

Review

Progress and Prospects of Ecosystem Disservices: An Updated Literature Review

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Abstract: Natural ecosystems may influence human well-being not only positively (i.e., ecosystem services), but also negatively (i.e., ecosystem disservices). As ecosystem services have become among the most important and active research domains of ecology, ecosystem disservices have been receiving more and more attention from ecologists. In this paper, the progress of ecosystem disservices research was reviewed based on the peer-reviewed literatures using the bibliometric method and knowledge graph visualization technology. Particularly, we focused on topic distribution and ecosystem types of ecosystem disservices, the balance and synergy between ecosystem services and disservices, the management and application of ecosystem disservices, and the indicator system in ecosystem disservices research. Furthermore, we discussed the limitations and shortcomings of the current ecosystem disservice research. We recommend that future research needs to be further deepened in establishing a comprehensive assessment of ecosystem services and disservices, promoting interdisciplinary participatory socio-ecological methods, and transforming research methods from static to dynamic.

Keywords: ecosystem disservices; ecosystem management; ecosystem services; research hotspots



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1. Introduction

In the late 1960s, the concept of ecosystem services was first proposed [1]. Subsequently, Holdren and Ehrlich [2] first proposed the concept of ecosystem services as an ecosystem function and environmental service. Since then, research on ecosystem services has gradually emerged. In “Nature’s Service: Societal Dependence on Nature Ecosystem”, Daily et al. [3] systematically explained the related concepts and assessment methods of ecosystem services, and defined ecosystem services as the results of ecological interactions and processes in which ecosystems maintained and met human well-being. The Millennium Ecosystem Assessment [4] defined ecosystem services as the benefits which were derived from ecosystems and divided them into four categories: support, regulation, supply, and culture. In the past decade, many scholars believed that the research on ecosystem services provided the basis for decision making in policy formulation and contributed to the sustainable development of ecosystems [5–7]. However, ecosystems provide human beings with a range of plenty of natural resources (e.g., clean air, water resources, forest resources, etc.), while also causing some damage to human well-being (e.g., pests and diseases, allergens, natural disasters, etc.). Most previous assessments of ecosystem services did not consider the impact of these adverse effects (disservices) on human welfare. Along with the deepening of ecosystem services research, the importance of ecosystem disservices for the ecosystem services research, ecosystem management, and decision-making is gradually recognized.

The concept of ecosystem disservices was explained by Lyytimäki and Sipilä [8] in detail for the first time, and they defined it as ecosystem functions adverse to human well-being. So far, however, the definition of ecosystem disservices has not been unified. We listed different definitions on ecosystem disservices (Table 1) abstracted from the literature.

Most of the definitions explained the core connotation of ecosystem disservices, but failed to improve its sources and application conditions. Chapin et al. [9] claimed that ecosystem disservices was due to the loss of biodiversity caused by the lack of ecosystem service value. Lyytimäki [10] further improved this concept, emphasizing the human perception of ecosystem disservices. Shackleton et al. [11] made the concept of ecosystem disservices more specific, noting that the definition of ecosystem disservices must have the following two points. First, the cause of the ecosystem disservices of an ecosystem is from features or processes of the ecosystem, rather than from human activities which has adversely affected the ecosystem. Secondly, it exerts detrimental impacts on one or more dimensions of human well-being, rather than on the ecosystem services. With the continuous improvement and development of the concept of ecosystem disservices, various intergovernmental or non-governmental policy platforms on ecosystem services have incorporated the concept of ecosystem disservices into their evaluation system or conceptual framework in a direct or indirect manner. For example, Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has transformed the concept of “ecosystem services” in the Millennium Ecosystem Assessment into “nature’s benefits or contributions to people” [12]. It indirectly expresses the possible adverse impacts of ecosystems on human welfare. In addition, the latest version of the Common International Classification of Ecosystem Services (CICES) V5.1 clearly lists eight types of ecosystem disservices, which were directly included in the conceptual framework of ecosystem services [4,12,13].

