate ecological asset classes. Huang et al. [115] used GIS spatial analysis to assess the change in EAs area and comprehensive index in key ecological functional areas, which showed an increasing trend in both quantity and quality of EAs. The results indicated that ecological engineering was the main driving force. This provides data support for the implementation of effective ecological engineering and the formulation of ecological compensation policies.

(3) Technology application

The theme of 6 articles was technology application. In order to comply with the development trend of the information age, we adhere to the principles of reducing evaluation costs, simplifying cumbersome procedures, and improving accounting efficiency. We use "3S" technology to evaluate, monitor, and analyze the spatiotemporal evolution of ecological assets, and effectively clarify their temporal trends, spatial distribution patterns, and influencing factors. For example, Chen et al. [38] showed that the value of ecosystem services in karst areas of China fluctuates upward over time, with higher ESVs in the southwest. Changes in wetlands, woodlands, and watersheds are the main reasons for the increase in ESV in this region. Xu et al. [116] pointed out that the overall trend of EAs in the Yangtze River Delta region has been decreasing over the past 12 years. The spatial distribution is characterized by a pattern of high in the south and low in the north, suggesting that the most effective way to increase regional EAs is to promote ecological restoration projects. In the regulation of ecological functions, the EPs of nature reserves play a crucial role. Through the assessment of water purification, soil conservation, and carbon sequestration, it was found that various ecosystem types supply different EPs [117]. There is a trend to use different types of data such as Landsat TM, MODIS, land use, NPP, and vegetation cover data to monitor and assess the value of EAs. This is particularly important for the scientific and systematic assessment of regional economic development levels.

(4) Model development

The theme of five articles was model development. Ecosystem services are assessed in terms of “physical quantity” and “value quantity”. Based on the calibration of the ESV equivalence scale compiled by previous studies, this model can assess the value of regional ecosystem services with the advantages of efficiency, accuracy, and classification refinement [118]. On the one hand, the InVEST model was used to assess the regional ecosystem service capacity of typical desertification environments. It can accurately grasp the vital role of the three modules of water purification, soil conservation, and carbon storage for regional ecological management and the enhancement of ecosystem service functions [119]. On the other hand, the equilibrium factor and the yield factor, based on the ecological footprint model, show the differences in the capacity of environmental services provided by different ecosystems and can better express the carrying capacity of various ecosystems [120]. In summary, to solve the problem of slow policy formulation and accounting results, the ecological asset optimization assessment model maintains the balance between regional socio-economic development and environmental protection.

Quantitative prediction of future scenario model: The ecosystem service value prediction model scientifically predicts past, present, and future scenarios that can ensure the sustainable provision of quality services by ecosystems in the future [121]. For example, the CA-Markov model can accurately represent future vegetation succession trends, and it showed that controlling the leading drivers during stochastic changes in landscape patterns is conducive to improving future habitat quality and biodiversity service functions [122]. The CLUE-S model can more accurately simulate small-scale areas that drive changes in land use patterns [123]. In summary, the analysis of the spatio-temporal evolution patterns of ESV in the past, present, and future, combined with the future economic development direction of the region, will produce sustainable solutions for land policy makers and managers.

3.4.5. Ecological Products

The theme of two articles was the balance between supply and demand of EPs. The research is gradually moving toward the balanced development of the "three living functions". The ecological function of grasslands is the basis for maintaining ecological security; the production function of grasslands is the extension of eco-industry; and the living function of grasslands is the carrier of people's welfare. The "three functions" form an interlocking and coupled mechanism that directly affects the sustainable development of grassland ecosystems [124–126]. Balancing the supply of ecosystems with the consumption needs of socio-economic development is a fundamental issue in accelerating the overall enhancement of grassland ecosystem quality and the scientific promotion of integrated desertification control. Thus, we elucidate the relationship between ecosystems (producers, consumers) and humans (individual preferences, willingness to pay). Following the research idea of "qualitative-quantitative-orientation-strategy", the basic laws and framework systems of spatial transfer, management practices, value assessment mechanisms, and differences between supply and demand of ecosystem services can be explored [127,128]. With technological innovation, the introduction of "3S" technology and ecological footprint models to quantify the supply and demand of EAs [129], we can identify an appropriate ecological footprint that can help alleviate the conflict between supply and demand in grasslands. These cases show that grassland degradation, the introduction of high-quality grass species and production management methods, and the transfer of surplus animal husbandry laborers are important initiatives to improve the service capacity of grasslands, laying the foundation for a comprehensive improvement of regional ecological quality.

