Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 11, No. 2, 2026
www.scholink.org/ojs/index.php/se

Original Paper

Implications of Protected Area Integrity Conservation and Buffer-Zone Agroforestry Development for the Protection of Karst World Heritage Sites

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Received: February 01, 2026 Accepted: March 22, 2026 Online Published: April 20, 2026

doi:10.22158/se.v12n1p255 URL: http://dx.doi.org/10.22158/se.v12n1p255

Abstract

Karst World Heritage sites, as natural wonders of the Earth, possess Outstanding Universal Value, and the conservation of their integrity is of great significance for maintaining global biodiversity and geological and geomorphological features. However, while protecting heritage sites, how to promote economic development in buffer zones, especially the development of agroforestry, has become an urgent issue to be addressed. As a sustainable agricultural practice, agroforestry can promote economic development while simultaneously protecting the environment. The implementation of agroforestry has effectively contributed to World Heritage conservation. Nevertheless, there is still a lack of comprehensive understanding regarding the research trends, focal topics, and latest developments in the fields of integrity conservation of protected area and agroforestry development in buffer zones. Therefore, this study employs the CNKI and Web of Science databases, together with CiteSpace software, to conduct a bibliometric analysis, and uses literature visualization to explore the major research themes and frontier issues related to the integrity conservation of natural World Heritage sites and the development of buffer-zone agroforestry. Based on the preliminary results obtained, we discuss current publication trends and outputs, keyword and abstract word frequencies, national publication productivity, collaboration networks, and major contributing institutions. The results show that the development of agroforestry has contributed to biodiversity conservation in heritage sites. However, studies on the role of buffer-zone agroforestry development in supporting the

integrity conservation of World Heritage sites remain limited. Accordingly, future research should place greater emphasis on the relationship between buffer-zone development and heritage integrity conservation, especially in ecologically fragile karst World Heritage sites, and should further strengthen the role of agroforestry development in buffer zones in promoting ecological balance and the sustainable development of heritage sites, so as to provide scientific references for the conservation and development of other geological heritage sites worldwide.

Keywords

protected area, buffer zone, agroforestry ecological product, value realization, mechanisms and paths

1. 1 Introduction

World Natural Heritage refers to natural areas of Outstanding Universal Value in terms of natural landscapes, geological and geomorphological features, ecosystems, and biodiversity. To be inscribed on the World Natural Heritage List, such areas must satisfy one or more of the relevant criteria0. World Heritage sites are not only precious natural assets of the Earth, but are also of great significance for maintaining biodiversity, conserving ecosystems, and promoting harmonious coexistence between humans and nature [2]. The establishment of World Heritage sites is intended to recognize and protect those unique and irreplaceable areas, as they embody the historical memory of Earth's evolution and perform important ecological functions. As of August 2025, there were 271 natural World Heritage properties worldwide, including 40 mixed cultural and natural heritage sites [3]. The conservation of World Natural Heritage involves not only preserving unique natural landscapes, but also ensuring the continued survival and reproduction of plant and animal populations within heritage sites, thereby maintaining ecosystem balance. However, with the accelerating processes of globalization and urbanization, World Natural Heritage is facing unprecedented threats. External environmental changes, such as climate change and the increasing frequency of natural disasters, have made these sensitive areas more vulnerable to damage, while internal development pressures, including tourism development and unreasonable human activities in buffer zones, have further intensified conservation risks at heritage sites. Greater attention should therefore be paid to the regulatory role of buffer zones, and pathways for achieving synergy and mutual benefits between environmental protection and economic development should be explored [4][5].

World Heritage integrity refers to the state of wholeness and intactness of natural and/or cultural heritage and its associated attributes. According to the definition of the United Nations Educational, Scientific and Cultural Organization (UNESCO), any property nominated for inclusion on the World Heritage List must meet the condition of integrity. Integrity is an important criterion for evaluating the wholeness and intactness of World Heritage properties and mainly includes the following aspects: first, the property should include all elements necessary to express its Outstanding Universal Value (OUV); second, it should be of adequate size to ensure the complete representation of its key features and related ecological processes; third, it should not suffer from adverse effects of development activities

and/or management deficiencies that may compromise its value and integrity [6]. Therefore, integrity is not only an important measure of heritage value, but also a key foundation for safeguarding the Outstanding Universal Value of World Heritage properties. The principles of World Heritage conservation are established on the basis of integrity, because integrity is both an important measure of heritage value and a core basis for maintaining its Outstanding Universal Value [7]. In addition, integrity also involves the rationality of heritage boundary delineation and its conservation status, including whether it encompasses all attributes necessary to sustain Outstanding Universal Value and whether it possesses sufficient spatial scale to fully represent its important features and processes [8]. For natural heritage, integrity is not static and unchanging, but rather a dynamic and sustainably maintained state of integrity [9].

