frontiers | Frontiers in Ecology and Evolution

TYPE Review
PUBLISHED 23 March 2023
DOI 10.3389/fevo.2023.1152907

Ecosystem service assessment under ecological restoration programs: A systematic review of studies from China

Junyan Liu[1,2†], Jie Du[3†], Chenfeng Zhang[2], Jindong Zhang[2], Hongbo Yang[4], Marion L. Donald[5], Yan Wu[1]* and Tingfa Dong[2]*

[1]Chengdu Institute of Biology, Chinese Academy of Sciences, Chengdu, China, [2]Key Laboratory of Southwest China Wildlife Resources Conservation, Ministry of Education, China West Normal University, Nanchong, Sichuan, China, [3]Jiuzhaigou Nature Reserve Administrative Bureau, Jiuzhaigou, China, [4]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China, [5]Manaaki Whenua Landcare Research, Lincoln, New Zealand

OPEN ACCESS

EDITED BY
Wei Zhao,
Institute of Geographic Sciences and Natural Resources Research (CAS),
China

REVIEWED BY
Zhuo Wu,
Guangzhou University,
China
Ümüt Halik,
Xinjiang University,
China

*CORRESPONDENCE
Yan Wu
✉ wuyan@cib.ac.cn
Tingfa Dong
✉ dongfar@163.com

†These authors have contributed equally to this work

SPECIALTY SECTION
This article was submitted to Population, Community, and Ecosystem Dynamics, a section of the journal Frontiers in Ecology and Evolution

RECEIVED 28 January 2023
ACCEPTED 06 March 2023
PUBLISHED 23 March 2023

CITATION
Liu J, Du J, Zhang C, Zhang J, Yang H, Donald ML, Wu Y and Dong T (2023) Ecosystem service assessment under ecological restoration programs: A systematic review of studies from China.
Front. Ecol. Evol. 11:1152907.
doi: 10.3389/fevo.2023.1152907

With a growing body of literature on the topic of ecosystem service (ES), there is an urgent need to summarize ES research in the context of ecological restoration programs (ERPs) in China and identify knowledge gaps for future directions. We conducted a systematic literature review of articles to examine the use of ES approaches for ERP assessments. Our results showed that previous studies mainly focused on the Shaanxi Province, and more than half of the reviewed studies considered no more than three ES types simultaneously. All ES categories were not covered equally; most of the studies focused on provisioning and regulating services, while cultural services have received little attention. Although regional-scale and short-term assessments dominated the reviewed papers, we suggest that multiple temporal and spatial scales for ERP assessments should be given more attention in future work. Moreover, we highlight that an oversimplified land use/land cover (LULC) categorization scheme may potentially lead to inaccuracies and biases in ESs detection under restoration programs. Based on this review, our findings can guide future ERP assessments by using the ES approach. Meanwhile, given the global LULC change brought by the proliferation of plantations under ERPs, our results are also expected to provide a path forward to assess ESs associated with LULC change globally.

KEYWORDS

China, ecological restoration program, ecosystem services, LULC, systematic review

1. Introduction

Ecosystem services (ESs) are widely defined as the benefits that people derive from ecosystems (Millennium Ecosystem Assessment (MEA), 2005). ESs are grouped into four categories including provisioning services (e.g., food, water, and timber), regulating services (e.g., carbon sequestration, water purification, and soil conservation), supporting services (e.g., biodiversity conservation, biomass production, and nutrient cycling) and cultural services (e.g., education, recreation, aesthetic; Zheng et al., 2013; Jiang et al., 2018; Cui et al., 2021). Sustainably managing and utilizing the ESs can improve human well-being (Millennium Ecosystem Assessment (MEA), 2005). However, intensive interference from human activities (e.g., extensive deforestation, cropland, and urban expansion) has dramatically altered ecosystems (Xu W. et al., 2017), causing reductions in two-thirds of all ESs over the last few decades (Millennium Ecosystem Assessment (MEA), 2005; Gao et al., 2017). Ecological restoration has become a major strategy to restore the degraded ecosystem and improve ESs (Chazdon, 2008; Bullock et al., 2011; Keesstra et al., 2018).

Since the beginning of this century, the Chinese government has implemented several ecological restoration programs (ERPs), including the Grain-for-Green Program (GTGP), Natural Forest Conservation Program (NFCP), Soil and Water Conservation Programs (SWCP), and so on (Li et al., 2016; Zhang et al., 2016; Bryan et al., 2018; Jiang et al., 2021). Correspondingly, increasing interest has been focused on temporal and spatial changes in ecosystem services in the context of ecological restoration (Wang et al., 2017; Lu et al., 2018; Zhou et al., 2021). Currently, applications of remote sensing monitoring and biophysical model simulation have demonstrated that these restoration programs promoted vegetation restoration (Li et al., 2015; Zhang et al., 2018, 2019), carbon sequestration (Zhou et al., 2020), biomass increase (Brandt et al., 2018), and soil conservation (Xia et al., 2021). With the continuous implementation of ERPs, it is important to monitor the efficiency and impacts of these ERPs (Hua et al., 2018). A review of previous ERP assessments is particularly important for adjusting current and planning for future ERPs more effectively and efficiently.

Evaluating ERPs has attracted extensive attention and a growing number of studies have been carried out in China for this purpose (Wang et al., 2017; Liu et al., 2019; Tang et al., 2019; Qi et al., 2021). A variety of methodological approaches are available to assess ERPs, such as monetary valuation (Geng et al., 2020), field measurements (Guo et al., 2021), or modeling approaches (Liang et al., 2021). In addition, these studies assess changes in ES caused by ERPs at different scales: Qi et al. (2021) at the county scale, Zhou et al. (2021) at the regional scale, and Wang et al. (2021) at the national scale. Previous review papers related to ERP assessment using ES approaches have been carried out by D'Amato et al. (2016) and Wen and Théau (2020). However, the former focused primarily on monetary valuation studies of forest ES between 2000 and 2012 rather than on the approaches themselves used to assess the ERPs; the latter examined the use of ES approaches by selecting only the peer-reviewed English journal articles and assessed the only two ERPs (i.e., GTGP and NFCP), which may lead to biases in ERPs assessment results. Therefore, integrating local publications and more restoration projects is necessary to obtain a fuller picture of ERP assessment.

In this context, we conducted a more comprehensive systematic review of the literature on ERP assessments using ES approaches in China. Particularly, we focused on answering the following two questions: (1) What is the prevalence of using ES approach on ERP assessments in China? (2) What are the methodological approaches employed to assess ERP? Here, we address these questions by systematically reviewing the relevant literature published in both English and Chinese journals. Our objective was to provide a basis for assessing ERP using ES approaches, identify current challenges and offer recommendations for future research directions.

Several important national or provincial ecological policies in China are relevant to the reviewed papers; they are described briefly below. As one of China's largest ecological restoration projects, the GTGP, which consists of 10 subprograms covering >73% of China's territory, has been devoted to converting sloping farmland (farmland land with a slope great than 25°) to forest and grassland since 2000 (Zhou et al., 2020). The NFPP, as another large-scale restoration program, is aimed to protect natural vegetation for sustainable development (Ouyang et al., 2016). The SWCP, which is designed and implemented to reduce soil loss and enhance the soil retention function of the ecosystem (e.g., Duan et al., 2020; Jiang et al., 2021), has gradually developed into a national key ecological construction project. The emerging Ecological Conservation Red Line (ECRL) policy, which was initiated in 2011, aimed to protect ecologically fragile areas and important ecological functional zones, and enhance various ecosystem services (Zhou et al., 2021). The Three-North Shelter Forest Program, which is known as the "Green Great Wall" because its massive area spans half of northern China, has led to desired reductions in local land desertification and soil erosion as well as decreases in airborne sand and dust regionally (Li et al., 2021). The Beijing-Tianjin Sand Source Control Project was initiated in 2001 to promote environmental conservation near the capital of China (Beijing) by controlling the risk of wind-sand and soil erosion disasters. The Returning Grazing Land to Grassland Project was launched in 2003 to reduce the impacts of overgrazing and promote grassland productivity (Lu et al., 2018).

2. Methods

We conducted a systematic literature review of peer-reviewed articles published in English and Chinese journals, using the ISI Web of Science (WOS) database and the China Academic Journal Network Publishing Database of the China National Knowledge Infrastructure (CNKI). Keywords for the search in WOS included a combination of the following: "ecosystem service*" AND ("forest recovery" OR "forest restoration" OR "ecological restoration" OR "vegetation recovery" OR "vegetation restoration") AND ("China" OR "Chinese"). Additionally, we search CNKI using the combining sets of "生态系统服务" AND ("生态恢复" OR "森林恢复" OR "植被恢复"; the translation of the search terms in WOS) in the topic. We limited the search to the timeframe of 2005–2021 because few ES studies were conducted before the publication of the Millennium Ecosystem Assessment (Dade et al., 2019; Zheng et al., 2019), and China has implemented numerous forest restoration projects since 2000 (Qi et al., 2019). We defined two specific criteria to select papers to be reviewed in this study. First, we only consider papers that assess the ERPs using ES approaches because assessment of ES change could reveal the successes and limitations of the ERPs geared toward enhancing ES (Tallis et al., 2008; Jenerette et al., 2011). Second, we grouped ES assessments into two categories based on De Groot et al. (2012): economic and non-economic assessment. Though economic valuation is easy for implementation and requires minimal data, it generally suffers from measurement and generalization errors, possibly leading to invalid and unreliable results (TEEB, 2010; Jiang, 2017). In addition, since the non-economic valuation encompasses the health state of the ecosystem, which is more applicable to the sustainability evaluation of ecosystem services than the economic assessment (Fu et al., 2013), we only included studies on non-economic assessment of ESs. Our review consisted of a two-step screening process (Figure 1). We first screened article abstracts for relevancy and, if relevant, we then read the entire paper in the second stage of screening. We identified 640 scientific articles meeting the search criteria and 542 articles after the first screening, which removed review articles, conceptual papers, or ones that lacked consideration of ES changes driven by ERPs (Figure 1). We then excluded papers that did not our screening criteria and resulted in 100 papers. See the Appendix for a full list of papers included.