Some scholars thought that it is undesirable to separate ecosystem disservices from the concept of ecosystem services and nor to conduct research in isolation [14–18]. Although this approach may be easier to quantify ecosystem disservices, it may lead to misunderstanding in the actual service delivery and delivery process. Saunders [14] used the following two points as criteria in the study of ecosystem disservices: first, identified ecological processes and interactions that generate ecosystem disservices; secondly, determined the correlation between ecosystem services and disservices on cross-scale and cross-value systems. It emphasizes that ecosystem disservices are the result of ecosystem processes and interactions involving service-providing units, and focus on the interactions and trade-offs between ecosystem services and disservices. Furthermore, Milanović et al. [15] extended the concept of ecosystem disservices to biodiversity. By establishing the framework of ecosystem services and ecosystem disservices, they linked the functional traits of invasive plants with the socio-economic sectors affected by them, and clarified the trends of ecosystem services and disservices under the background of invasive biology. We hold the opinion that it is biased to regard ecosystem disservices as an addition or by-product of biodiversity and ecosystem services. First, ecosystem disservices are not only caused by the loss of biodiversity, but they may also be the result or product of ecosystem functions, processes, or attributes. Secondly, ecosystem disservices and service are two relatively independent concepts, and they are two different results of ecosystem processes and functions.

Table 1. Illustrative descriptions on definition of ecosystem disservices (EDS).

Order	Definition	Reference
1	Disturbed or missing services as consequences of loss of biodiversity.	[9]
2	Negative effects of ecosystem changes.	[19]
3	Agriculture also receives an array of reduced productivity or increased production costs.	[20]
4	Functions of ecosystems that are perceived as negative for human well-being.	[8]
5	Functions and structures of an ecosystem that have negative consequences on human life are referred to as ecosystem disservices.	[21]
6	Functions or properties of ecosystems that cause effects that are perceived as harmful, unpleasant, or unwanted.	[10]

Table 1. *Cont.*

Order	Definition	Reference
7	EDS often associate with decreased aesthetic, economic, and health-related human well-being, and involved in driving the perceived harms and nuisances of nature.	[22]
8	Functions or end products of ecosystems that are perceived as negative for human well-being.	[23]
9	The ecosystem-generated functions, processes, and attributes that result in perceived or actual negative impacts on human wellbeing.	[11]
10	Expand definition of EDS that consider the direct “perceived or actual negative impacts on human wellbeing” (after Shackleton et al. 2016 [11]).	[24]
11	EDS generate functions, processes, and attributes in ecosystems that result in perceived or actual negative impacts on human well-being, besides, we extend this notion to encompass biodiversity, as well.	[15]
12	Outcomes of ecological processes and interactions that are shown to impact human well-being and are assessed as damaging under a relevant value system.	[14]

However, there is still a lack of systematic and comprehensive frameworks and methods on ecosystem disservices. Nonetheless, we listed some research cases to provide some reference. Herd-Hoare and Shackleton [25] adopted a mixed framework method combining focus group discussions, field investigation, structured household surveys, and key informant interviews to qualify the economic contribution and loss of ecosystem services and disservices provided by arable agricultural systems in southeastern South Africa. In agricultural systems, especially small-scale arable agricultural systems, the impact of disservices could not be ignored. In addition, a wide range of methods have been used to assess ecosystem services and disservices provided by urban trees. Roy et al. [26] reviewed 115 original urban tree studies and found that almost all studies (91.3%) adopted quantitative research, and that most studies (60%) used natural science methods to demonstrate its disservices including infrastructure damage, light attenuation, and health problems.

It is believed that the lack of awareness of ecosystem disservices may have a serious adverse impact on the overall management of the ecosystem. Research on ecosystem disservices can improve the existing framework of ecosystem services and reduce the cost to human well-being [14]. Therefore, deepening the understanding of ecosystem disservices and exploring their antagonistic effects on ecosystem services and the ecological significance behind them are important in maintaining biodiversity and improving human welfare. However, most of the current review articles on ecosystem disservices use the method of document sorting [12,22,27], which makes it difficult to comprehensively sort out the knowledge network. In this paper, CiteSpace software is used to objectively present the hotspots and development trends of ecosystem disservices research through visual means, in order to provide a theoretical basis for relevant researchers and support the excavation of new research directions.

2. Progress of Ecosystem Disservices Research

In recent years, the research on ecosystem disservices has attracted more and more attention, and scholars around the world have continuously selected different entry points for research and exploration. Here, we have summarized from the perspectives of hotspot distribution, ecosystem types, and research methods.