A buffer zone refers to an area surrounding a protected unit in which certain rules and restrictions are imposed on human activities, with the aim of minimizing the adverse impacts of external activities on the protected area as much as possible [10]. As a key management instrument for maintaining World Heritage integrity, the primary function of a buffer zone is to reduce the disturbance caused by external development activities to the core heritage area. Through the establishment of buffer zones, the negative impacts of urban expansion, agricultural activities, and other human interventions can be isolated to a certain extent, thereby preserving the natural or cultural characteristics of heritage properties [11]. A buffer zone is a specific area delineated around a nominated heritage property for its effective protection, including important landscapes surrounding the heritage location as well as other areas or elements that are functionally critical to heritage conservation. As an important management tool for strengthening control over the transitional space between World Natural Heritage properties and their surrounding areas, buffer zones can protect landscape patterns, ecological environments, and land-use order through the establishment of relevant restrictions. At the same time, buffer zone management should actively promote the development of communities surrounding heritage properties, facilitate the sustainable use of resources around the heritage sites, and safeguard the fundamental interests of local residents [12]. One of the major challenges in buffer zone management lies in balancing conservation and development and in seeking the optimal integration of World Heritage conservation with the construction of surrounding areas, so as to achieve the goals of ecological connectivity, visual integrity, and cultural continuity, while also taking into account the maintenance of public interests and the sustainable use of resources [13]. Therefore, the fundamental purpose of establishing buffer zones is to safeguard the integrity and authenticity of heritage properties and to prevent adverse impacts from external development activities.

Global warming, invasive alien species, and unreasonable land-use practices all pose major threats to the integrity conservation of World Natural Heritage properties. Therefore, strengthening the construction and management of buffer zones and incorporating them into the heritage conservation and management system are crucial to the sustainable development of heritage properties[4]. As a nature-based solution, agroforestry not only helps buffer zones maintain the Outstanding Universal

Value of heritage properties, but also coordinates the relationship between heritage conservation and economic development in buffer zones, thereby enhancing the capacity of buffer zones to respond to multiple threats [14]. The development of agroforestry not only contributes to maintaining the integrity of natural World Heritage properties, but also promotes the sustainable ecological and economic development of buffer zones [15]. For World Heritage properties where land-use development is subject to strict restrictions, agroforestry, as a sustainable agricultural model capable of both improving land productivity and enhancing ecological environmental functions, has demonstrated considerable application potential [16]. In recent years, positive agricultural practices represented by agroforestry development in buffer zones have played an important role in reducing environmental risks in protected areas and improving economic benefits, while also generating positive effects on regional socioeconomic development, biodiversity conservation, and the improvement of the natural ecological environment. This is particularly significant for karst World Heritage regions characterized by ecologically fragile environments and relatively underdeveloped regional economies, where such practices are important for reducing human disturbance and promoting coordination between conservation and development [17][18]. In terms of biodiversity conservation, carbon storage, sustainable agroforestry management, and the stability of production returns, agroforestry is regarded as a relatively ideal land management model [19]. In some communities in the Brazilian Amazon, appropriate agroforestry practices have not only promoted local economic development, but have also effectively reduced pressure on natural forests [20].

This paper systematically analyzes studies related to protected area integrity conservation and agroforestry development in buffer zones up to 2025, and classifies them on the basis of annual literature distribution, research themes, and document types. On this basis, the key issues, research hotspots, and methodological advances in protected area integrity conservation and agroforestry development in buffer zones are reviewed, with the aim of clarifying the research trajectory and practical significance of their synergistic relationship and providing a scientific reference for the conservation and development of karst World Heritage properties.

2. Standards for Literature Retrieval, Acquisition and Screening

To identify relevant studies, a literature search was conducted based on the China National Knowledge Infrastructure (CNKI) database and the Web of Science (WOS) Core Collection. The search covered the maximum time span available in the databases, with the search deadline set at December 31, 2025. Using “Topic” as the search field, the following terms were employed: World Natural Heritage / National Park / Protected Land / Protected Area / Reserve / Biosphere / Nature Reserve + Integrity + Agroforestry / Agriculture / Forestry / Animal Husbandry. A total of 402 publications were initially retrieved, including 359 English-language publications and 43 Chinese-language publications. Subsequently, titles and abstracts were screened and duplicate records were removed, resulting in 329 publications after the second round of selection, including 290 English-language publications and 39

Chinese-language publications. Finally, according to the research objective of "protected area integrity conservation and agroforestry development in buffer zones," manual screening and identification were carried out, yielding 288 valid publications, including 37 Chinese-language publications and 251 English-language publications.

