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Editorial

Loess Plateau: from degradation to restoration

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GRAPHICAL ABSTRACT

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ABSTRACT

United Nations established 2021–2030 as the decade for ecosystem restoration and "*prevent, halt and reverse the degradation of ecosystems worldwide*". Ecosystem and land degradation are a global phenomenon. As a consequence of land degradation, in the late 1990s, the "Grain for Green Program" (GFGP) was established in Loess Plateau (China). It converted slope farmlands to forest or grassland over the, resulting in a visible "greening" trend. Other effects of GFGP on soil properties, land production, hydrological conditions, ecosystem services, and policy implications are the topics of this Special Issue. This Special Issue includes 17 contributions that cover recent research carried out in Loess Plateau in the mentioned topics at different spatial and temporal scales. The collection of papers presented in this Special Issue discusses critical issues in vegetation restoration and sustainable land management in the region. This Special Issue will contribute to United Nations strategy for ecosystems restoration.

1. Background

United Nations established 2021–2030 as the decade for ecosystem restoration and "*prevent, halt and reverse the degradation of ecosystems*

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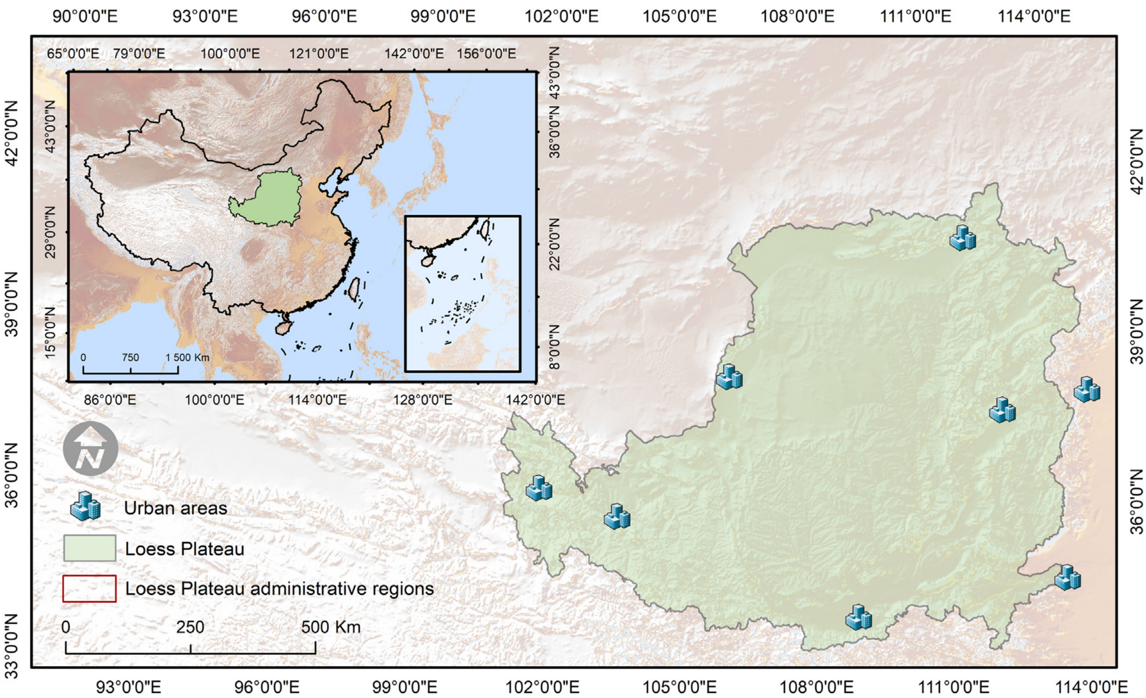

Fig. 1. The location of the study region, Loess Plateau of China.