From each of the selected publications, we retrieved the following information: geographical location, driver factors, ESs that were assessed, and spatial and temporal scales (Table 1). We also reviewed assessment methodologies used to assess the ERPs. Methodologies were categorized into three classes: (1) field measurement refers to the use of field observations or laboratory analysis to provide information on ESs, (2) model simulation refers to the incorporation of representations of physical processes underpinning the functioning of the ecosystem to map ESs, and (3) questionnaire survey refers to the evaluation using a perception study that presented a questionnaire or interview, which is often used to evaluate cultural services. We further recorded whether to consider interactions among ESs in each study. Finally, we recorded the changes in ESs related to ERPs based on the findings reported in the literature (i.e., increased, decreased, or no change), considering the differences in the response of ESs to ERPs (Wilson et al., 2017; Benra et al., 2019; Wu et al., 2019). This classification allowed us to synthesize results consistently from different methodological approaches.

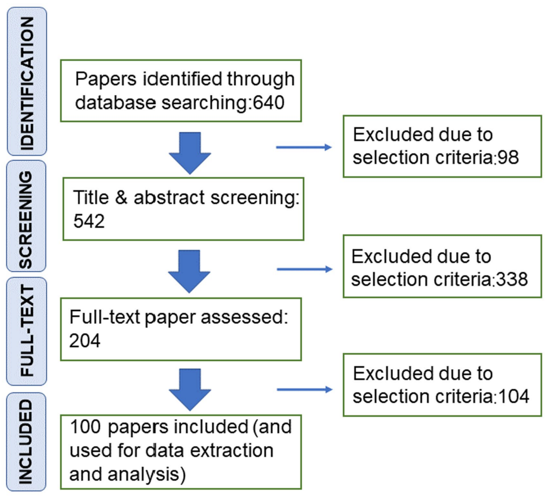

FIGURE 1
Overview of the selection process of the peer-reviewed publications identified in the review.

3. Results and discussion

3.1. The publication trends and geographical distribution

We identified 100 papers in total on the topic of ERP assessments using ES approaches in China in the WOS and CNKI from 2005 to 2021 that met our specific criteria. The first paper was published in 2007 (Wu et al., 2007), and it assessed the change in soil conservation brought about by the ecological restoration in the karst region. Figure 2 shows the number of related studies per year on this topic. It shows that since 2015, the number of studies has dramatically increased. Furthermore, nearly a quarter of the studies were published in 2019 and no studies were published from 2008 to 2010. Although the ES research work became popular and exponentially increase after the publication of the millennium assessment report in 2005 (Schägner et al., 2013), the ES approach used to assess ERPs started rather late in China. China implemented multiple ERPs in the 2000s, and the high number of publications two decades later may reflect the intense interest in understanding these programs' outcomes.

The spatial distribution of ES study regions within China was heterogeneous (Figure 3). Nearly half of the reviewed papers chose a case study located in Shaanxi Province, of which Bojie Fu and his research team from Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences made the biggest contribution to ES research related to ERPs assessment within this province, of 16 percentage points. The Qinghai Province was the next most studied area (38% of studies).

TABLE 1 Details of variables extracted from each paper during the literature review.

Variables extracted	Categories
Geographical location	Province(s) where the study was located
Consideration of the ES relationship	Whether to consider interactions among ESs
Driver factors	Ecological restoration program(s) the study evaluated
ESs that were assessed	Categorized based on Millennium Ecosystem Assessment (MEA) (2005) and De Groot et al. (2002), group level: regulating services (i.e., air-quality regulation, climate regulation, pollination, erosion regulation, water regulation and water purification); provisioning services (i.e., food production, fresh water provision, fiber and timber, genetic resources, biochemicals and ornamental resources), supporting services (i.e., nutrient cycling, primary production, soil formation, and biodiversity/habitat for species); cultural services (i.e., aesthetic values, cultural diversity, educational values, knowledge systems, recreation and ecotourism, spiritual and religious values)
Changes in ESs	Increased, decreased, or no change
Assessment methodologies	Categorized based on previous reviews (Andrew et al., 2015; Thom and Seidl, 2016), group level: field measurement, model simulation and questionnaire survey
Spatial scale	Categorized based on Wen and Théau (2020), group level: the county level assessment refers to the evaluation of ERPs in a specific county; the regional level assessment refers to watershed or catchment, and provincial scales; the national level assessment refers to the assessment of ERPs across China
Temporal scale	As for the period covered, we defined two classes: the short-term evaluation (<20 years); the long-term evaluation (more than 20 years)

However, the eastern coastal regions (e.g., Fujian, Shandong and Jiangsu Province) received the least amount of attention in terms of ERP assessment. This is likely because these regions were not covered by the two largest ERPs (i.e., GTGP and NFCP). Moreover, studies in the southwestern and northeastern regions also received less attention, as each province accounted for <16% of the reviewed paper considered. As the southwestern and northeastern regions are the two largest forested areas in China, massive deforestation for timber production in the past has led to the deterioration of the ecological environment in these regions, which may induce severe catastrophic events (Li, 1999; Cai et al., 2014). Indeed, a large-scale flood occurred in the Yangtze River basin in 1998, and the southwestern and northeastern regions were the source areas of this flood, indicating the importance of these regions in water conservation (Li, 1999). Since then, the Chinese government has launched a series of ERPs in these regions, which has resulted in a significant increase in tree cover (Hua et al., 2018). Despite the clear importance of ES on environmental impacts, the changes in ES under restoration programs remain poorly understood because of the paucity of studies for this purpose conducted in these regions. Thus, we need more studies in these regions to determine if the impacts and effectiveness of restoration programs are similar or different across China.

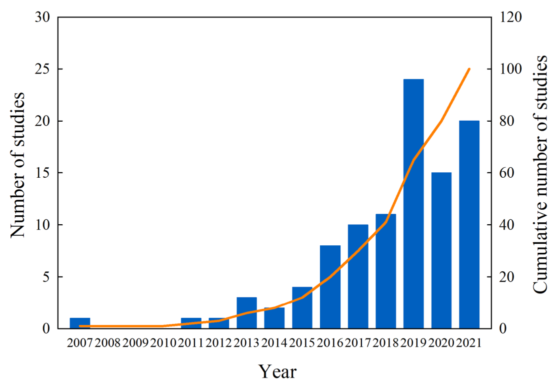

FIGURE 2
Number of studies on ecosystem services in China has increased in recent years. The line is the cumulative number of studies.

3.2. Findings through the review analysis

3.2.1. Number of ecosystem service considered

The number of ES considered concurrently in each study varied from 1 to 11 (Figure 4). However, most studies considered between

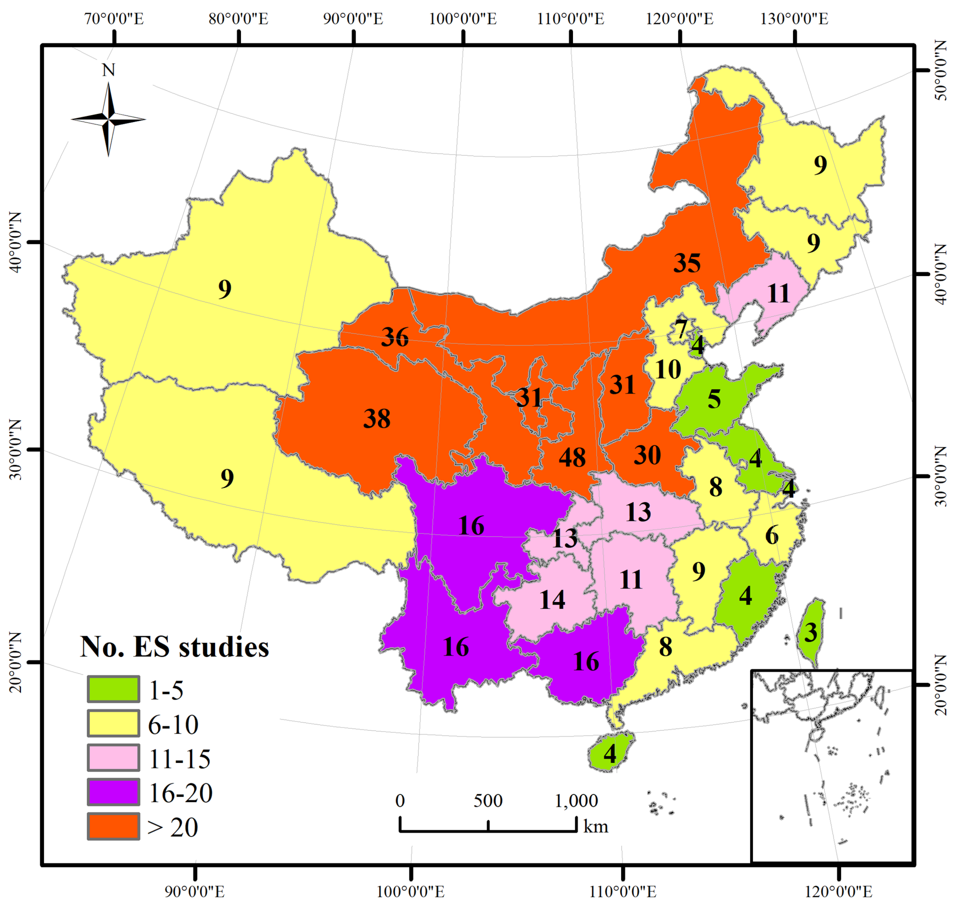

FIGURE 3
Geographical distribution of case studies included in the review. Colors represent the number of ecosystem service case studies (as a few studies consider several regions, the sum of studies in this figure exceeds the total number of studies reviewed).