2.1. Topics in Ecosystem Disservices Research

2.1.1. Research Hotspots Distribution Based on Bibliometrics

Based on searches on the Web of Science Core Collection database on 7 June 2022 using the keyword “ecosystem disservices”, a total of 524 related studies published in 218 journals were retrieved. Since 2009, Lyytimäki and Sipilä [8] first explained the concept of ecosystem disservices in detail, and then the number of publications increased yearly (Figure 1). The top 10 countries were from Europe, North America, East Asia, and Africa

(Table 2). The United States published 146 articles, ranking first. Only 75 papers were published by developing countries, including South Africa and China, indicating that there was still a certain gap between developing and developed countries in this field. The authors, topics, abstracts, keywords, and other information in the sample were analyzed by CiteSpace software, and the hot keywords in the ecosystem disservices literatures were obtained (Figure 2). The relatively high frequency keywords were “ecosystem service”, “biodiversity”, “management”, “ecosystem disservice”, “conservation” and so on. The hot keywords were closely related, and the number of connection lines directly reflected the degree of correlation between hot topics.

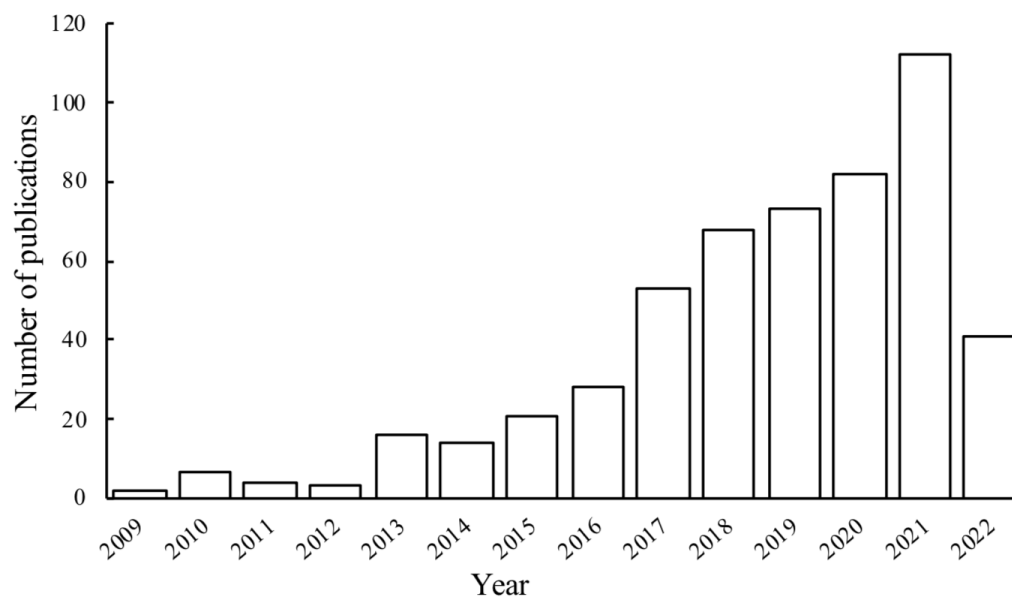


Figure 1. Number of publications on ecosystem disservices (searching with the keyword of ‘ecosystem disservices’ based on Web of Science at 7 June 2022).

Table 2. Top 10 countries in field of ecosystem disservices research in terms of number of papers published and their total citations.

Order	Country	No. of Publications	Total Citations
1	United States	146	2536
2	Germany	68	1208
3	United Kingdom	60	1068
4	France	55	725
5	Australia	46	840
6	South Africa	42	378
7	Spain	42	718
8	Sweden	40	497
9	Italy	38	822
10	China	33	1436



Figure 2. Cloud of keywords in the research of ecosystem disservices. The size of the green dot in the figure indicates the frequency of the keyword, and the size of the text represents the centrality of the keyword. The stronger the centrality, the greater the impact of the keyword in the co-occurrence network. In general, the frequency of keywords and centrality are positively correlated to each other.