worldwide." This is a serious issue that we should be a concern and work together to reverse this trend. "*It's time to rebuild what has been lost*".[1] The good conditions of the ecosystems are a crucial in achieving sustainable development goals and contributing to food security, climate change, water and biodiversity conservation, and poverty eradication. As consequences of the use (and abuse) of natural resources, many ecosystems are degraded. Land degradation is a global phenomenon and is a consequence of natural processes or human in the ecosystems. It is estimated that 25% of the earth is affected by land degradation. At the current pace of ecosystems exploitation, it is expected that by 2050, 95% of earth's surface will be affected by land degradation. As a consequence of non-sustainable agriculture practices, it is estimated that 24 billion tons of soil are eroded. This has implications on approximately 3.2 billion people.[2] Land degradation is expressed as a long-term reduction or loss of at least one of the following: biological productivity, ecological integrity, or value to humans (IPCC, 2019). Land degradation is the leading cause of losses of ecosystem functions, including changes in the structure, composition, or ecological processes. This reduces the capacity of these ecosystems in providing ecosystem services (ES) in quality and quantity (Smiraglia et al., 2016; Pereira et al., 2016, 2018). This reduction of ES provisioning can be caused by one of the complex interactions of several drivers of change (e.g., habitat change, climate change, overexploitation, invasive species, and pollution) (Pereira, 2020a). We entered a new era, the Anthropocene and land degradation will have impacts on key resources such as soil and water (Malhi, 2017; Ferreira et al., 2018; Fu, 2020; Pereira et al., 2020). Also, the rates of biodiversity decrease and defaunation are unprecedented and grow at a fast rate as a consequence of land degradation in the entire world (e.g., Sousa and Srbek-Araujo, 2017; Mace et al., 2018; Gardner et al., 2019). In this context, it is crucial to achieving land degradation neutrality (LDN). LDN is defined as "*a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems*" (UNCCD, 2016). This concept was adopted under the sustainable goal 15 (Life on Land), and the framework around this concept is described in detail in Cowie et al. (2018). As a consequence of multidimensional aspects, degradation needs to be analyzed at various spatial scales, from a local focus on specific degradation processes to landscape and regional scales and using diverse methods including in-situ experiments monitoring, plot-based measurements, remote sensing, model simulation, expert knowledge and evaluation of stakeholders experiences (King and Hobbs, 2006; Reed et al., 2011; Rindfuss et al., 2004; Turner et al., 2016).

Ecological restoration projects are one of the options to alleviate land degradation and increase the capacity of the ecosystem to provide ES such as habitat support, food regulation, water purification, pollination, food, freshwater, recreation, and aesthetic values (e.g., Tolvanen and Aronson, 2016; Brown and MacLeod, 2017; Hausner et al., 2018; Liu et al., 2019; Abera et al., 2019). They have been carried out in several parts of the world including Africa – South Africa (Crookes and Blignaut, 2019), Ethiopia (Moges et al., 2018), Mozambique (Bouley et al., 2018), Nigeria (Zabbey and Tannee, 2016) and Republic Democratic of Congo (Boisson et al., 2016) – America – Brazil (Brancalion et al., 2019), Colombia (Galindo-Rodriguez and Roa-Fuentes, 2017), Argentina (Perez et al., 2019), Peru (Flores-Alvarez et al., 2018), Mexico (Hruska et al., 2017), The USA (Sanchez Meador et al., 2017) and Canada (Danneyrolles et al., 2017) – Europe – Portugal (Arsénio et al., 2020), Spain (Peris et al., 2017), France (Buisson et al., 2018), Italy (Root-Bernstein and Frascaroli, 2016), Germany (Staentzel et al., 2019), Austria (Sengl et al., 2017) Poland (Bednarska et al., 2018) and Greece (Sidiropoulos et al., 2017) – Asia – Israel (Tessler et al., 2019), Saudi Arabia (Mayence et al., 2017), India (Ahirwal et al., 2016), China (Li et al., 2016) and Japan (Furuta and Shimatani, 2018) – Oceania – Australia (MacDonald et al., 2016) and New Zealand (Clarkson and Kirby, 2016).

Ecological restoration measures were implemented in several parts of China. One of the key areas was the Loess Plateau in, where many works were carried out (e.g., Zhang et al., 2016; Zhou et al., 2016; Zhu et al., 2017; Wang et al., 2018). The Loess Plateau of China is known for its severe land degradation, soil erosion and water scarcity problems (Shi and Shao, 2000; Chen et al., 2007; Liang et al., 2015; Fu et al., 2017). Located in central northern China, the Loess Plateau is a highland region of about 640,000 km^2 (Fig. 1). The loess plateau comprises a mix of arid,

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[1] https://www.decadeonrestoration.org/.