one and five ES types. More than two-thirds of all studies (71%) considered only three or fewer ES types simultaneously, with 42% only considering a single ES, while only 8% of studies considered more than five ES types (Figure 4). The ecosystem should be considered as a whole because the changes or impacts on one part of an ecosystem can have consequences for the whole system (Wen and Théau, 2020). The narrow focus on one or a few ES types may provide little information to policymakers for an appropriate management of ES, and therefore a comprehensive assessment of a broad array of ES is necessary.

Change of ESs under ecological restoration programs has revealed interactions (i.e., trade-off and synergy) between multiple ES types (Fu et al., 2015): a single service's supply might have a positive or negative impact on the supply of another ES. Although an increasing number of studies have begun to focus on the relationships among ESs, nearly half of the reviewed papers, which excluded the studies considered a single ES, analyzed ESs in isolation (i.e., without considering any interactions; Figure 4). Given that identifying interrelations of ESs is critical to the sustainable management of ES (Raudsepp-Hearne and Peterson, 2016), interactions of multiple ESs need to be further examined to maintain ecosystem health.

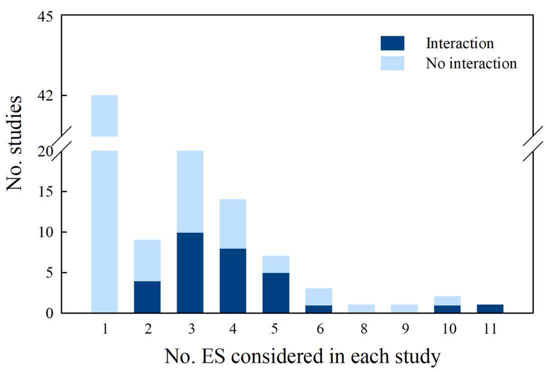

FIGURE 4
Frequency distribution of the number of ecosystem services evaluated in each case study. The proportion of studies that considered no interaction among ecosystem services is in gray, while the proportion that considered interactions among ecosystem services is in dark gray.

3.2.2. Types of ecosystem service

Following the Millennium Ecosystem Assessment (MEA) (2005) and De Groot et al. (2002), ESs are grouped into four broad categories: provisioning, regulating, cultural and supporting ES. Even though ES approaches have been widely used to analyze the ecological impact of ERPs, reviewed ERP assessment studies showed that not all ESs were considered (Figure 5). Specifically, five types of ESs (i.e., genetic resources, biochemicals, ornamental resources, pollination, and knowledge systems) were not evaluated in the reviewed papers, whereas 77% of studies evaluated the impact of ERPs on regulation services. In addition, reviewed studies primarily focused on provisioning services, particularly services associated with agricultural activities (i.e., fresh water provision and food provision), which has also been evaluated in other studies (Foley et al., 2005; Paudyal et al., 2019; Sylla et al., 2020). However, the reviewed papers showed little interest in evaluating the impacts of ERPs on cultural services, with only 7% of the studies related to these topics. Also, we observed an uneven distribution of types of ESs within each category: of the regulating services, 62 studies estimated the impacts of ERPs on erosion regulation, but only 10 studies focused on air quality regulation; of the cultural services, most studies mainly looked at spiritual and religious values, whereas few studies considered other cultural services (e.g., education and aesthetic). Similarly, studies evaluating provisioning services mostly focused on fresh water provision, and studies evaluating supporting services mostly focused on opportunities for soil formation (Figure 5). Ecosystem services provide benefits to people across various dimensions. While much focus has been placed on the ES categories of provisioning and regulating, cultural services have

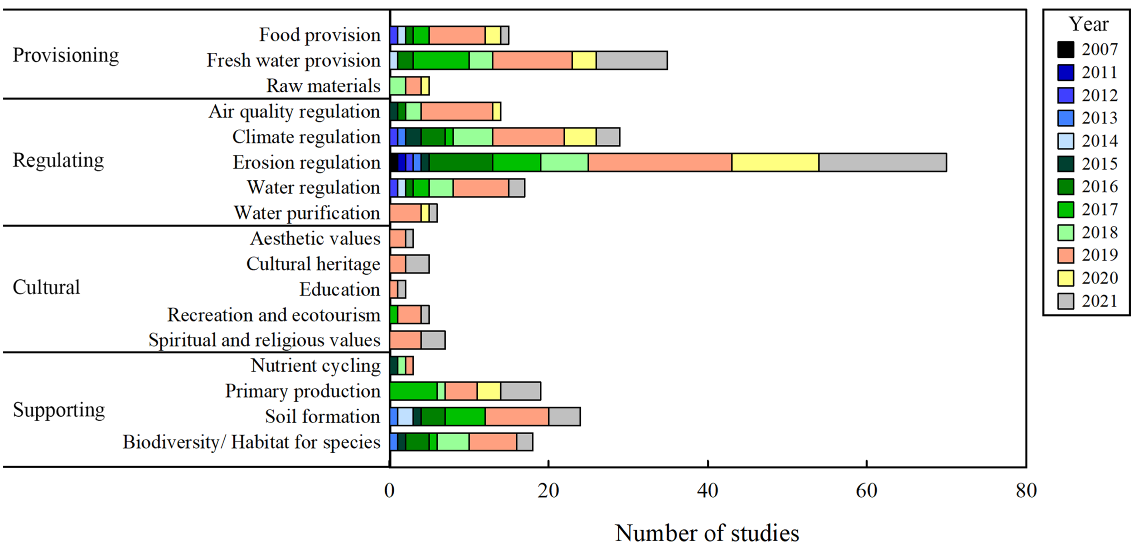

FIGURE 5
The number of studies that address each type of ecosystem service and their distribution across each year (because most of the studies consider several ecosystem services, the sum of studies in this figure exceeds the total number of studies reviewed).

received little attention in previous studies. One reason often cited is the difficulty in assessing cultural ESs because of their subjective and intangible character (Daniel et al., 2012; Schirpke et al., 2018; Kalinauskas et al., 2021). Cultural services are of great importance, not only for understanding the human-nature relationship but also for policy development (Jiang, 2017). We suggest that future research should take cultural services into account to build a more comprehensive assessment of ESs.

To summarize the features of regionalized differences, we further analyzed the focus of existing literature and the gaps of major ecosystem services within each region or province by taking into account the spatial distribution of the key ecological function zones (KEFZs) in China. Given that KEFZs are categorized by their functions of fresh water provision, sand fixation, soil and water conservation, water regulation, and biodiversity conservation (from the Resource and Environment Science and Data Center, https://www.resdc.cn; Figure 6A), we analyzed the spatial coverage of its corresponding ESs (i.e., fresh water provision, air quality regulation, erosion regulation, water regulation and biodiversity/habitat for species) in the reviewed papers. We found that the study site selection in the reviewed papers was not evenly distributed throughout KEFZs. Specifically, many papers chose Shaanxi Province as the case study sites to assess changes in fresh water provision and erosion regulation caused by ERPs (Figures 6B,C), which was in line with major local ecological characteristics or problems (e.g., water shortage and soil erosion; Cao et al., 2009). However, the northwest regions of China (e.g., Xinjiang and Tibet) and the southwestern regions (e.g., Guizhou, Guangxi and Chongqing) received less attention in terms of fresh water provision and erosion regulation evaluations, respectively, although there are a few KEFZs located in these regions (Figures 6B,C). Similarly, uneven distribution was detected in air quality regulation and water regulation evaluations related to ERPs assessments (Figures 6D,E). Moreover, we observed that the research on biodiversity conservation in some specific regions like Yunnan, Xinjiang and Tibet was still rare (Figure 6F). So there need to be more studies in these regions to better understand the effect of ecological restoration on biodiversity maintenance, especially for biodiversity hotspots such as Yunnan Province. Due to the importance of the KEFZs that contain degraded ecosystems and affect the ecological security of the entire country or large regions within it (Fan et al., 2017; Sun et al., 2021), we recommend that full consideration should be given to the regions with different ecosystem service functions, to provide targeted regional ecological restoration strategies.