2.1.2. Ecosystem Types in Studies of Ecosystem Disservices

Currently, relevant searches on ecosystem disservices can be found on various ecosystem types (Table 3). Among them, there are abundant research cases on ecosystem disservices in urban and agricultural ecosystems. In agricultural ecosystems, the impact of disservices on agricultural productivity, wildlife habitats, excessive fertilization, and run-off pollution caused by pesticide spraying are mostly discussed [28–30]. Zhang et al. [20] explained how ecosystem disservices reduced productivity and discussed management issues related to improving ecosystem services and disservices. Swinton et al. [30] discussed the reduction in biodiversity caused by agricultural land use, and proposed the importance of understanding people’s perceptions of ecosystem services and disservices, which could be mitigated by scientific and reasonable public policies. Secondly, in the urban ecosystem, the research on ecosystem disservices is also relatively concentrated. Lyytimäki and Sipilä [8] proposed and clarified the concept of ecosystem disservices for the first time from the perspective of urban ecosystems, emphasizing that human values and needs were placed at the center of the framework of ecosystem services. Additionally, he noted that urban ecosystem disservices were associated with changes of biodiversity, which had a positive effect on the comprehensive evaluation of ecosystem disservices and the improvement of urban green space decision-making management. Roman et al. [17] advocated for better integrated ecosystem services and disservices into stakeholders’ urban green space decision-making by assessing trade-offs and synergies. Tian et al. [18] associated the disservices of urban ecosystems with the public awareness and demand for urban green space. Through the understanding of the causal relationship of public willingness to pay for the protection of urban green space, we can predict the impact of changes in the spatial pattern of urban green space on the public perception of ecosystem services or disservices, providing a basis for further improvement of the management of urban green space.

In the case study of forest ecosystems, the residents were aware of the relative importance of the allocation of ecosystem services and attached great importance to ecosystem-related disservices [31]. In addition, in aquatic ecosystems, the understanding of the negative consequences of ecosystems will promote the improvement of the future fishery management framework [32]. At the same time, the residents' willingness to pay for cultural services and disservices was also discussed in relation to the functional diversity of the rural landscape [33]. In desert ecosystems, studies on the relationship between the positive and negative values of ecosystem services and the invasions of local species, provided suggestions for public participation in the design of response measures for the management of biological invasion [34,35].

Table 3. Major ecosystem types of ecosystem disservices research in terms of number of papers published and their total citations.

Ecosystem Type	No. of Publications	Total Citations	References
Urban	198	6958	[8,17,18]
Forestry	154	4598	[31]
Agriculture	123	3596	[20,28–30]
Rural	38	739	[33]
Wetland	28	389	[32]
Desert	5	98	[34,35]

2.1.3. Research Methods in the Study of Ecosystem Disservices

At present, the systematic research on ecosystem disservices has still been developing, and most of the studies have focused on the concept of ecosystem disservices of specific types of environments or ecosystems and the selection of indicators. Saunders et al. [14] analyzed 301 published papers and screened out 85 empirical studies on explicitly quantifying or determining the ecosystem disservices in specific ecosystems. Most studies were based on researchers' subjective opinions or proxy data sources to quantify disservices. Only 15% of researchers collected in-situ data on disservices generated by ecological interactions. Most studies considered management costs, nuisances, or man-made aversions to ecosystem services as negative. Some studies quantified ecosystem disservices by measuring trade-offs and synergies between ecosystem services and disservices, as reflected in the correlation or relative score of services and disservices [15,36,37] and a simple calculation of 'revenue minus cost' [38,39]. In addition, studies considered the potential of ecosystem services and disservices by constructing cascade models of ecosystem services in specific habitats as a basis for assessing ecosystem services and disservices [40].

2.2. Hotspots of Research on Ecosystem Disservices

2.2.1. Balance and Synergy between Ecosystem Services and Ecosystem Disservices

The interaction and connection between ecosystem services and disservices are mainly reflected in trade-off and synergy. Ecosystem services and disservices are both the products of ecosystem attributes and processes, which have strong interdependence at different time, space, and socio-economic scales. It may not be possible to describe ecosystem services and disservices through a single or universal category [14,24]. For example, although urban trees regulate the climate through carbon sequestration in the carbon cycle, they also release volatile organic compounds (VOC) and solid particulate matter (PM), leading to air pollution and human health problems [17]. In this case, it is necessary to incorporate the related concepts of ecosystem disservices into the existing general framework of ecosystem services. Vaz et al. [24] argued that ecosystem services and disservices were essentially two coupled concepts and proposed an indicator framework that took both concepts into account, in order to find an assessment approach that could accurately balance the benefits and costs of ecosystem services and disservices. Rodríguez-Morales et al. [16] used the Public Participation Geographic Information System (PPGIS) for participatory mapping, and quantified disservices into the evaluation framework of ecosystem services. Based on

residents' attitudes and preferences towards urban trees, Roman et al. [17] assessed the synergy and trade-off between ecosystem services and disservices, and better integrated them into stakeholder decision-making. The evaluation of trade-offs and synergies between ecosystem services and disservices helps stakeholders to develop appropriate measures to address the inevitable negative results.