[2] https://www.thegef.org/topics/land-degradation.

semi-arid and semi-humid areas, and most of the plateau is in a semi-arid zone in terms of an aridity index. The average annual rainfall is approximately 400 mm. It has both the deepest and largest loess deposit region in the world. In order to support the increasing population, the forests have been gradually turned into farmland because loess soils are perfectly suitable for agriculture, although it is at the same time vulnerable to water and wind erosion. More than 60% of the plateau is severely impacted by soil and wind erosion and contributes to ~90% of sediment sources in the Yellow River. The long history of deforestation in this area degrades the land, lowers agricultural productivity, and leads to poverty in many of the farming communities (Fu et al., 2017).

The Chinese government recognized this problem and initiated the "Grain for Green Program" (GFGP) in the late 1990s. This large-scale vegetation restoration engineering converted slope farmlands into forests or grasslands to minimize soil water loss, mitigate flood risk, and improve livelihoods in the area (Fu et al., 2017). The program successfully converted 16,000 km^2 of rain-fed cropland to non-crop vegetation, resulting in a visible "greening" trend (Li et al., 2017a, 2017b). Meanwhile, it reduced soil erosion and water loss over the Loess Plateau and the sediment transported into the Yellow River (Miao et al., 2010; Wang et al., 2016). Over the past twenty years, state-of-the-art management strategies and technical innovations were implemented under GFGP to restore degraded landscape (Wen and Zhen, 2020).

Though some positive achievements have been established in the past decade, there are still many tasks to be done. Considering the effects of the large-scale ecological restoration on the Loess Plateau, there are numerous long-term processes (e.g., soil environment, hydrological cycle, nutrient storage, and regional ES) that need to be observed, monitored and analyzed at different scales. To facilitate our understanding of those processes, this Special Issue in Science of The Total Environment aims to compile numerous studies that examine changes in the environment of the Loess Plateau, including the effects of ecological restoration on soil environment and land production, hydrological conditions and ES. This Special Issue also facilitates the assessment of environmental policies related to restoration strategies, including their significances and problems with the implementation of GFGP in the Loess Plateau. When addressing the conflict between environmental sustainability and economic development, these achievements can assist decision-makers in other regions of the world when implementing management policies.

2. From degradation to restoration

2.1. Land use changes after GFGP

From 2000 to 2010, the land cover of the Loess Plateau changed significantly in terms of both spatial patterns and area (Fig. 2). Forest, grassland, and farmland were the main land cover types in the Loess Plateau. During this period, the land cover change occurred mainly in the middle and the southern parts of the plateau. This change was characterized by a decreasing farmland and water bodies and by an increase of vegetation cover and built-up areas. Specifically, farmland decreased by 28.3%, grassland, and forest coverage increased by 12.4% and 5.0%, respectively. The built-up areas expanded by 10.8%. Increased vegetation and urbanization are the manifestations of land-use change on the Loess Plateau after GFGP (Fig. 3).

2.2. Vegetation changes

After the implementation of GFGP, there has been a steady increase in normalized difference vegetation index (NDVI) ($Z = 3.65$, $p < 0.001$) in the Loess Plateau, since the 2000s (Fig. 4A and B), with an annual increase of 1.06% (Fig. 4D). Most changes occurred in the middle part of the region, where gullies and hills are distributed. It is also the main

Fig. 2. From degradation to restoration. Photo provided by Professorial senior engineer, Quangang Yu. Photography location, Yulin City, Shaan'Xi province of the Loess Plateau.