3.2.3. Spatial and temporal scales

Scale plays an important role in estimating ESs and analyzing their interactions (Gret-Regamey et al., 2014). This is not surprising because ESs and their interactions in response to ERPs vary across spatiotemporal scales (Haines-Young et al., 2012; Costanza et al., 2014; Locatelli et al., 2014; Sannigrahi et al., 2019). We found that regional-level assessments account for 80% of the review papers, followed by county-level assessment (13%). Only 7% of studies considered national scales (see Appendix). Studies focused on the regional and national scales can detect the dynamic changes of ESs at large geographical extents but are limited in their ability to provide detailed information on local scale changes in ES (Raudsepp-Hearne and Peterson, 2016). However, studies focused on small spatial scales limit the ability of policy-makers to assess the full ecological impacts of restoration programs because ecological restoration could provide substantial influences to areas outside the region through the flow of ESs (Wolff et al., 2015). For instance, some specific ESs are provided locally but the benefits can accrue at different scales, ranging from local (e.g., food) to global (e.g., carbon sequestration; Xu S. et al., 2017). Certain ESs may be best considered at specific scales (Millennium Ecosystem Assessment (MEA), 2005). Generally, regulating and provisioning services may be best considered on a broad and small scale, respectively, while some specific services (e.g., carbon sequestration, climate regulation) should be considered on a national or global scale (Fu et al., 2011).

Additionally, the spatial patterns of ESs and their interactions are closely associated with the spatial scale (Sannigrahi et al., 2019), and thus findings from studies conducted in the same regions but on different spatial scales may not be consistent (Qiao et al., 2019). For instance, a study conducted in the floodplain of the Piedra River in central Spain found that the scale effects on changes in ES change will increase with spatial scale, as a higher pairwise correlation was observed at a larger scale (Felipe-Lucia et al., 2014). However, other studies identified a high correlation between changes in ES at fine spatial scales, with this trend disappearing as the spatial scale increases (Hou et al., 2017; Xu W. et al., 2017; Xu S. et al., 2017). Despite the differences in response to different spatial scales, few studies in the reviewed papers examined the variations in relationships among ESs across multiple spatial scales. Given that ecosystems are complex, and some ecological processes may occur across multiple scales (Agarwal et al., 2002), the single-scale observations may capture, miss, or distort ES interactions (Raudsepp-Hearne and Peterson, 2016). Therefore, determining the spatial patterns of ES and identifying associations that exist among them at multiple spatial scales is a critical need of future research aimed at accurately assessing the impacts of ERPs.

The temporal scale is also critical for ES research about ERPs as ESs vary from the short-term (e.g., amenity services) to the long-term (e.g., carbon sequestration; Turner et al., 2000; Limburg et al., 2002). Understanding the temporal changes in multiple ESs and their interactions contributes to assessing the long-term environmental impact of restoration programs (Hein et al., 2016). However, our results indicated that studies covered temporal scales unevenly; 76% of the total reviewed papers evaluated the changes in ESs related to the ERPs in the short term (<20 years; see Appendix), and 28% papers focused on evaluating <10 years of temporal extent. Only 24% papers analyzed more than 20 years of data. Furthermore, 45% of studies in the reviewed papers are based on static or semi-static (two-time points) analysis, without considering a temporal dynamic (at several time intervals or a continuous time series). These studies may ignore the uncertainty in analyzing changes in ESs and their interactions. For instance, changes in modeled ES may likely be dominated or overwhelmed by the external environment (e.g., fluctuations in weather in 1 year), which may result in detecting biased interactions between ESs (Li et al., 2017). Instead, studies based on temporal dynamic analysis may help detect continuous changes in ecosystem services and threshold or lag effects in interactions among ES (Li et al., 2017; Yin et al., 2019).

3.2.4. Changes in ESs and driver factors

Changes in ESs related to ERPs were different among multiple ESs (Figure 6). Generally, after the implementation of ERPs, all the studies in reviewed papers showed an increase in raw materials, air quality

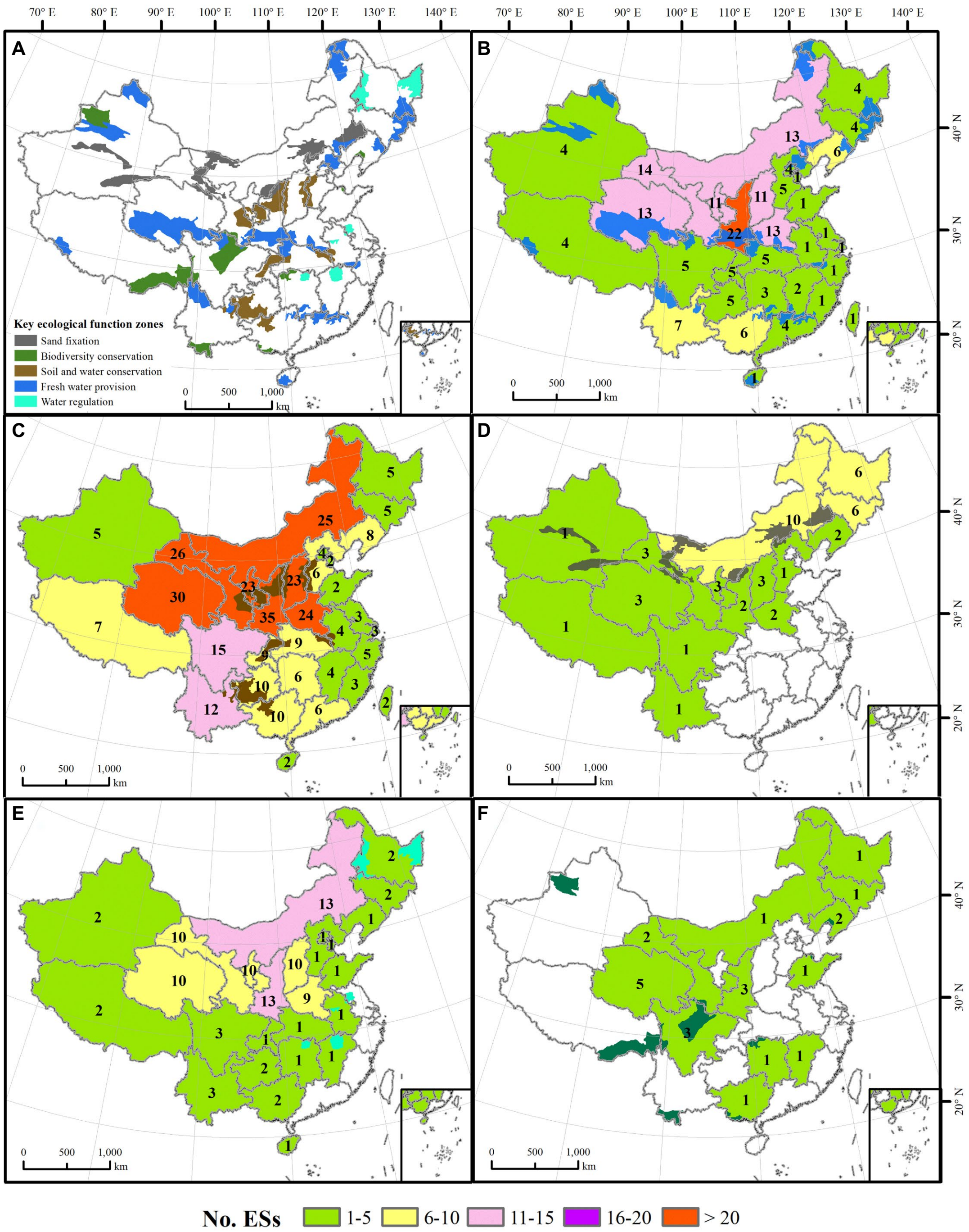

FIGURE 6
The key ecological function zones in China **(A)**, the number of ESs and their geographical distribution. **(B–F)** Stand for fresh water provision, air quality regulation, erosion regulation, water regulation and biodiversity/habitat for species, respectively.

regulation, water purification, education and nutrient cycling, followed by erosion regulation (93%), climate regulation (90%), and biodiversity/habitat for species (89%) (Figure 7). However, more than half of the studies (60%) showed that the ERPs resulted in a decrease in fresh water provision. There are also studies demonstrating that no change in ESs is related to ERPs, for instance, 11% of studies found no change in primary production. Overall, ecological restoration was beneficial to improving ESs (except for fresh water provision in some areas). This is likely because ecological restoration can improve the environment of the region (Chen et al., 2020; Tan et al., 2021). In addition, the landscape diversity caused by ecological restoration, and the consequent livelihood changes may make the public perceive more cultural ESs in several ways (Xian et al., 2020). However, our results also indicated that previous studies have yielded inconsistent results regarding ERPs' effect on ESs. This may be explained by geographical differences, historical factors, and economic conditions of the study regions. In China, most of the ERPs were not tailored for the local hydrological, climate, and land conditions of all regions covered by the