2.2.2. Management and Application of Ecosystem Disservices

Concepts of ecosystem disservices and the related have penetrated various fields, and become an important aspect that cannot be ignored in stakeholder decision-making and strategy selection. In agriculture, the purpose of agricultural landscape management is to obtain enough ecosystem supply services and regulation services, while reducing the negative impact of ecosystem disservices, to maximize agricultural productivity. Appropriate management can reduce the negative impact of agricultural production, and may improve the ability of agricultural ecosystems to provide extensive ecosystem services [25,41–43]. However, this is closely related to the promulgation and implementation of relevant policies and close interdisciplinary cooperation.

In terms of urban landscape, Lyytimäki et al. [44] proposed to increase public participation in urban landscape planning and management. Through the perception of the comprehensive concepts of urban ecosystem services and ecosystem disservices, urban residents' lifestyles and biodiversity were combined into urban landscape planning and management. In North America, most municipal administrations recognized the central role of residents in the management of urban forests, and the management documents issued more directly that identified strategies to address perceived ecosystem disservices [23,45]. In addition, Shackleton et al. [11] proposed several strategies to integrate ecosystem disservices into the ecosystem management framework to comprehensively understand the value of ecosystems for human well-being.

2.2.3. Indicator System in Ecosystem Disservices Research

Ecosystem disservices may differ in their specific manifestations among different research scales and/or environmental backgrounds. The index classification of ecosystem disservices begins with its concept. We listed the index classification of ecosystem disservices in different studies (Table 4). The concept of ecosystem disservices was first applied to agricultural production, which was helpful to improve agricultural productivity and optimize management decisions. Lyytimäki et al. [46] studied the interaction between ecosystem services, disservices, and urban residents' lifestyles, and divided urban ecosystem disservices into aesthetics, safety, health, economy, and transportation. While explaining the classification of indicators in detail for each, they explained the driving forces of various types of ecosystem disservices under different spatial scales and the root causes. Since then, with deepening research by scholars in different fields, the indicator framework of ecosystem disservices has also been further improved and developed.

Table 4. Index system in research of ecosystem disservices in different ecological contexts.

Ecological Context	Index System of Ecosystem Disservices	References
Agriculture	Pest damage; Habitat loss; Biodiversity loss; Nutrient runoff; Pesticide poisoning of non-target species; Competition for pollination and water from other ecosystems; Decreasing water quality and/or quantity; Odors.	[20,25,30]
Urban	Damage to physical structures; Economic losses; Aesthetic and hygiene problem; Security and health issues (allergies or poisoning); Decreasing air quality; Bringing about negative psychological effects (sounds, smells, behavior of plants/animals); Decreasing water quality and/or quantity; Introduction of invasive species; Displacement of endemic species.	[8,22,27,44,46]
Urban forest	Damage to infrastructure; Green waste; Health and safety issue; Cultural, aesthetic, and social issues; Water quantity and quality; Decreasing air quality; Increased humidity; Introduction of invasive species.	[8,17,27,46,47]

Table 4. *Cont.*

Ecological Context	Index System of Ecosystem Disservices	References
Urban birds	Noisy; Diseases; Dirty; Mess; Defecate; Aesthetic; Aggressive; Damage.	[48]
Plant invasions	Health EDS—affecting human health; Material EDS—damaging built infrastructures; Security and safety EDS—disrupting physical, personal, national, and financial stabilization; Cultural and aesthetic EDS—impacts on mental/cultural interactions with nature, bad smell; Leisure and recreation EDS—causing inhibition of physical interactions with nature.	[15,24,49,50]
Environment	Biological: Economy (e.g., invasive species, red tide), Health (e.g., allergens, human diseases from pathogens), Cultural (e.g., bird droppings) Abiotic: Economy (e.g., droughts), Health (e.g., floods, storms), Health (e.g., soil erosion).	[11,15,24,48]

3. Prospects in Research of Ecosystem Disservices

Although the research on ecosystem disservices has gradually become a hot topic in many related disciplines and has achieved some research results, there are still some problems and limitations.