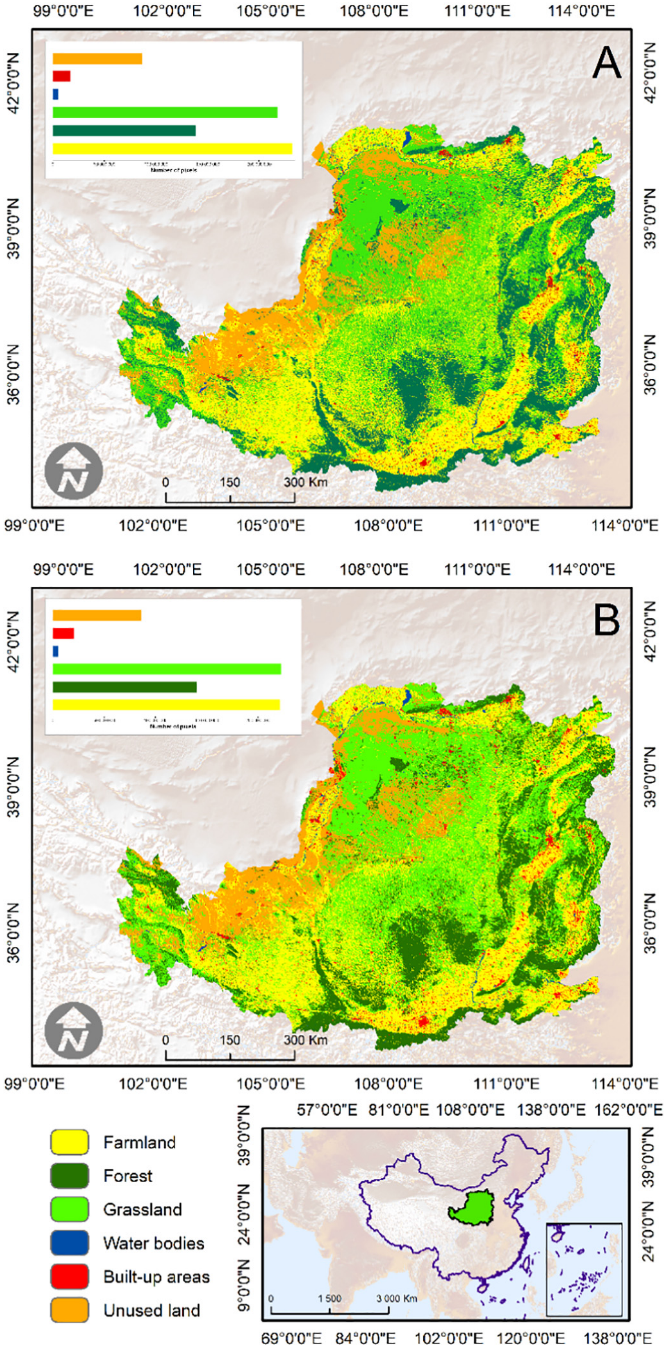

Fig. 3. Spatial pattern of increased (A) and decreased (B) land cover types of the Loess Plateau between 2000 and 2010.
Data source: http://www.resdc.cn.

area where GFGP was implemented, generating NDVI increase by >20% (Fig. 4C). On the contrary, changes in the northern and western areas (sand and desert regions) as well as in the southern areas (irrigated regions) of the Loess Plateau were minimal.

2.3. Water recharge and sediment load

Fig. 5 shows the trends of annual runoff and sediment yield of Toudaoguai and Tongguan hydrological station in the middle reaches of the Yellow River. Over 59 years, from 1960 to 2018, the annual runoff and sediment load decreased dramatically at the two stations. At Toudaoguai hydrological station, the annual runoff ($Z = -3.43$) and