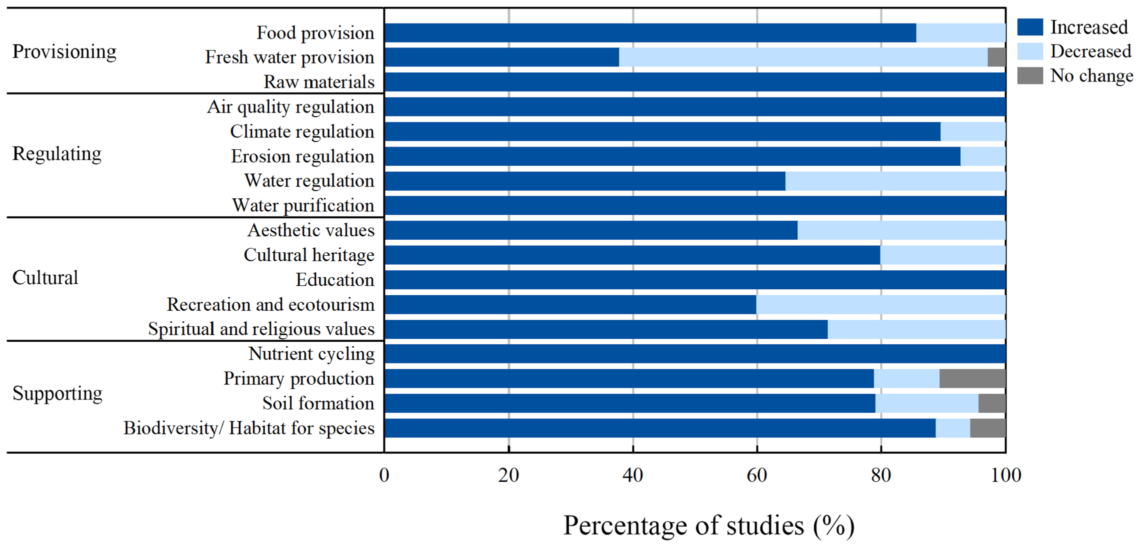

FIGURE 7
Changes in ecosystem services after ERPs.

program (Cao et al., 2011), and therefore, these programs may have negative impacts on ESs in some areas. More studies are needed to examine the interactions between multiple ESs and the mechanism behind these relationships, which could help improve the program's effectiveness.

Changes in ESs mentioned above were mainly driven by the implementation of ERPs. Indeed, ecological restoration engineering, including the GTGP, NFCP, SWCP, was the main factor that is responsible for improving ESs in China. However, previous reviews assessed only two ERPs (GTGP and NFCP; Wen and Théau, 2020), neglecting other ERPs' impacts. Our review found that there was a wide variety in the type of driver factors identified in the reviewed papers (see Appendix). The most identified driver was GTGP ($n = 53$), followed by NFCP ($n = 10$) and SWCP ($n = 6$). However, 33 studies in the reviewed papers did not specify the restoration programs. Although there was considerable variation in the number of papers focusing on each driver, GTGP and NFCP were two of the most studied drivers in ERPs assessment. This is likely because NFPP and GTGP are the two largest ERPs almost cover two-thirds of the Chinese territory (Liu et al., 2008) and have raised wider attention (Lu et al., 2018; Liu et al., 2019; Niu and Shao, 2020; Tan et al., 2021). However, to obtain a fuller picture of the influences of ERPs on ESs, restoration projects with different emphases (e.g., the emerging Ecological Conservation Red Line policy, ecological restoration after earthquake and the Three-North Shelter Forest Program) should be included in ERP assessments.

3.2.5. Methodologies used to assess the ERPs

Eighty-two reviewed papers assessed the ERPs based on model simulation, which shows the dominance of using simulation models in ES assessment (see Appendix). In particular, relatively simple ES models like the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST; https://naturalcapitalproject.stanford.edu/software/invest) or other comprehensive hydrological models such as the Soil Water Assessment Tool (SWAT; Arnold et al., 1998) can generate maps of the delivery and temporal distribution of water-related ESs across the landscape (Leh et al., 2013). The soil conservation assessment methods are mainly based on empirical soil erosion models, i.e., the Revised Universal Soil Loss Equation (RUSLE; Renard, 1997) or the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978). Carbon sequestration mapping was commonly modeled using the CASA (Carnegie-Ames-Stanford Approach) model, which is fundamental to vegetation carbon sequestration assessment (Lü et al., 2012). Moreover, 16 reviewed papers used field observations or laboratory analysis to assess the ERPs. This approach can collect information directly from sample plots and is usually used to assess the soil formation services (e.g., soil moisture, soil organic carbon and soil nutrient elements) and biodiversity (e.g., Li L. et al., 2018; Li Y. et al., 2018). Only two papers used a questionnaire survey and the application focused on evaluating cultural ESs after ERPs.

Although our results indicated that model-based assessments have been widely used to evaluate ESs about ERPs, some uncertainties identified from the process of modeling physical quantities remain in these model-based studies that may affect the accuracy of results (Qiao et al., 2019). For example, using undifferentiated modeling parameter values can lead to uncertainties due to spatial heterogeneity in the environmental conditions (e.g., climate and soil; Jiang and Zhang, 2016). Using the land use/land cover (LULC) data as the main source of input data can be another possible source of uncertainty. Since the availability of LULC data depends largely on the spatial resolution of the remotely sensed images (Ghassemian, 2016), the broad categories of LULC obtained from the interpretation of the remote sensing images may cause the loss of some critical information (Su and Fu, 2013). Specifically, ERPs are usually achieved by afforestation and conservation of native forests, while current LULC classifications of forest cover do not differentiate between plantations and native forests. This can be problematic for assessing ERPs impacts on ES, as previous research has shown that plantations and native forests differ in their capacity to provide ESs; for example, plantations may support lower biodiversity, and lower soil and water provisioning services compared with native forests (Wilson et al., 2017; Hua et al., 2018, 2022). Therefore, using the oversimplified LULC categorization scheme may potentially lead to inaccuracies and biases in ESs detection under restoration programs.

Similarly, uncertainties also exist in field measurement because these plot-level studies can often not account for the heterogeneity of complex landscapes and therefore do not sufficiently represent all the study areas (Birkhofer et al., 2015). Additionally, observations at large spatial scales and long-term, consecutive temporal-scale are usually scarce (Martínez-Harms and Balvanera, 2012), which may bring a difficulty to assess ERPs at large scales. This can be resolved by adding more field experiments, but they are usually time-consuming and labor-intensive. In addition, our results indicated that a questionnaire survey is usually used to identify the influences of ERPs on cultural ESs from human perceptions. Unlike some ESs that can be quantified based on the objective units of measure (e.g., the mass of pollutants sequestered per acre per year as a measure of the regulating service), the concept of cultural ESs is more difficult to quantify because they are subjective and driven by personal preferences (Booth et al., 2017), which potentially causes results uncertainties.

The uncertainties associated with the use of simulation models and the loss of information when using the oversimplified LULC categorization scheme may limit the accuracy and precision of evaluation results. Thus, it is necessary to find ways to reduce such uncertainties to improve the accuracy of results. First, a combination of methodology (e.g., field measurement and modeling) could be a possible solution. Model parameters for a regional scale or smaller spatial scale should be adjusted by using the results from field measurements which could provide direct on-ground data for parameterization and parameter optimization of ecosystem process models (Yu et al., 2018). Second, a more rigorous LULC categorization scheme that classifies the subtypes of forests (i.e., plantations versus native forests) is necessary. This is of particular importance as China's remarkable increase in forest cover has been dominated by tree plantations, usually monocultures following restoration (Hua et al., 2016), while native forests continue to decrease (Zhai et al., 2014). A multi-source data integration strategy that results from the comparison of historical aerial photographs and remote sensing data with high resolutions can be applied to reduce the imprecision and inconsistencies in LULC detection (Balthazar et al., 2015). Additionally, other datasets such as the China National Forestry Inventory should be considered as important Supplementary material, which not only can help us to differentiate between plantations and native forests (Hua et al., 2018) but also can be used to validate the results whether the simulation results or questionnaire survey results to improve the accuracy and precision of evaluation results.

4. Conclusion

This study reviewed 100 papers to evaluate ERPs using ES approaches in China. Our results show that most studies focused on specific regions and specific ES types (e.g., provisioning service and regulating service). Many studies did not consider the association among ES types, which may lead to an incomprehensive understanding of the ecological impact of China's restoration programs. In addition, the oversimplified LULC categorization scheme used in previous studies may limit the accuracy and precision of ERPs assessment results. Although our review showed that ES approaches have been widely used to analyze the ecological impact of ERPs in China, we identify some major elements that can improve future ERPs assessments. Priority should be given to performing studies on different regions, especially southwestern and northeastern China. Additionally, we suggest that multiple ESs, particularly cultural services, the interactions between multiple ESs, and multiple temporal and spatial scales for ERP assessments should be given more attention in future work. Further, we recommend that future studies should develop a more detailed LULC categorization scheme that differentiates the plantations from native forests to improve the accuracy and precision of evaluation results.

Author contributions

JL: conceptualization, formal analysis, writing an original draft. JD: conceptualization and review and editing. CZ: investigation and methodology. JZ, HY, and MD: review and editing. TD: conceptualization, supervision, and writing–review and editing. YW: project administration and supervision. All authors contributed to the article and approved the submitted version.

Funding

This study was supported by the National Key Research and Development Program of China (no. 2017YFC0505005), the Project of Jiuzhaigou National Nature Reserve (no. 5132202020000046), and (no. 22kE024).