4. Discussion

We comprehensively reviewed the research process of grassland EAs and EPs through an overview of annual changes and stages in the literature and the distribution of research themes. The landmark results of recent research in structure optimization, function enhancement, service management, EAs, and EPs were summarized. On the basis of the above studies, we propose five key scientific issues to be addressed to apply the research on enhancing ecosystem service functions in desertification control, which we will systematically elaborate on in the following sections.

4.1. Key Scientific Issues That Need to Be Addressed

4.1.1. There Is an Urgent Need to Identify the Drivers of Change in Ecosystem EAs and EPs of Grasslands and to Find the Mechanisms of the Effects from Climate Change and Soil Characteristics

Natural and human factors, such as climate change, population density, urbanization, and industrial upgrading, combine to drive land use change and alter the supply of ecosystem services [61,130]. However, the drivers of grassland ecosystems require further analysis. The drivers of grassland ecosystems require a spatio-temporal perspective to highlight changes in the individual ecosystem service functions of grasslands. Remote sensing was used to analyze the seasonal spatio-temporal evolution of EAs of grassland ecosystems and to assess the carrying capacity of primary ecosystem functions. Similarly, individual ecosystem services are influenced to varying degrees by the soil biology of the sample site [131,132]. Therefore, the degree of influence of plant functional traits and soil characteristics on ecosystem services is essential to understanding the interrelationships and weights of different functions and to improve the quality of regional ecosystems.

4.1.2. Assessment Models and Techniques Should Focus on Enhancing Multifunctionality, Breaking Down Supply and Demand Barriers between Karst Grassland Ecosystems and Human Society, and Promoting a Balance between the Three Regional Functions

Grassland ecosystem assessment models and techniques are key to problem solving for the current state of land production functions only. Ecological footprint models and ecosystem service techniques can be used to assess ecological and livelihood functions, thus revealing the balancing mechanism of multiple ecosystem functions [133]. The analysis of the capacity and ecological footprint of grasslands is the basis for life–production–ecological functions. For example, some scholars have used the CASA and STARFM models to re-evaluate the ecological and environmental capacity of grassland ecosystems to produce a sustainable supply [134]. In particular, the preliminary assessment aimed to improve the ecological function of grassland ecosystems, to change grazing behavior and grassland distribution, and thus to provide sustainable and healthy management practices [135]. It also elucidated the state of grassland overload caused by the spatial mismatch between the rapid growth of livestock and the supply and demand of grassland resources. Therefore, scenario prediction for optimizing the future land, is a key factor in clarifying the supply and demand relationship between ecosystems and human society and the balance of living–production–ecological functions [64], which helps to optimize and enhance the grassland ecosystem assessment models and techniques.

4.1.3. In Response to the Inefficient Transformation of Grassland EAs and EPs, the Input–Output Ratio Should Be Improved to Increase the Supply Capacity of Grassland EPs in Karst Areas

To address the need for more research on the input–output relationship of EAs in grassland ecosystems, we proposed an optimization scheme for grassland ecosystem services by analyzing the factors affecting the supply of EPs. The transfer of EAs in grassland ecosystems currently occurs between regions and individual ecosystems, and preliminary knowledge has been developed on the mechanisms of transfer media, regions, and drivers [31,136]. However, the key to optimizing and controlling a single ecosystem lies in the positive transfer between different service functions. This measure should accelerate the efficiency of the conversion of EAs of grassland ecosystems into EPs, thus increasing the supply capacity of the ecosystem. At the same time, consideration should also be given to reducing the artificial input costs of ecological assets and increasing the output volume of EPs.