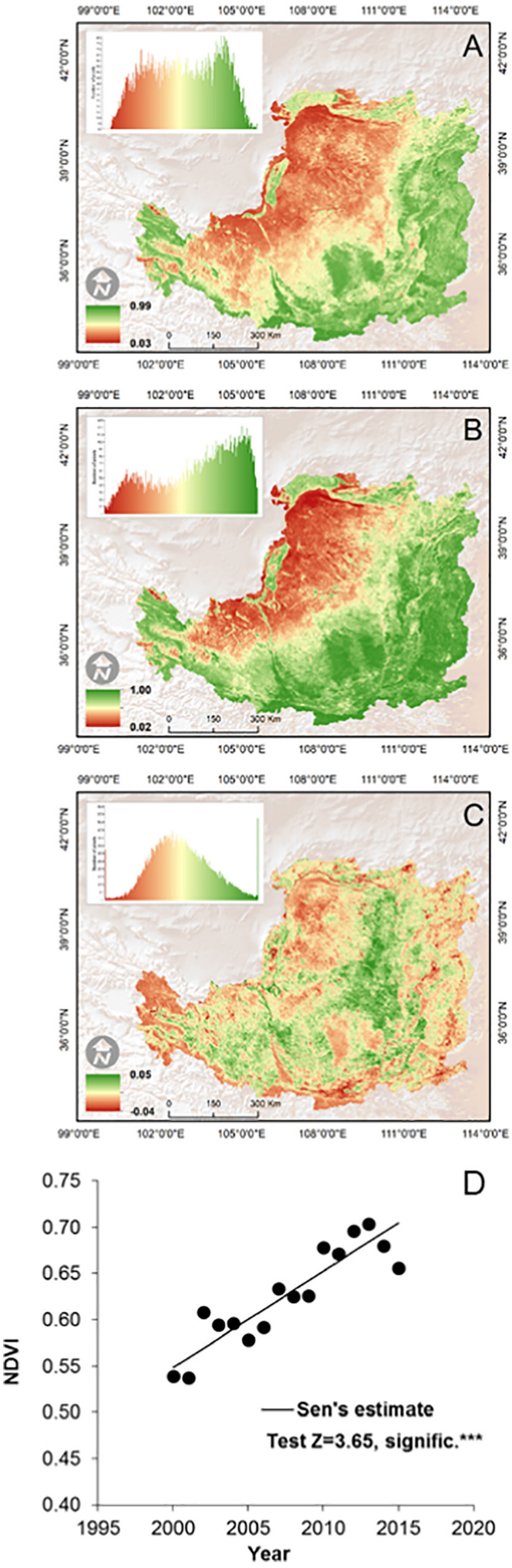

Fig. 4. Spatial pattern and temporal trend of the NDVI of the Loess Plateau (A) NDVI in 2000 (at the beginning of the implementation of the GFGP); (B) NDIV in 2015 (16 years after the GFGP was carried out); (C) the range of the NDVI change (from 2000 to 2015), and (D) the annual NDVI from 2000 to 2015.
Data source: http://westdc.westgis.ac.cn.