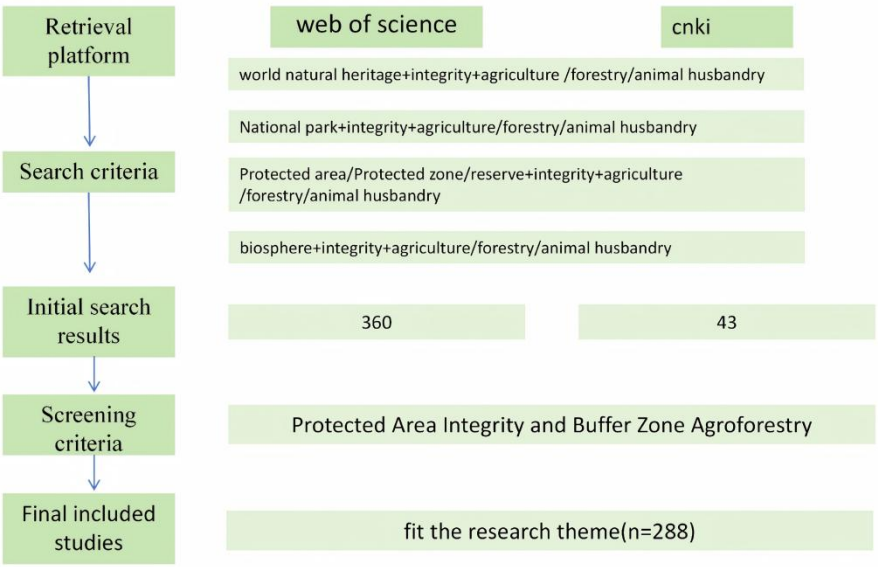

Figure 1. Process of Literature Search and Screening

3. Analysis and Results

3.1 Distribution by Country and Region

A total of 81 countries have conducted research on protected area integrity and agroforestry development in buffer zones. Based on the retrieved English-language literature, only countries and regions with no fewer than 30 publications were included in the analysis. At the national level, the United States published 65 articles on protected areas, with research primarily focusing on ecological connectivity, habitat quality assessment, monitoring of human activity impacts, and climate change adaptation. China published 60 articles, with research mainly addressing ecological value assessment in protected areas, ecological restoration, the ecological benefits of agroforestry, and regional sustainable development. The United Kingdom published 30 articles, with major research themes including ecosystem services and valuation, the ecological benefits of agroforestry, and the sustainable management of agroforestry. In terms of the national distribution of research on protected area integrity, developed countries tend to place greater emphasis on theoretical frameworks and monitoring technologies, whereas developing countries emphasize practical applications and pathways toward sustainable development.

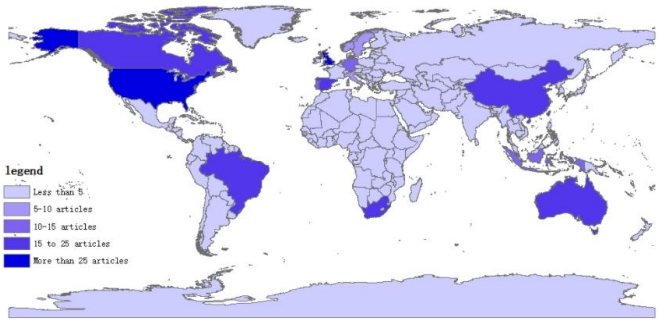

Figure 2. Distribution of Literature in Countries and Regions

3.2 Distribution of Hotspots and Trends

Research hotspots concerning integrity conservation of Protected Area and agroforestry development in buffer zones can be summarized as follows. In terms of protected area integrity conservation, the main research focuses include ecosystem service value assessment, which provides a basis for management decision-making by quantifying services such as water conservation and soil retention; biodiversity conservation strategies, including the formulation of species protection plans and the establishment of ecological corridors to maintain ecosystem integrity; and the assessment and management of human activity impacts, with measures designed to reduce the negative effects of tourism development and other disturbances on protected areas. Regarding agroforestry development in buffer zones, research hotspots include the optimization of agroforestry models, in which suitable combinations of tree species and crops are selected according to natural conditions and socioeconomic circumstances; the assessment of ecological and economic benefits, with attention to its advantages in both ecological conservation and income generation; and policy support and community participation, which aim to stimulate farmers' enthusiasm and achieve win-win outcomes for ecology and economy. In terms of research trends, greater emphasis will be placed on interdisciplinary studies, including the use of technologies such as GIS for precise assessment and monitoring; the establishment of long-term monitoring networks for the dynamic evaluation of protected area integrity; and responses to climate change through the formulation of adaptive management strategies. Agroforestry development in buffer zones will also increasingly rely on technological innovation and intelligent management, using modern agricultural technologies to improve production efficiency; on the expansion and enhancement of ecosystem service functions, such as developing ecotourism to increase income sources; and on promoting coordinated regional development of agroforestry in protected area buffer zones through strengthened experience sharing and technical cooperation among different regions. Representative agroforestry development models should be selected for demonstration and promotion, so as to provide replicable approaches for ecological conservation in protected areas and economic development in buffer zones.