3.1. Difficulties in Research of Ecosystem Disservices

So far, there has not been consensus on the concept of ecosystem disservices yet. One of the reasons may be that the concept of ecosystem disservices cannot be easily separated from the common influence of many aspects such as society, economy, culture, and human perception. There is a lack of research on the identification and quantification of the impact of ecosystem disservices. Furthermore, the source of ecosystem disservices has not been clarified in detail, and it is unclear what attributes, functions, structures, and levels of ecosystems may have adverse or even harmful impacts on human welfare. In terms of the degree of influence, it is not clear what specific types of audience are affected by ecosystem disservices [22]. Although the research on ecosystem disservices has developed rapidly, there are still ambiguities in the concepts and methods related to the supply and delivery of ecosystem disservices, especially for stakeholders. Dealing with the interaction between ecosystem services and disservices in frameworks of management and measurement will require more attention in future research. In addition, ecosystem disservices that people perceive do not always match with actual disservices. There may be some indirect loss that have been overlooked or exaggerated. Furthermore, it is important that we consider both ecosystem services and disservices in resource allocation and management decisions with appropriate integration of residents' perspectives.

3.2. Prospects in Ecosystem Disservices Research

3.2.1. Comprehensive Assessment of Ecosystem Services and Disservices

Ecosystem services and disservices can be transformed to each other in the values and perceptions of different populations since they are interdependent in space, time, and social-economy aspects. Some scholars thought that emphasizing the concept of disservices would hamper the development of a constructive dialogue on conservation [51,52]. Nonetheless, Lyytimäki [10] counter-argued that the core question of the ecosystem disservices is about putting both ecosystem services and disservices under the common framework rather than highlighting the disservices per se. Following this argument, this review would serve as a call for greater research and management attention to integrate disservices into the ecosystem service framework. It is key not only to their comprehensive assessment, but also to further understanding and clarifying how ecosystem services interact with disservices. Promoting the research on the interaction between ecosystem services and disservices helps to understand the ecological mechanism of disservices and promote the formulation of relevant management decisions. However, it is necessary to further clarify the specific categories of ecosystem functions and structures, considering that these single ecosystem functions and structures may have negative impacts while providing useful services.

3.2.2. Interdisciplinary and Participatory Socio-Ecological Methods

Identifying and measuring ecosystem disservices and adopting standardized methods to comprehensively consider the costs and benefits in the process of ecosystems are bound to involve the knowledge of ecology, social economics, management, and other disciplines. Therefore, interdisciplinary collaboration is essential, just like most research cases which consider the views, attitudes, preferences and values of stakeholders, and the public regarding ecosystem disservices simultaneously. With further research considering the interaction between ecosystem services and disservices, it is necessary to deepen the understanding of stakeholders' feedback and their values, and to explore how these values and feedback reflect the results of relevant ecosystem processes. This is conducive to maintaining the interaction between people and the natural environment and promoting their sustainable development.

3.2.3. From Static Research to Dynamic Research

At present, the studies of ecosystem disservices were mostly static research, which were generally concluded according to a survey result. However, ecosystem disservices are time, space, and social environment dependent. However, there is a lack of dynamic research on the continuity and systematicness of ecosystem disservices. In future research, we suggest adopting a more flexible ecosystem service-disservice coupling framework in a changing ecosystem, and combine corresponding management decisions to cope with many challenges at the social-ecological level.

4. Conclusions

The establishment of ecosystem service frameworks has proven to contribute to a comprehensive understanding of the beneficial outputs of ecosystems for human well-being [6,7,22], whereas ecosystem disservices provided by ecosystems have not received equal attention. In recent years, the related research on ecosystem disservices has been increasing rapidly, and some have successfully taken ecosystem disservices into consideration while assessing the benefits provided by ecosystem services [25,26]. Although the recognition of ecosystem disservices is growing, a real integration of both concepts has not yet been properly developed. In different fields, the lack of systematic and comprehensive quantitative indicators for ecosystem disservices is still the difficulty and the direction should be continuously promoted in the future. For example, in agricultural ecosystem, some research adopted informant interviews to quantify the negative impact of disservices. Although this method incorporates residents' perception into quantitative framework, it is inevitable that over-reliance on residents' perception and recalls may exaggerate the actual losses. Therefore, understanding the interaction and feedback between ecosystem services and disservices is still the premise and key to establish the quantitative indicators of ecosystem disservices. In addition, incorporating ecosystem services and disservices into a unified framework is conducive to a comprehensive understanding of how stakeholders benefit or suffer the costs from nature, and further reflect the investment allocation under trade-off considerations in relevant decision management.

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