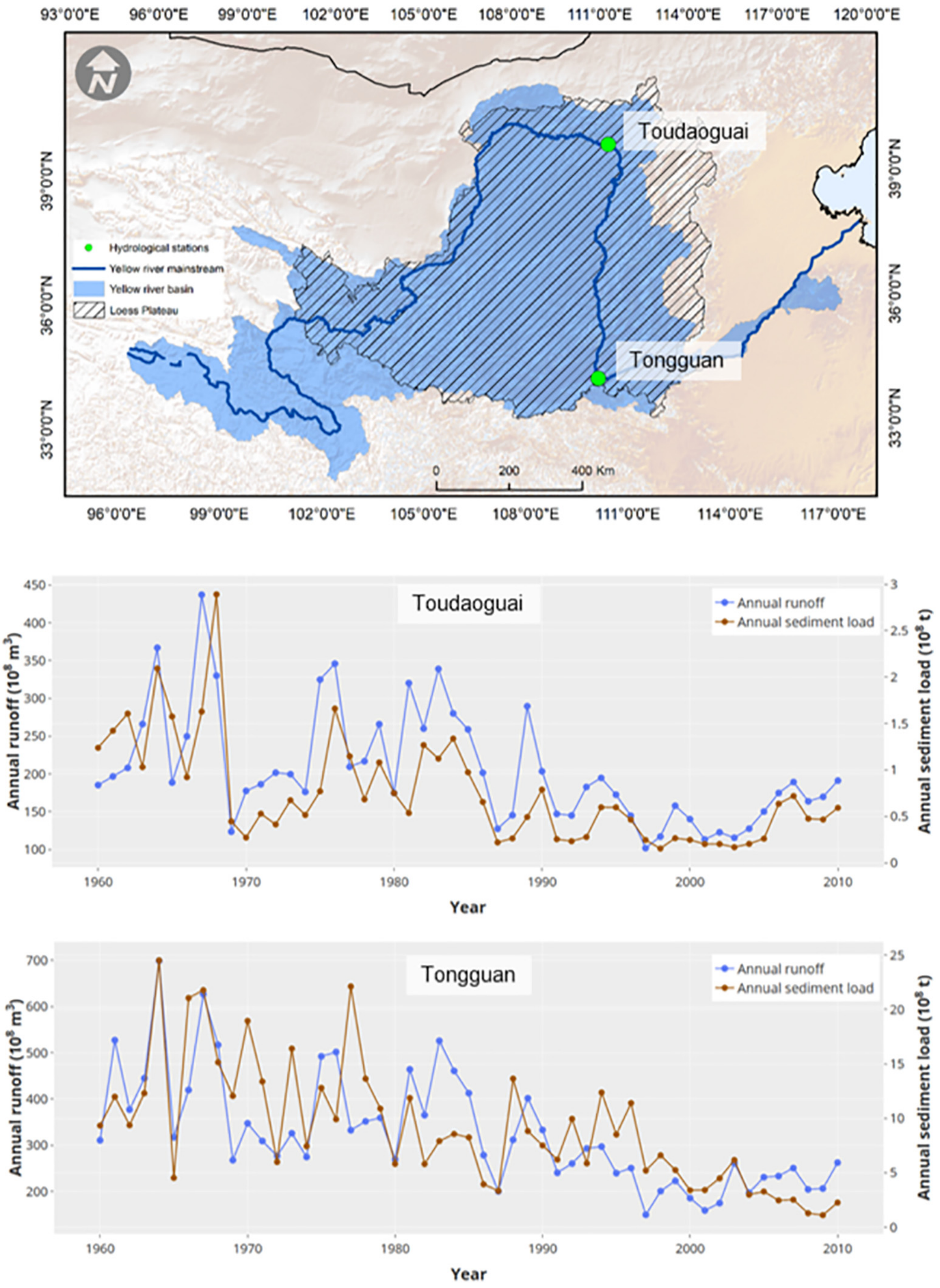

Fig. 5. Trends analysis of annual runoff and sediment yield of two main hydrological stations in main stream of the Yellow River during 1960–2010.
Data source: http://loess.geodata.cn and Yellow River Sediment Bulletin.

sediment load ($Z = -4.70$) had significant decreasing trends, with an annual decrease of 1.57×10^8 m^3 and 0.02×10^8 t, respectively. At Tongguan hydrological station, the annual runoff ($Z = -5.14$) and sediment load ($Z = -6.96$) showed significant decreasing trends, with an annual decrease of 3.76×10^8 m^3 and 0.25×10^8 t, respectively.

3. Special issue contributions

The Chinese Loess Plateau is sensitive to anthropogenic disturbances and climate change (Fu et al., 2017; Feng et al., 2016; Wang et al., 2016). Understanding land degradation and restoration processes in the Loess Plateau offer new insights into the ecological/hydrological/geomorphological implications of regional-scale restoration efforts. In total, we received 17 original contributions. From the methodological point of view, these contributions involve in-situ field observations, laboratory experiments, and modeling studies developed at multiple scales (from hillslope to watershed and regional scales). Specifically, the contributions focus on the following main topics: 1) Soil erosion and conservation; 2) Land use change and its environmental effects; 3) Eco-hydrology, and 4) ES and policy implications.