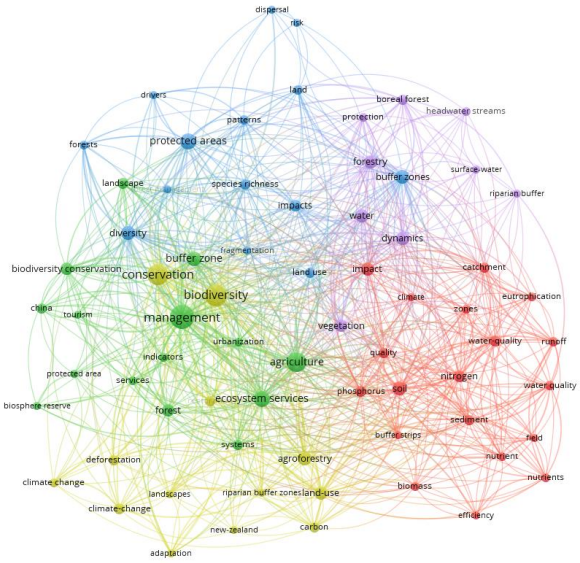

Figure 3. Analysis of Literature Keywords

3.3 Annual Distribution of Literature

Through a statistical analysis of the annual distribution of the literature, it can be observed that research on protected area integrity conservation and the development of agroforestry in buffer zones has shown an overall upward trend. The ecological and economic benefits of buffer-zone agroforestry have received widespread attention from countries around the world. Research on the development of agroforestry in buffer zones first began in the 1990s. After a long period of development, studies on buffer-zone agroforestry have gone through a process of evolution from simple to complex, from qualitative to quantitative, and from a single-discipline approach to multidisciplinary integration.Early studies on agroforestry mainly focused on basic research, such as the classification of different agroforestry types in buffer zones [21], the characteristics of vegetation canopies [22], and the composition of agroforestry tree species [23], which provided a theoretical foundation for the development of buffer-zone agroforestry. Research on agroforestry has mainly concentrated on its economic and ecological benefits [24], its impacts on biodiversity, and the management of buffer-zone agroforestry [27][28]. Overall, the research content has gradually become more in-depth.

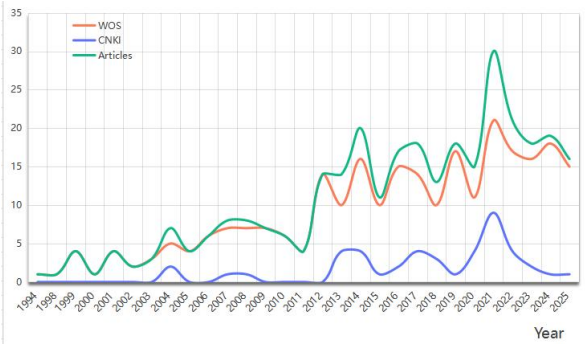

Figure 4. Annual Distribution of the Literature

3.4 Research Stage Classification

According to the annual distribution of the literature and changes in keywords shown in the document, research on protected area integrity conservation and agroforestry development in buffer zones can be broadly divided into the following three stages. In the embryonic stage (before 2000), research mainly focused on the establishment and management of protected areas. Although agroforestry emerged in some regions during this period, it had not yet been incorporated into protected area systems. In the initial development stage (2001-2010), increasing attention was paid to the ecological integrity of protected areas and their relationships with surrounding landscapes, as well as to the application of agroforestry in buffer zones. In the rapid development stage (2011 to the present), research became more comprehensive and in-depth, involving the assessment of ecosystem integrity in protected areas, the coordinated management of protected areas and buffer zones, and the optimized design and management of agroforestry systems. A study published in 1998 focused on wildlife management issues within protected areas, reflecting an early awareness of protected area integrity conservation, while a study published in 1999 explored the role of biodiversity in agroecosystems, thereby laying the foundation for subsequent research on agroforestry.

4. Key Findings and Future Research Directions

4.1 Protected Area Integrity Conservation

(1) Research on protected area integrity conservation and land-use change in buffer zones has revealed the mechanisms by which land-use change in buffer zones affects the structure and function of protected area ecosystems, and has proposed a theoretical framework for achieving integrity conservation through the optimization of land-use structure in buffer zones.