Acknowledgments

We are very grateful to Heng-Xing Zou for his helpful suggestions.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1152907/full#supplementary-material

References

Andrew, M. E., Wulder, M. A., Nelson, T. A., and Coops, N. C. (2015). Spatial data, analysis approaches, and information needs for spatial ecosystem service assessments: a review. *GISci. Remote Sens.* 52, 344–373. doi: 10.1080/15481603.2015.1033809

Agarwal, C., Green, G. M., Grove, J. M., Evans, T. P., and Schweik, C. M. (2002). A review and assessment of land-use change models: dynamics of space, time, and human choice. Gen tech rep NE-297 Newton Square, US Department of Agriculture, Forest Service, Northeastern Research Station

Arnold, J. G., Srinivasan, R., Muttiah, R. S., and Williams, J. R. (1998). Large area hydrologic modeling and assessment part I: model development. *J. Am. Water Resour. Assoc.* 34, 73–89. doi: 10.1111/j.1752-1688.1998.tb05961.x

Balthazar, V., Vanacker, V., Molina, A., and Lambin, E. F. (2015). Impacts of forest cover change on ecosystem services in high Andean mountains. *Ecol. Indic.* 48, 63–75. doi: 10.1016/j.ecolind.2014.07.043

Benra, F., Nahuelhual, L., Gaglio, M., Gissi, E., Aguayo, M., Jullian, C., et al. (2019). Ecosystem services tradeoffs arising from non-native tree plantation expansion in southern Chile. *Landscape Urban Plan.* 190:103589. doi: 10.1016/j.landurbplan.2019.103589

Birkhofer, K., Diehl, E., Andersson, J., Ekroos, J., Früh-Müller, A., Machnikowski, F., et al. (2015). Ecosystem services—current challenges and opportunities for ecological research. *Front. Ecol. Evol.* 2:87. doi: 10.3389/fevo.2014.00087

Booth, P. N., Law, S. A., Ma, J., Buonagurio, J., Boyd, J., and Turnley, J. (2017). Modeling aesthetics to support an ecosystem services approach for natural resource management decision making. *Integr. Environ. Assess. Manag.* 13, 926–938. doi: 10.1002/ieam.1944

Brandt, M., Yue, Y., Wigneron, J. P., Tong, X., Tian, F., Jepsen, M. R., et al. (2018). Satellite-observed major greening and biomass increase in South China karst during recent decade. *Earth Future* 6, 1017–1028. doi: 10.1029/2018EF000890

Bryan, B. A., Gao, L., Ye, Y., Sun, X., Connor, J. D., Crossman, N. D., et al. (2018). China's response to a national land-system sustainability emergency. *Nature* 559, 193–204. doi: 10.1038/s41586-018-0280-2

Bullock, J. M., Aronson, J., Newton, A. C., Pywell, R. F., and ReyBenayas, J. M. (2011). Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trend Ecol. Evol.* 26, 541–549. doi: 10.1016/j.tree.2011.06.011

Cai, W., Borlace, S., Lengaigne, M., van Rensch, P., Collins, M., Vecchi, G., et al. (2014). Increasing frequency of extreme El Niño events due to greenhouse warming. *Nat. Clim. Chang.* 4, 111–116. doi: 10.1038/nclimate2100

Cao, S. X., Chen, L., and Liu, Z. (2009). An investigation of Chinese attitudes towards the environment: case study using the grain for Green project. *Ambio* 38, 55–64. doi: 10.1579/0044-7447-38.1.55

Cao, S. X., Sun, G., Zhang, Z., Chen, L., Feng, Q., Fu, B., et al. (2011). Greening China naturally. *Ambio* 40, 828–831. doi: 10.1007/s13280-011-0150-8

Chazdon, R. L. (2008). Beyond deforestation: restoring forests and ecosystem services on degraded lands. *Science* 320, 1458–1460. doi: 10.1126/science.1155365

Chen, Y., Chen, L., Cheng, Y., Ju, W., Chen, H. Y., and Ruan, H. (2020). Afforestation promotes the enhancement of forest LAI and NPP in China. *For. Ecol. Manag.* 462:117990. doi: 10.1016/j.foreco.2020.117990

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., et al. (2014). Changes in the global value of ecosystem services. *Glob. Environ. Change* 26, 152–158. doi: 10.1016/j.gloenvcha.2014.04.002

Cui, F., Wang, B., Zhang, Q., Tang, H., De Maeyer, P., Hamdi, R., et al. (2021). Climate change versus land-use change—what affects the ecosystem services more in the forest-steppe ecotone? *Sci. Total Environ.* 759:143525. doi: 10.1016/j.scitotenv.2020.143525

D'Amato, D., Rekola, M., Li, N., and Toppinen, A. (2016). Monetary valuation of forest ecosystem services in China: a literature review and identification of future research needs. *Ecol. Econ.* 121, 75–84. doi: 10.1016/j.ecolecon.2015.11.009

Dade, M. C., Mitchell, M. G. E., McAlpine, C. A., and Rhodes, J. R. (2019). Assessing ecosystem service trade-offs and synergies: the need for a more mechanistic approach. *Ambio* 48, 1116–1128. doi: 10.1007/s13280-018-1127-7

Daniel, T. C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J. W., Chan, K. M. A., et al. (2012). Contributions of cultural services to the ecosystem services agenda. *Proc. Natl. Acad. Sci. U. S. A.* 109, 8812–8819. doi: 10.1073/pnas.1114773109

De Groot, R., Brander, L., Ploeg, S., Costanza, R., Bernard, F., Braat, L., et al. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst. Serv.* 1, 50–61. doi: 10.1016/j.ecoser.2012.07.005

De Groot, R., Wilson, M. A., and Bouman, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecol. Econ.* 41, 393–408. doi: 10.1016/S0921-8009(02)00089-7

Duan, X., Bai, Z., Li, R., Li, Y., Ding, J., Tao, Y., et al. (2020). Investigation method for regional soil erosion based on the Chinese soil loss equation and high-resolution spatial data: case study on the mountainous Yunnan Province, China. *Catena* 184:104237. doi: 10.1016/j.catena.2019.104237

Fan, J., Wang, Y. F., Ouyang, Z. Y., Li, L. J., Xu, Y., Zhang, W. Z., et al. (2017). Risk forewarning of regional development sustainability based on a natural resources and environmental carrying index in China. *Earth Future* 5, 196–213. doi: 10.1002/2016EF000490

Felipe-Lucia, M. R., Comín, F. A., and Bennett, E. M. (2014). Interactions among ecosystem services across land uses in a floodplain agroecosystem. *Ecol. Soc.* 19:20. doi: 10.5751/ES-06249-190120

Foley, J. A., De Fries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., et al. (2005). Global consequences of land use. *Science* 309, 570–574. doi: 10.1126/science.1111772

Fu, B., Su, C., Wei, Y., Willett, I. R., Lü, Y., and Liu, G. (2011). Double counting in ecosystem services valuation: causes and countermeasures. *Ecol. Res.* 26, 1–14. doi: 10.1007/s11284-010-0766-3

Fu, B., Wang, S., Su, C., and Forsius, M. (2013). Linking ecosystem processes and ecosystem services. *Curr. Opin. Environ. Sust.* 5, 4–10. doi: 10.1016/j.cosust.2012.12.002

Fu, B., Zhang, L., Xu, Z., Zhao, Y., Wei, Y., and Skinner, D. (2015). Ecosystem services in changing land use. *J. Soils Sediments* 15, 833–843. doi: 10.1007/s11368-015-1082-x

Gao, J., Li, F., Gao, H., Zhou, C., and Zhang, X. (2017). The impact of land-use change on water-related ecosystem services: a study of the Guishui River basin, Beijing, China. *J. Clean Prod.* 163, S148–S155. doi: 10.1016/j.jclepro.2016.01.049

Geng, Q., Ren, Q., Yan, H., Li, L., Zhao, X., Mu, X., et al. (2020). Target areas for harmonizing the grain for Green Programme in China's loess plateau. *Land Degrad. Dev.* 31, 325–333. doi: 10.1002/ldr.3451

Ghassemian, H. (2016). A review of remote sensing image fusion methods. *Inform. Fusion* 32, 75–89. doi: 10.1016/j.inffus.2016.03.003

Gret-Regamey, A., Weibel, B., Bagstad, K. J., Ferrari, M., Geneletti, D., Klug, H., et al. (2014). On the effects of scale for ecosystem services mapping. *PLoS One* 9:e112601. doi: 10.1371/journal.pone.0112601

Guo, Z., Zhang, X., Dungait, J. A. J., Green, S. M., Wen, X., and Quine, T. A. (2021). Contribution of soil microbial necromass to SOC stocks during vegetation recovery in a subtropical karst ecosystem. *Sci. Total Environ.* 761:143945. doi: 10.1016/j.scitotenv.2020.143945

Haines-Young, R., Potschin, M., and Kienast, F. (2012). Indicators of ecosystem service potential at European scales: mapping marginal changes and trade-offs. *Ecol. Indic.* 21, 39–53. doi: 10.1016/j.ecolind.2011.09.004

Hein, L., van Koppen, C. S. A., van Ierland, E. C., and Leidekker, J. (2016). Temporal scales, ecosystem dynamics, stakeholders and the valuation of ecosystems services. *Ecosyst. Serv.* 21, 109–119. doi: 10.1016/j.ecoser.2016.07.008