4.1.4. To Address the Issue of Trade-Off/Synergy Mechanisms for Grassland Ecosystem Services and Based on the Cascade Framework of "Ecosystem Structure–Process–Function–Services", a Holistic Approach to Improving Ecosystem Quality in Karst Areas Is Proposed

Using a qualitative and quantitative approach to identify GES trade-offs/synergies, the relevance of the different indicators needs to be clarified. Scholars have argued for enhancing the influence of internal and external factors on ecosystems based on the ecosystem "structure–process–function–services" cascade framework. Attention needs to be paid not only to the external factors that balance the multifunctional demand for grassland productive potential, but also to the complex trade-offs and synergies within different ecosystem functions [137,138]. As a result, rationalization grassland ecological management can help to balance and synergize the complex relationships between the different ecosystem services [139]. Especially in ecologically fragile karst areas, we can clarify the trade-offs and synergies between grassland ecosystem services in desertification control, to explore their impacts on human well-being.

4.1.5. In Response to the Uneven Spatio-Temporal Distribution of Grassland Resources in Different Regions, Different Functional Areas of Use Should Be Identified to Enhance the Supply of EPs in Karst Areas

The recent research has focused on cross-sectional comparisons of ecological asset values, establishing dimensionless metrics. However, based on the assessment of the status of EAs in regional grassland ecosystems, the composite indices and rankings vary significantly and only provide a basis for resource managers and policy makers to delineate different functional areas at the macroscopic level [54]. At the micro level, however, there is an urgent need for technology development, policy refinement and risk prevention awareness to optimize grassland management. For example, ecological intensification of grasslands (e.g., intercropping between agriculture and grass) maintains high levels of ecosystem services and biodiversity. Simultaneously increasing forage availability and the area of grass sown is key to improving the supply capacity of grassland ecosystems [140]. Some scholars have pointed out that the design of forest and grassland conservation models is aimed at optimizing management strategies from the perspective of farmers' food needs. However, the advantages and disadvantages of species invasions on ecosystems should considered, whether in terms of artificial management practices or in terms of improving service functions from the perspective of ecosystem interactions [141,142].

4.2. The Intrinsic Relationship between Grassland EAs, Products, and Desertification Control

Grassland EAs and EPs connote the conditions and utility that natural resources and ecological environments provide to humans [143]. An accurate analysis of the virtuous cycle and malignant development impulse of grassland ecosystems facilitates the formation of a cascading framework for a long-term mechanism of improving ecological livestock husbandry and human well-being under stone desertification management (Figure 7). This framework, based on the interplay between grassland ecosystem structures, processes, and functions, clarifies the ownership and scarcity of natural ecological resources. Through the value-added system of EA investment and operations, we can explore the market-based supply method and value realization mechanism of EPs. The ecological compensation standard, scope, and mode should be clarified, and weighing the pros and cons of the ecosystem is conducive to providing a research framework for the economic development of karst regions.

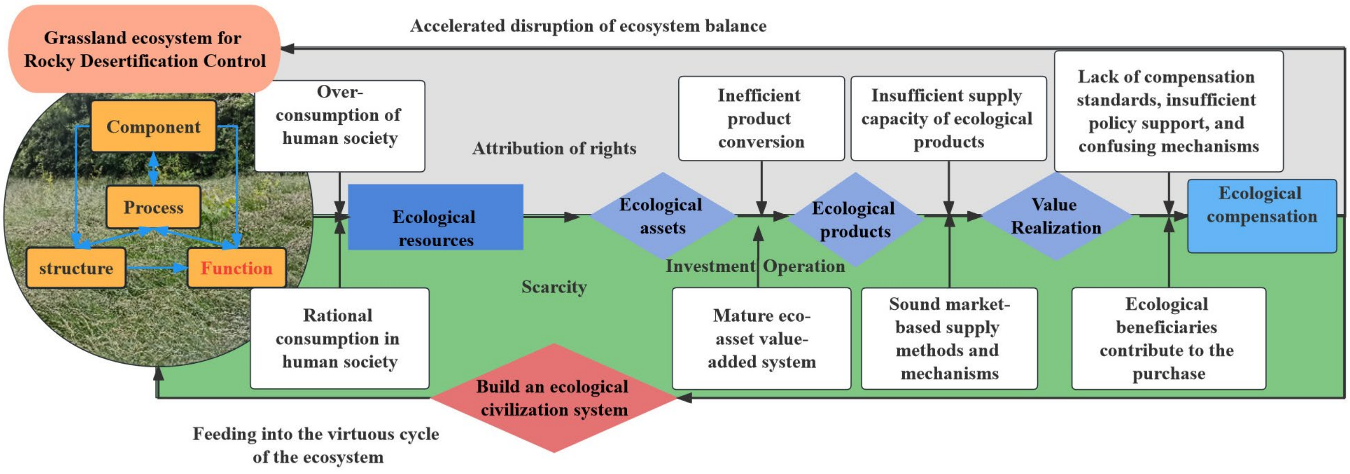

Figure 7. Framework diagram for forming final eco-products from grassland ecosystems for desertification control.