Protected areas are designated regions established to maintain the stability of natural ecosystems, species diversity, and ecosystem services. Their integrity is reflected not only in spatial stability, but also in the health and functional completeness of internal ecosystems [29]. With the expansion of human activities, many protected areas are facing the risk of isolation, as their boundaries are increasingly disturbed by agricultural expansion, infrastructure construction, and resource exploitation [30]. This outside-in transmission of pressure means that protected area integrity depends greatly on the land-use pattern and management level of buffer zones. Existing studies have shown that land-use change in buffer zones significantly affects protected area integrity [31]. At the spatial-structural level, such change causes habitat fragmentation and landscape restructuring [32], reduces landscape connectivity, and hinders species migration and gene flow, thereby weakening ecosystem stability [33]. At the level of ecological processes, it alters pathways of material cycling and energy flow, affecting the normal functioning of ecosystems within protected areas [34]. At the functional level, it may weaken ecosystem services such as water conservation, soil retention, and carbon sequestration capacity [35]. Land-use change in buffer zones is driven by both natural and socioeconomic factors.

Therefore, the management and optimization of land-use practices in buffer zones are regarded as important approaches to mitigating negative impacts on protected area integrity[36].

(2) Research on protected area ecological integrity and the impacts of human activities has revealed the relationship between the intensity of human activities and ecosystem degradation, and has proposed a management model for achieving protected area integrity conservation through the monitoring and regulation of human activities.

Protected areas, as core spaces for biodiversity conservation, provide refuges for threatened species and are regarded as one of the most important means of biodiversity protection. However, they are not completely isolated from external human activities. As surrounding populations expand and agricultural land extends toward protected area boundaries, the ecological integrity of protected areas is increasingly threatened [37]. The intensification of human activities poses serious threats to ecosystem structure and processes, causing habitat fragmentation and biodiversity loss, and ultimately leading to habitat degradation [38], while regional ecological security faces severe challenges. Human activities such as intensive agriculture, overgrazing, and urban construction intensify ecological disturbance, causing changes in community structure and ecological functions, reducing ecological quality and quantity, and ultimately leading to biodiversity decline [39][40]. Research in the Wolong Nature Reserve has shown that hydropower station construction, activities around settlements, and agricultural reclamation have affected landscape structure. The increase in landscape heterogeneity within the range of these activities has in turn affected the ecological integrity of the reserve [41]. Human development activities affect the ecological integrity of protected areas through multiple pathways, including direct habitat destruction, land cover change, and impacts on species distribution and migration routes. Therefore, protected area integrity conservation should focus not only on whether development occurs in buffer zones, but also on the intensity, frequency, and spatial distribution of human activities and their impacts, so as to ensure that protected areas can effectively perform their ecological functions.

4.2 Agroforestry Development in Buffer Zones

(1) Research on agroforestry development in protected area buffer zones has found that agroforestry plays important roles in maintaining biodiversity and providing ecosystem services, and has proposed agroforestry as an important land-use model for buffer zones.

Within the global protected area governance framework, protected areas aim primarily to maintain ecosystem stability, biodiversity, and ecosystem service functions. Accordingly, core zones are usually placed under strict protection, while development and utilization activities are mainly shifted to buffer zones. As transitional areas linking protected areas with external human activity spaces, buffer zones not only reduce external disturbances and maintain ecological process continuity, but also support surrounding community livelihoods and alleviate conflicts between conservation and development [42]. In this context, agroforestry is considered an important pathway for promoting both conservation and development. By integrating crops and trees on the same land, agroforestry creates a land-use model with both ecological and economic benefits [43]. This form of land use is not only productive and easy

to implement, but also sustainable, with sustainability being its most prominent advantage [44]. By increasing vegetation cover, improving landscape heterogeneity, and enhancing habitat connectivity, agroforestry reduces disturbance along protected area edges and mitigates surrounding habitat degradation, while enhancing ecosystem services such as soil retention and water conservation. Agroforestry management practices also help strengthen community livelihood resilience, reduce dependence on protected area resources, and alleviate development pressure [45]. Thus, agroforestry in buffer zones is important not only for optimizing land-use structure, but also for transforming buffer zones into governance spaces that serve as ecological barriers and livelihood support systems.

(2) Through a comprehensive analysis of the ecological, social, and economic benefits of agroforestry, studies have revealed that agroforestry can simultaneously improve ecological environmental quality and residents' livelihoods in buffer zones, and have proposed agroforestry as an important pathway for achieving both protected area conservation and coordinated regional development.