Hou, Y., Lu, Y., Chen, W., and Fu, B. (2017). Temporal variation and spatial scale dependency of ecosystem service interactions: a case study on the central loess plateau of China. *Landsc. Ecol.* 32, 1201–1217. doi: 10.1007/s10980-017-0497-8

Hua, F., Bruijnzeel, L. A., Meli, P., Martin, P. A., Zhang, J., Nakagawa, S., et al. (2022). The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches. *Science* 376, 839–844. doi: 10.1126/science.abl464

Hua, F., Wang, L., Brendan, F., Zheng, X., Wang, X., Yu, D. W., et al. (2018). Tree plantations displacing native forests: the nature and drivers of apparent forest recovery on former croplands in southwestern China from 2000 to 2015. *Biol. Conserv.* 222, 113–124. doi: 10.1016/j.biocon.2018.03.034

Hua, F., Wang, X., Zheng, X., Fisher, B., Wang, L., Zhu, J., et al. (2016). Opportunities for biodiversity gains under the world's largest reforestation programme. *Nat. Commun.* 7:12717. doi: 10.1038/ncomms12717

Jenerette, G. D., Harlan, S. L., Stefanov, W. L., and Martin, C. A. (2011). Ecosystem services and urban heat riskscape moderation: water, green spaces, and social inequality in Phoenix, USA. *Ecol. Appl.* 21, 2637–2651. doi: 10.1890/10-1493.1

Jiang, W. (2017). Ecosystem services research in China: a critical review. *Ecosyst. Serv.* 26, 10–16. doi: 10.1016/j.ecoser.2017.05.012

Jiang, C., Guo, H., Wei, Y., Yang, Z., Wang, X., Wen, M., et al. (2021). Ecological restoration is not sufficient for reconciling the trade-off between soil retention and water yield: a contrasting study from catchment governance perspective. *Sci. Total Environ.* 754:142139. doi: 10.1016/j.scitotenv.2020.142139

Jiang, C., and Zhang, L. (2016). Ecosystem change assessment in the three-river headwater region, China: patterns, causes, and implications. *Ecol. Eng.* 93, 24–36. doi: 10.1016/j.ecoleng.2016.05.011

Jiang, C., Zhang, H., and Zhang, Z. (2018). Spatially explicit assessment of ecosystem services in China's loess plateau: patterns, interactions, drivers, and implications. *Glob. Planet. Change* 161, 41–52. doi: 10.1016/j.gloplacha.2017.11.014

Kalinauskas, M., Miksa, K., Inacio, M., Gomes, E., and Pereira, P. (2021). Mapping and assessment of landscape aesthetic quality in Lithuania. *J. Environ. Manag.* 286:112239. doi: 10.1016/j.jenvman.2021.112239

Keesstra, S., Nunes, J., Novara, A., Finger, D., Avelar, D., Kalantari, Z., et al. (2018). The superior effect of nature based solutions in land management for enhancing ecosystem services. *Sci. Total Environ.* 610-611, 997–1009. doi: 10.1016/j.scitotenv.2017.08.077

Leh, M. D. K., Matlocka, M. D., Cummingsa, E. C., and Nalley, L. L. (2013). Quantifying and mapping multiple ecosystem services change in West Africa. *Agric. Ecosyst. Environ.* 165, 6–18. doi: 10.1016/j.agee.2012.12.001

Li, W. (1999). Flood of Yantze river and ecological restoration. *J. Nat. Res* 14, 1–8. (in Chinese with English Abstract. doi: 10.11849/zrzyxb.1999.01.001

Li, Q., Chen, D., Zhao, L., Yang, X., Xu, S., and Zhao, X. (2016). More than a century of grain for Green program is expected to restore soil carbon stock on alpine grassland revealed by field ^{13}C pulse labeling. *Sci. Total Environ.* 550, 17–26. doi: 10.1016/j.scitotenv.2016.01.060

Li, Z., Liu, X., Niu, T., Kejia, D., Zhou, Q., Ma, T., et al. (2015). Ecological restoration and its effects on a regional climate: the source region of the Yellow River, China. *Environ. Sci. Technol.* 49, 5897–5904. doi: 10.1021/es505985q

Li, Y., Piao, S., Li, L., Chen, A., Wang, X., Ciais, P., et al. (2018). Divergent hydrological response to large-scale afforestation and vegetation greening in China. *Sci. Adv.* 4:eaar4182. doi: 10.1126/sciadv.aar4182

Li, L., Tietze, D. T., Fritz, A., Lü, Z., Bürgi, M., and Storch, I. (2018). Rewilding cultural landscape potentially puts both avian diversity and endemism at risk: a Tibetan plateau case study. *Biol. Conserv.* 224, 75–86. doi: 10.1016/j.biocon.2018.05.008

Li, Y., Zhang, L., Qiu, J., Yan, J., Wan, L., Wang, P., et al. (2017). Spatially explicit quantification of the interactions among ecosystem services. *Landsc. Ecol.* 32, 1181–1199. doi: 10.1007/s10980-017-0527-6

Li, R., Zheng, H., O'Connor, P., Xu, H., Li, Y., Lu, F., et al. (2021). Time and space catch up with restoration programs that ignore ecosystem service trade-offs. *Sci. Adv.* 7:eabf8650. doi: 10.1126/sciadv.abf8650

Liang, Y., Hashimoto, S., and Liu, L. (2021). Integrated assessment of land-use/land-cover dynamics on carbon storage services in the loess plateau of China from 1995 to 2050. *Ecol. Indic.* 120:106939. doi: 10.1016/j.ecolind.2020.106939

Limburg, K. E., O'Neill, R. V., Costanza, R., and Farber, S. (2002). Complex systems and valuation. *Ecol. Econ.* 41, 409–420. doi: 10.1016/S0921-8009(02)00090-3

Liu, J., Li, S., Ouyang, Z., Tam, C., and Chen, X. (2008). Ecological and socioeconomic effects of China's policies for ecosystem services. *Proc. Natl. Acad. Sci. U. S. A.* 105, 9477–9482. doi: 10.1073/pnas.0706436105

Liu, Y., Lü, Y., Fu, B., Harris, P., and Wu, L. (2019). Quantifying the spatio-temporal drivers of planned vegetation restoration on ecosystem services at a regional scale. *Sci. Total Environ.* 650, 1029–1040. doi: 10.1016/j.scitotenv.2018.09.082

Locatelli, B., Imbach, P., and Wunder, S. (2014). Synergies and trade-offs between ecosystem services in Costa Rica. *Environ. Conserv.* 41, 27–36. doi: 10.1017/S0376892913000234

Lü, Y., Fu, B., Feng, X., Zeng, Y., Liu, Y., Chang, R., et al. (2012). A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the loess plateau of China. *PLoS One* 7:e31782. doi: 10.1371/journal.pone.0031782

Lu, F., Hu, H., Sun, W., Zhu, J., Liu, G., Zhou, W., et al. (2018). Effects of national ecological restoration projects on carbon sequestration in China from 2001 to 2010. *Proc. Natl. Acad. Sci. U. S. A.* 115, 4039–4044. doi: 10.1073/pnas.1700294115

Martínez-Harms, M. J., and Balvanera, P. (2012). Methods for mapping ecosystem service supply: a review. *Inter. J. Biodiver. Sci. Ecosyst. Serv. Manage.* 8, 17–25. doi: 10.1080/21513732.2012.663792

Millennium Ecosystem Assessment (MEA). (2005). *Ecosystems and human well-being.* Washington, DC: Island Press.

Niu, L., and Shao, Q. (2020). Soil conservation service spatiotemporal variability and its driving mechanism on the Guizhou plateau, China. *Remote Sens.* 12:2187. doi: 10.3390/rs12142187

Ouyang, Z., Zheng, H., Xiao, Y., Polasky, S., Liu, J., Xu, W., et al. (2016). Improvements in ecosystem services from investments in natural capital. *Science* 352, 1455–1459. doi: 10.1126/science.aaf2295

Paudyal, K., Baral, H., Bhandari, S. P., Bhandarie, A., and Keenan, R. J. (2019). Spatial assessment of the impact of land use and land cover change on supply of ecosystem services in Phewa watershed. *Nepal. Ecosyst. Serv.* 36:100895. doi: 10.1016/j.ecoser.2019.100895

Qi, X., Li, Q., Yue, Y., Liao, C., Zhai, L., Zhang, X., et al. (2021). Rural–urban migration and conservation drive the ecosystem services improvement in China karst: a case study of HuanJiang County, Guangxi. *Remote Sens.* 13:566. doi: 10.3390/rs13040566

Qi, W., Li, H., Zhang, Q., and Zhang, K. (2019). Forest restoration efforts drive changes in land-use/land-cover and water-related ecosystem services in China's Han River basin. *Ecol. Engineer* 126, 64–73. doi: 10.1016/j.ecoleng.2018.11.001

Qiao, X., Gu, Y., Zou, C., Xu, D., Wang, L., Ye, X., et al. (2019). Temporal variation and spatial scale dependency of the trade-offs and synergies amongmultiple ecosystemservices in the Taihu Lake Basin of China. *Sci. Total Environ.* 651, 218–229. doi: 10.1016/j.scitotenv.2018.09.135

Raudsepp-Hearne, C., and Peterson, G. D. (2016). Scale and ecosystem services: how do observation, management, and analysis shift with scale —lessons from Québec. *Ecol. Soc.* 21:16. doi: 10.5751/ES-08605-210316

Renard, K. G. (1997). *Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE)*. Washington DC: United States Government Printing.