4.3. Insights into the Enhancement of Grassland Ecosystem Services in Desertification Control

In the 1990s, China carried out large-scale ecological restoration projects in response to the spread of desertification, with measures such as improving degraded grasslands and artificial planting in grassland ecosystems, which played a pivotal role in curbing the growth of desertification [144,145]. In this context, we present the findings of the recent grassland ecosystem research on karst desertification control from the perspective of preconditions, intermediate links, and important initiatives. We aim to provide directions for promoting the restoration of system quality in ecologically fragile areas.

4.3.1. A Deeper Understanding of the Fragility of the Karst Natural Environment Is a Prerequisite for Optimizing the Structure of Grassland EAs

Through a systematic review and compilation of the research on EAs and EPs of grassland ecosystems, the analysis focused on optimizing the allocation of grassland EAs to achieve the revitalization objectives under the natural conditions of the karst ecosystems. Based on the natural environment, karst ecosystems are located in a binary, three-dimensional landscape structure above and below the ground, with shallow and fragmented surface soils, which are mostly alkaline soils rich in calcium [146]. The sloping land has well-developed subsurface pore (fissure) spaces, which can easily cause soil nutrient and water loss in areas with heavy rainfall and high slopes. The rugged and steep topography, significant elevation differences due to the heterogeneity of water and thermal conditions, and vegetation diversity, growth, and development form a non-zonal distribution [147], resulting in considerable differences in the supply of GES. As a result, karst environmental ecosystems are prone to reverse succession of deterioration. Only plant populations with physiological characteristics of calcium liking, drought resistance, and lithophytic growth, as well as species with roots that adapt to rock and survive in crevices to extract nutrients, can grow and develop in this special environment.

4.3.2. Identifying the Relationship between the Supply and Demand of Grassland Ecosystems Is an Intermediate Step in the Functional Enhancement of Ecological Assets

The critical point in the development of organic livestock is the balance between human social consumption demands and the supply capacity of grassland ecosystems. The classification survey of EPs of karst grasslands and assessment of their supply capacity and influencing factors can prevent seasonal fodder shortage for livestock. This can reduce the cost of ecological asset valuation and ecological product distribution, accelerate improvements in input–output efficiency, and provide evidence to support decisions for optimizing grassland ecosystem functions.

4.3.3. Grassland Ecological Management Practices Are an Important Initiative to Enhance the Supply of Grassland Ecological Products

The measures to improve grassland ecosystem services are as follows: (1) A mixture of leguminous and herbaceous forages can be used to take advantage of their complementary benefits of increasing the net photosynthetic rate and water use rate. The nitrogen fixation properties of leguminous forages have a facilitating effect on the growth and development of herbaceous forages [148,149]. (2) Grasslands can use withered mulch to address the problem of accelerated surface water evaporation thanks to the reflection of solar radiation from rocky outcrops and to mitigate the effects of harsh environmental factors on the water-holding capacity of ecosystems [150]. Their planting structures and configurations should be optimized to modify the soil water–fertilizer exchange interactions and, to some extent, improve soil physicochemical properties. These studies will guide us in restoring degraded karst grassland ecosystems.

Therefore, to achieve the goal of a sustainable supply of high-quality EPs in the grassland ecosystem for karst desertification control, we need to optimize the allocation of grassland EAs and adjust the spatial distribution of water and fertilizer conditions in grassland ecosystems (Figure 8). We also need to facilitate the enhancement of the EPs supply capacity of grasslands, thereby promoting the improvement of the overall ecosystem service function.