In buffer zone governance for protected areas, comprehensive analyses of the ecological, social, and economic benefits of agroforestry have shown that agroforestry is not merely a single agricultural production method, but rather a complex land-use system that integrates ecological restoration, resource regulation, and livelihood support. In terms of ecological benefits, by increasing woody vegetation cover, optimizing landscape structure, and enhancing habitat connectivity, agroforestry can effectively alleviate edge effects in protected areas, reduce disturbances to surrounding natural habitats caused by agricultural expansion and extensive land use, and at the same time enhance ecosystem services such as soil retention, water conservation, carbon storage, and biodiversity maintenance. In terms of economic benefits, by organically combining trees, crops, and livestock activities, agroforestry improves comprehensive land-use efficiency and production stability, reduces the market and environmental risks associated with single-crop farming, and helps create more diversified, stable, and resilient livelihood systems [44][45]. By introducing diversified planting patterns and management techniques, agroforestry can increase farmers' income sources and improve their living standards[46]. In terms of social benefits, agroforestry can improve community production conditions, expand green livelihood opportunities, and enhance the tangible returns of local residents' participation in ecological conservation. In this way, it can, to some extent, alleviate the contradiction between conservation objectives and local development needs, reduce communities' direct dependence on protected area resources, and lessen the pressure exerted by activities such as land reclamation, grazing, and resource extraction on the ecological integrity of protected areas [47][15].

4.3 Coordinated Development

(1) Through studies employing remote sensing, GIS, ecological models, and comprehensive indicator evaluation, researchers have revealed the interaction mechanisms between protected area integrity conservation and buffer zone development, and have used integrated multi-model assessment frameworks to identify key factors affecting ecological security and regional development in protected

areas, thereby providing a theoretical basis for protected area integrity conservation and buffer zone development.

Protected area integrity conservation and buffer zone development are not simply oppositional; rather, they involve complex interactions among ecological protection, resource use, and community development. Protected areas are primarily intended to conserve wildlife and habitats, thereby ensuring species diversity and ecosystem integrity. In buffer zone development, it is necessary to consider potential impacts on the protected area core. Studies have identified tensions between conservation and development and sought paths to reconcile them. Remote sensing and GIS have been used to monitor land-use/land-cover change, vegetation productivity, and landscape fragmentation, thereby revealing the spatiotemporal dynamics of protected areas and buffer zones. Integrated frameworks such as PLUS-ESI-circuit theory, MaxEnt-InVEST-Zonation, MSPA plus graph-theoretic indices, MCR, and coupling coordination models have been applied to simulate ecological security patterns and functional zone responses under different development scenarios. Based on field investigations, an indicator evaluation model of ecological disaster protection measures and their impacts on nature reserves was established to assess ecotourism impacts. Applied in China, the results suggested that ecological protection measures should be further improved and strengthenedidentify priority ecological conservation areas in the karst regions of Southwest [49]. Ecological integrity indices based on biodiversity variables have also been constructed to assess global forest ecosystem integrity, with the Amazon region showing relatively high integrity [50]. In addition, soil erosion equation models have been used to quantify the spatial distribution of biodiversity and ecosystem services, while biodiversity indices, ordered weighted averaging, and overlay analysis have been applied in China under dual objectives [51].

(2) Studies on the relationship between protected area conservation and buffer zone development using the coupling coordination degree model have revealed the dynamic coordinated relationship between ecological conservation and socioeconomic development. Based on coupling coordination analyses, optimization strategies have been proposed to promote protected area integrity conservation.

Coupling coordination refers to the coordinated development state manifested by two or more systems or subsystems during interconnection and interaction. Coupling reflects the closeness of mutual influence among systems or elements, whereas coordination emphasizes the orderly and balanced relationship formed through interaction. In research on sustainable tourism in protected areas, the coupling coordination degree model and obstacle degree model have been used to evaluate tourism sustainability in Qinghai Lake Nature Reserve, China. These analyses effectively reflected temporal changes in tourism system sustainability, while the identification of obstacle factors provided insights for ecological-economic-social coordinated management [52]. To address sustainable development at the Jiuzhaigou World Heritage Site, an evaluation index system was constructed for sustainable development and economic development [54]. In the Bogda Mountain Protected Area of Xinjiang, a tourism-environment coupling coordination model was established to analyze dynamic changes and

propose planning strategies for sustainable use [54]. To promote sustainable geopark development, and based on human-land coupling coordination theory, an indicator system for evaluating comprehensive benefit coordination in the Koktokay Global Geopark, China, was established using multi-year statistical data, with the aim of balancing geotourism development and ecological protection. For Nanshan National Park in Hunan Province, a coupling coordination model was constructed to analyze the relationship between settlement patterns and landscape fragmentation in forest land and biodiversity conservation areas.