Sannigrahi, S., Chakraborti, S., Joshi, P. K., Keesstra, S., Sen, S., Paul, S. K., et al. (2019). Ecosystem service value assessment of a natural reserve region for strengthening protection and conservation. *J. Environ. Manag.* 244, 208–227. doi: 10.1016/j.jenvman.2019.04.095

Schägner, J. P., Brander, L., Maes, J., and Hartje, V. (2013). Mapping ecosystem services' values: current practice and future prospects. *Ecosyst. Serv.* 4, 33–46. doi: 10.1016/j.ecoser.2013.02.003

Schirpke, U., Meisch, C., Marsoner, T., and Tappeiner, U. (2018). Revealing spatial and temporal patterns of outdoor recreation in the European Alps and their surroundings. *Ecosyst. Serv.* 31, 336–350. doi: 10.1016/j.ecoser.2017.11.017

Su, C., and Fu, B. (2013). Evolution of ecosystem services in the Chinese loess plateau under climatic and land use changes. *Glob. Planet. Change* 101, 119–128. doi: 10.1016/j.gloplacha.2012.12.014

Sun, M., Yang, R., Li, X., Zhang, L., and Liu, Q. (2021). Designing a path for the sustainable development of key ecological function zones: a case study of Southwest China. *Glob. Ecol. Conserv.* 31:e01840. doi: 10.1016/j.gecco.2021.e01840

Sylla, M., Hagemann, N., and Szewrański, S. (2020). Mapping trade-offs and synergies among peri-urban ecosystem services to address spatial policy. *Environ. Sci. Pol.* 112, 79–90. doi: 10.1016/j.envsci.2020.06.002

Tallis, H., Kareiva, P., Marvier, M., and Chang, A. (2008). An ecosystem services framework to support both practical conservation and economic development. *Proc. Natl. Acad. Sci. U. S. A.* 105, 9457–9464. doi: 10.1073/pnas.0705797105

Tan, Q., Gong, C., Li, S., Ma, N., Ge, F., and Xu, M. (2021). Impacts of ecological restoration on public perceptions of cultural ecosystem services. *Environ. Sci. Pollut. Res.* 28, 60182–60194. doi: 10.1007/s11356-021-14793-7

Tang, Y., Shao, Q., Liu, J., Zhang, H., Yang, F., Cao, W., et al. (2019). Did ecological restoration hit its mark? Monitoring and assessing ecological changes in the grain for Green program region using multi-source satellite images. *Remote Sens.* 11:358. doi: 10.3390/rs11030358

TEEB (2010). *The economics of ecosystems and biodiversity*. Ecological and Economic Foundations. Earthscan, London and Washington.

Thom, D., and Seidl, R. (2016). Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests. *Biol. Rev. Camb. Philos. Soc.* 91, 760–781. doi: 10.1111/brv.12193

Turner, R. K., van den Bergh, J. C. J. M., Söderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E., et al. (2000). Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecol. Econ.* 35, 7–23. doi: 10.1016/S0921-8009(00)00164-6

Wang, J., Peng, J., Zhao, M., Liu, Y., and Chen, Y. (2017). Significant trade-off for the impact of grain-for-Green Programme on ecosystem services in North-Western Yunnan, China. *Sci. Total Environ.* 574, 57–64. doi: 10.1016/j.scitotenv.2016.09.026

Wang, H., Zhao, W., Li, C., and Pereira, P. (2021). Vegetation greening partly offsets the water erosion risk in China from 1999 to 2018. *Geoderma* 401:115319. doi: 10.1016/j.geoderma.2021.115319

Wen, X., and Théau, J. (2020). Assessment of ecosystem services in restoration programs in China: a systematic review. *Ambio* 49, 584–592. doi: 10.1007/s13280-019-01214-w

Wilson, S. J., Schelhas, J., Grau, R., Nanni, A. S., and Sloan, S. (2017). Forest ecosystem-service transitions: the ecological dimensions of the forest transition. *Ecol. Soc.* 22:38. doi: 10.5751/ES-09615-220438

Wischmeier, W. H., and Smith, D. D. (1978). Predicting rainfall erosion losses – A guide to conservation planning. Agriculture handbook no. 537 USDA/science and education administration, US Govt. Printing Office, Washington, DC.

Wolff, S., Schulp, C. J. E., and Verburg, P. H. (2015). Mapping ecosystem services demand: a review of current research and future perspectives. *Ecol. Indic.* 55, 159–171. doi: 10.1016/j.ecolind.2015.03.016

Wu, K. Y., Jiang, Z. C., and Luo, W. Q. (2007). Techniques of ecological restoration and evaluation of economic value of their results in Guohua demonstration area. *Earth Environ.* 35, 159–165. doi: 10.3969/j.issn.1672-9250.2007.02.011

Wu, D., Zou, C., Cao, W., Xiao, T., and Gong, G. (2019). Ecosystem services changes between 2000 and 2015 in the loess plateau, China: a response to ecological restoration. *PLoS One* 14:e0209483. doi: 10.1371/journal.pone.0209483

Xia, H., Kong, W., Zhou, G., and Sun, O. (2021). Impacts of landscape patterns on water-related ecosystem services under natural restoration in Liaohe River reserve, China. *Sci. Total Environ.* 792:148290. doi: 10.1016/j.scitotenv.2021.148290

Xian, J., Xia, C., and Cao, S. (2020). Cost–benefit analysis for China's grain for Green program. *Ecol. Eng.* 151:105850. doi: 10.1016/j.ecoleng.2020.105850

Xu, S., Liu, Y., Wang, X., and Zhang, G. (2017). Scale effect on spatial patterns of ecosystem services and associations among them in semi-arid area: a case study in Ningxia Hui autonomous region, China. *Sci. Total Environ.* 598, 297–306. doi: 10.1016/j.scitotenv.2017.04.009

Xu, W., Xiao, Y., Zhang, J., Yang, W., Zhang, L., Hull, V., et al. (2017). Strengthening protected areas for biodiversity and ecosystem services in China. *Proc. Natl. Acad. Sci. U. S. A.* 114, 1601–1606. doi: 10.1073/pnas.1620503114

Yin, L., Wang, X., Zhang, K., Xiao, F., Cheng, C., and Zhang, X. (2019). Trade-offs and synergy between ecosystem services in National Barrier Zone. *Geogr. Res.* 38, 2162–2172. (in Chinese with English Abstract. doi: 10.11821/dlyj020180578

Yu, G., He, H., and Zhou, Y. (2018). Ecosystem observation and research under background of big data. *Bull. Chin. Acad. Sci.* 33, 832–837. (in Chinese with English Abstract. doi: 10.16418/j.issn.1000-3045.2018.08.010

Zhai, D., Xu, J., Dai, Z., Cannon, C. H., and Grumbine, R. E. (2014). Increasing tree cover while losing diverse natural forests in tropical Hainan, China. *Reg. Environ. Change* 14, 611–621. doi: 10.1007/s10113-013-0512-9

Zhang, B., He, C., Burnham, M., and Zhang, L. (2016). Evaluating the coupling effects of climate aridity and vegetation restoration on soil erosion over the loess plateau in China. *Sci. Total Environ.* 539, 436–449. doi: 10.1016/j.scitotenv.2015.08.132

Zhang, M., Wang, K., Liu, H., Zhang, C., Yue, Y., and Qi, X. (2018). Effect of ecological engineering projects on ecosystem services in a karst region: a case study of Northwest Guangxi, China. *J. Clean. Prod.* 183, 831–842. doi: 10.1016/j.jclepro.2018.02.102

Zhang, Y., Xu, X., Li, Z., Liu, M., Xu, C., Zhang, R., et al. (2019). Effects of vegetation restoration on soil quality in degraded karst landscapes of Southwest China. *Sci. Total Environ.* 650, 2657–2665. doi: 10.1016/j.scitotenv.2018.09.372

Zheng, H., Robinson, B. E., Liang, Y.-C., Polasky, S., Ma, D.-C., Wang, F.-C., et al. (2013). Benefits, costs, and livelihood implications of a regional payment for ecosystem service program. *Proc. Natl. Acad. Sci. U. S. A.* 110, 16681–16686. doi: 10.1073/pnas.1312324110

Zheng, H., Wang, L., and Wu, T. (2019). Coordinating ecosystem service trade-offs to achieve win-win outcomes: a review of the approaches. *J. Environ. Sci.* 82, 103–112. doi: 10.1016/j.jes.2019.02.030

Zhou, M., Deng, J., Lin, Y., Zhang, L., He, S., and Yang, W. (2021). Evaluating combined effects of socio-economic development and ecological conservation policies on sediment retention service in the Qiantang River basin, China. *J. Clean. Prod.* 286:124961. doi: 10.1016/j.jclepro.2020.124961

Zhou, J., Zhao, Y., Huang, P., Zhao, X., Feng, W., Li, Q., et al. (2020). Impacts of ecological restoration projects on the ecosystem carbon storage of inland river basin in arid area, China. *Ecol. Ind.* 118:106803. doi: 10.1016/j.ecolind.2020.106803