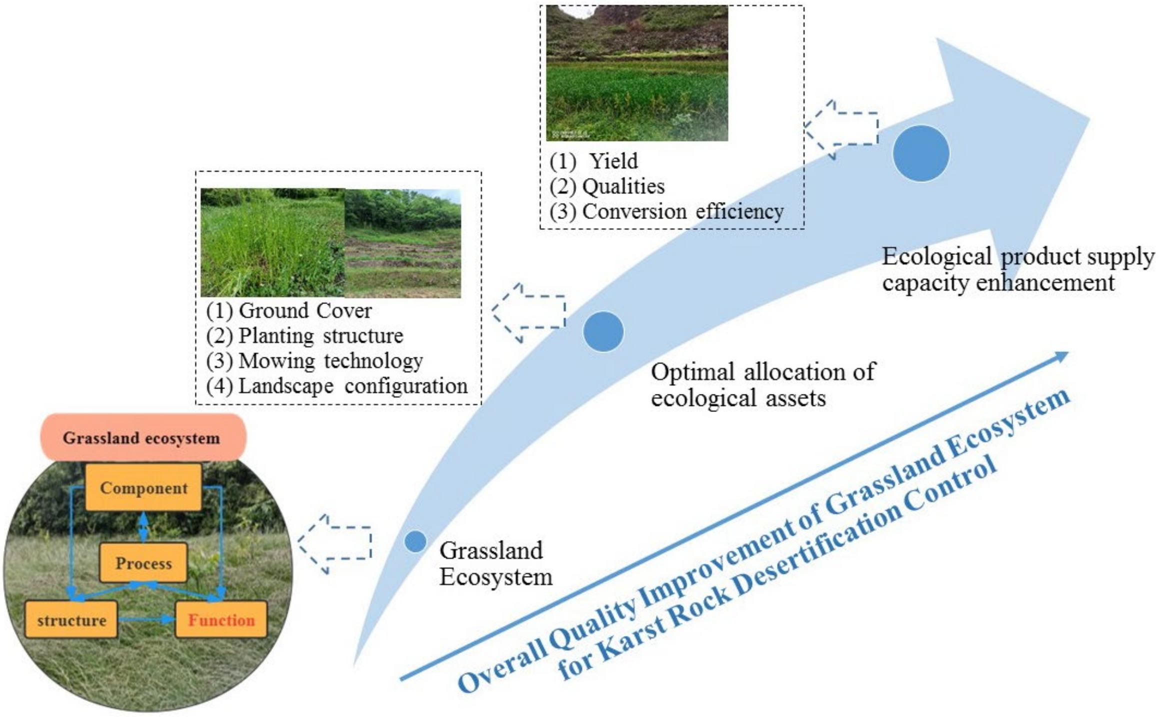

Figure 8. Roadmap for the optimal allocation of eco-assets in grassland ecosystems and the mechanism for eco-products supply capacity enhancement.

4.4. Limitations

The only databases used in this paper were WOS and CNKI, not Springs, Scoup, or other databases, and the search results may be biased. The summary of the research topic classification method and the key scientific issues to be addressed were also somewhat subjective.

5. Conclusions

In this paper, we conducted a systematic literature review of 143 articles retrieved through the CNKI and WOS foreign language journal resource service system, and the main conclusions were as follows: (1) The annual number of papers on EAs and EPs of grassland ecosystems has increased rapidly since 2012; the research stages can be divided into budding (1994–2004), development (2005–2011), and diversification periods (2012–2022). (2) The most common research themes were EAs, function enhancement, and service management, which accounted for 82.09% of the literature. The research regions were mainly located in Asia and North America. (3) The main progress and landmark achievements were in structural optimization, functional enhancement (functional traits and diversity and regulation techniques), service management (ecological management measures and diversified ecological compensation techniques), EAs (construction of index systems and selection of appropriate methods, monitoring and evaluation, application of technology, and model development), and EPs. (4) The five key scientific issues to be addressed in the future are identifying spatial and temporal changes in ecosystem assets and products; developing assessment models and technologies focused on enhancing multifunctionality; grassland EAs and products should focus on improving the efficiency of input–output ratios; establishing a synergistic mechanism for grassland ecosystem service trade-offs; and strengthening grassland ecological management in order to improve the supply of EPs. In the future, we should focus on the relationship between the optimal landscape allocation of EAs and the improvement of ecological product supply capacity; we also need to change the way decision makers and managers use grasslands, and give full play to the important role of grasslands in karst desertification control in improving ecosystem quality.

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