4.4 Optimization Measures

(1) Through research on the synergistic relationship between protected area integrity conservation and regional sustainable development, scholars have revealed the mechanisms and main influencing factors of coordinated human-nature development, and have proposed optimization measures for protected area integrity conservation through the optimization of land-use structure in buffer zones and the strengthening of community participation.

By analyzing the main contradictions and practical problems existing between protected area conservation and regional development, studies have proposed optimization approaches that fully utilize the functional advantages of buffer zones and coordinate the relationship between conservation and development. Ecosystems within protected areas require strict protection in order to maintain their integrity and prevent external disturbances from disrupting ecological balance. However, the strict conservation measures applied in protected areas may also restrict the economic development space of buffer zones. As transitional areas between protected areas and the outside world, buffer zones often face dual pressures from economic development and ecological conservation. In pursuit of better living conditions, local residents may overexploit buffer zone resources, such as through excessive logging or overharvesting of aquatic organisms, which not only damages the ecological functions of the buffer zone, but also poses potential threats to the integrity of the protected area. Taking villages within Wuyishan National Park as the research object, one study comprehensively measured the levels of social well-being and ecological well-being in 12 villager groups. On this basis, it constructed a community well-being assessment framework for national parks in China, explored the coupling coordination characteristics and influencing factors between social well-being and ecological well-being, and proposed classified regulation and optimization pathways for different community types (chen et al., 2024). Understanding the needs of local communities and how they interact with the natural environment can help identify ways to meet human needs while protecting nature [57][58]). proposed a combined method for optimizing functional zoning within national parks so as to eliminate conflict areas between ecological conservation zones and community development. By comprehensively considering ecological, social, and economic factors, this method enables a more scientific and rational spatial layout.

(2) Studies on protected area conservation and development have found that land-use practices surrounding protected areas can affect the protected areas themselves, and have proposed the use of agroforestry to promote biodiversity conservation in protected areas.

Land-use practices surrounding protected areas can have significant impacts on ecosystems and biodiversity within protected areas. Agricultural activities, especially traditional monoculture systems, may negatively affect ecological functions within protected areas, resulting in such problems as natural habitat loss and the decline of ecosystem service functions [51]. To mitigate this conflict and promote biodiversity conservation in protected areas, some studies have proposed agroforestry as a land-use model for protected area buffer zones. Agroforestry is an agricultural system that combines trees with other crops and/or livestock, and it can provide multiple ecological benefits without sacrificing farmers' livelihoods, such as increasing habitat complexity, improving soil fertility, and reducing erosion, thereby contributing to the maintenance and restoration of biodiversity within protected areas. By introducing agroforestry and other sustainable agricultural measures, it is possible to effectively enhance biodiversity both inside and outside protected areas while ensuring food security.

5. Future Research Directions

5.1 Research on the Coupling Mechanism Between Integrity Conservation of Karst World Heritage Sites and Land Use in Buffer Zones

Compared with general protected areas, karst regions are characterized by fragmented surfaces, shallow soil layers, weak soil and water conservation capacity, and slow ecological recovery[59]. Activities in buffer zones, such as agricultural expansion, settlement construction, and road development, are therefore more likely to affect the integrity of heritage sites through pathways including landscape fragmentation, reduced ecological connectivity, and disturbance of hydrological processes . Further research should deepen understanding of the relationship between integrity conservation of karst World Heritage sites and land-use change in buffer zones, and reveal the transmission mechanisms through which buffer-zone land-use patterns influence the ecological structure, processes, and functions of heritage sites under the fragile ecological background of karst regions. Building on existing studies of land-use change and ecological integrity, future research should further strengthen the systematic analysis of the chain linking development intensity in World Heritage buffer zones, ecological risk accumulation, and integrity responses of heritage sites. It should also develop a multiscale coupling analytical framework applicable to karst World Heritage sites [60], identify the key driving factors, action pathways, and threshold characteristics affecting integrity conservation, and thereby provide a stronger theoretical basis for optimizing spatial zoning in buffer zones, controlling development boundaries, and constructing ecological security patterns.

5.2 Quantitative Assessment of the Ecological Functions of Agroforestry in Karst Buffer Zones and Its Effects on Heritage Conservation

Existing studies have shown that agroforestry has significant advantages in maintaining biodiversity, conserving soil and water, enhancing carbon sequestration, and improving community livelihoods. However, there is still a lack of a unified, systematic, and comparable evaluation framework to determine whether, and to what extent, it promotes the conservation of World Heritage integrity. Particularly in karst regions, agroforestry is not only a mode of industrial development in buffer zones, but also a potentially important ecological regulatory approach for mitigating rocky desertification, soil erosion, and anthropogenic disturbance. Future research should focus on the Outstanding Universal Value and integrity conservation requirements of karst World Heritage sites, and integrate indicators such as ecosystem services, landscape patterns, biodiversity, soil erosion control, water quality maintenance, and visual landscape to construct a comprehensive assessment system for "agroforestry development-buffer-zone ecological improvement-heritage-site integrity enhancement." This would help shift related research from experience-based judgment and qualitative description toward measurable, comparable, and simulation-based quantitative studies, thereby providing a scientific basis for optimizing industrial structures in buffer zones and promoting the transformation toward ecological land use.

5.3 Research on Synergistic Pathways for Karst World Heritage Conservation and Community Development

Research should address the synergetic relationship between the conservation objectives of karst World Heritage sites and the livelihood needs of buffer-zone communities, and promote a shift from "development restriction" to "conservation-development symbiosis." Karst World Heritage sites often face the dual pressures of ecological fragility and relatively lagging regional development, while residents in buffer zones are highly dependent on land, forestland, and other natural resources[62]. In the absence of appropriate alternative industries and benefit-linkage mechanisms, such dependence can easily generate persistent pressure on the integrity of heritage sites. Therefore, future research should not remain limited to conservation constraints or industrial guidance alone, but should further analyze systematically, from the perspectives of community participation, benefit distribution, ecological compensation, and green livelihood transformation, the mechanisms through which agroforestry alleviates human-land conflicts, reduces resource dependence, and strengthens local conservation incentives [63]. In particular, it is necessary to ground research in the realities of karst World Heritage sites, explore agroforestry development models that balance ecological security, farmers' income growth, and heritage conservation requirements, and build a synergistic development pathway linking heritage conservation, buffer-zone industries, and community well-being, so that buffer zones can truly become a critical bridge between strict conservation and regional sustainable development.

5.4 Research on Dynamic Monitoring and Adaptive Governance of Karst World Heritage Sites Driven by Multi-Technology Integration

Although current studies have widely adopted methods such as remote sensing, GIS, ecological modeling, and coupling coordination analysis, they remain insufficient in the continuous identification of ecological risk evolution, the effects of industrial expansion in buffer zones, and dynamic changes in heritage-site integrity under the complex geomorphological conditions of karst regions. Future research should further integrate technical approaches such as remote sensing monitoring, UAV surveys, ecological modeling, machine learning, and multi-scenario simulation to establish a dynamic monitoring and early warning system supported by multisource data, thereby improving the capacity to identify changes in land use, fluctuations in habitat quality, risks of soil erosion, and shifts in landscape integrity at karst World Heritage sites. At the same time, the translation of research findings into governance practice should be strengthened. Efforts should focus on functional zoning optimization, ecological corridor construction, regulation of agroforestry layout, and differentiated policy design so as to form management models adapted to the characteristics of karst World Heritage sites, and to promote a transition in conservation strategies from passive response to proactive regulation and from phased protection to long-term adaptive governance.

6. Conclusion

This study systematically reviewed and conducted a bibliometric analysis of the literature related to protected area integrity conservation and agroforestry development in buffer zones based on the core databases of CNKI and Web of Science, covering the period from 1994-2025. From the perspectives of annual literature distribution, distribution by countries and regions, institutional and author collaboration, research hotspots, the evolution of research stages, and key issues, this study comprehensively summarizes the knowledge structure and developmental trajectory of this field. The results show that research on protected area integrity conservation and agroforestry development in buffer zones has generally demonstrated a continuous growth trend, and has gradually shifted from the early stage of concept introduction, case description, and single-issue research to a comprehensive research stage characterized by multidisciplinary integration, multi-technology application, and a coordinated orientation toward both conservation and development.

The buffer zone is not merely a passive transitional space surrounding protected areas, but rather a key governance unit linking strict conservation with regional development. Likewise, agroforestry is not simply a single agricultural production mode, but an important land-use pattern that integrates ecological buffering, livelihood support, and spatial regulation functions. For World Natural Heritage sites, especially karst World Heritage sites that are ecologically fragile and subject to strong development constraints, agroforestry can, to a certain extent, alleviate development pressure in buffer zones, reduce the direct disturbance of human activities on core heritage areas, and support the integrity conservation of heritage sites by improving landscape patterns, enhancing ecological connectivity,

strengthening ecosystem services, and optimizing community livelihood structures. Future research should pay greater attention to the impacts of buffer-zone agroforestry development on heritage site conservation, so as to promote the sustainable development of heritage sites.

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