In terms of the different approaches presented to investigate soil erosion and conservation, Liu et al. (2020a-in this issue) applied meta-analysis to assess the effectiveness of forestland, scrubland, and grassland, in maintaining runoff while reducing soil erosion. The authors reported that grassland may be the best choice for optimizing the trade-off between water yield and soil conservation. Grassland showed the lowest ratios between runoff and sediment reduction. Qi et al. (2020-in this issue) investigated the effects of terracing on the root distribution of *Pinus tabulaeformis Carr.* forest and soil properties in Longtan Watershed. Specifically, vertical and fine root distribution was detected under three terrace types after long-term ecosystem restoration. The authors reported that terracing caused significant differences in root distribution, and at the same time, different roots had different influences on soil properties. Level benches are a more suitable terracing measure for plantation during the ecosystem restoration. Yuan et al. (2020-in this issue), identified that gully erosion increased with rainfall intensity. The gully density was 60% high in cropland hen compared to grassland land use. Yang et al. (2020-in this issue) reported that apple cultivation might not be appropriate for semi-arid region of the Loess Plateau based on soil monitoring. Although apple orchards and ecological plantations both consumed a large amount of deep soil water, from an ecological benefits perspective, the ecological benefits (e.g., soil organic carbon sequestration and water conservation) of apple orchards were lower than those of ecological plantations. Kou et al. (2020-in this issue) observed a severe rill erosion in artificial earth-fill embankments and excavated slopes. Finally, Mi et al. (2020-in this issue) found that long term cultivation (11 years) in reclaimed mine areas increased soil carbon stocks.

In the 'land-use change' category, Shi et al. (2020a-in this issue) investigated the effects of vegetation restoration on soil respiration in Zhifanggou watershed. The authors used isotopes to identify the source of carbon dioxide emissions from soil respiration in four different land-use types: cropland, forest, shrubland, and grassland. The authors reported that soil respiration in the rainy season was significantly higher than that in the dry season. Grassland and forestland had significantly higher soil respiration than shrub and cropland in the rainy season. Roots were the primary source of soil respiration in cropland. Zhang et al. (2020c-in this issue) assessed the relationship between the change of erosion rate and the migration process of heavy metals in soil. The authors reported that land use and soil erosion were essential factors influencing the redistribution of heavy metals. By optimizing land use patterns and reducing soil erosion, it is possible to control the migration and accumulation of heavy metals in the watershed. Luo et al. (2020-in this issue) studied the spatiotemporal differences in land cover change and found that between 1990 and 2000 topography had a negative impact on agricultural intensification. This effect was also verified in urban areas between 2000 and 2010. Between 2000 and 2015 topography had a positive effect on ecological restoration.

In the 'eco-hydrology' category, Hou et al. (2020-in this issue) used a trait-based approach for investigating the relationship between runoff and vegetation at the hillslope scale. The authors indicated that plant functional structure had different effects on slope runoff at a different stage. At the watershed scale, Zhang et al. (2020b-in this issue) analyzed the effects of vegetation cover on soil moisture across soil profiles (0–180 cm) based on *an* in-situ vegetation-removal experiment. Their results indicated that tall plants with small-leaves and shallow-roots were beneficial for soil water retention and replenishment on flat topographies. Song et al. (2020-in this issue) investigated seasonal plant-available water and fine-root distribution in the 0–8 m soil profile of apple orchards having different stand ages. The authors reported that stand ages and rainfall affected the water balance. They also explained the strategies of soil water use of those apple trees under certain precipitation years. Zhang et al. (2000a-in this issue) applied a partial least square regression (PLSR) approach to investigate the relationship between precipitation extremes and streamflow generation. The authors reported the dominant climatic variables controlling annual streamflow and quantified the contribution of ecological restoration to streamflow reduction. At a basin scale, Liu et al. (2020b-in this issue) proposed a new classification method for instream ecological water demand (IEWD). They developed hydrology–hydrodynamic–habitat model for implementing river ecosystem restoration and aquatic ecosystem management in the Huangshui River Basin. When the IEWD meets the management requirements, the authors reported that its fundamental values may not meet the demand for vital ecological processes. They also suggested that water quality will be involved in analyzing IEWD to accomplish a comprehensive evaluation of water volume in the future. On a regional scale, Wang et al. (2020-in this issue) used the Vegetation Interfaces Processes model and factorial analysis of variance to quantify the evapotranspiration changes croplands and their associated driving factors. The authors reported that increasing evapotranspiration in croplands could be related to agricultural intensification in the region. Three models—Weather Research and Forecasting-Community Land Model 4.0 (WRF-CLM4.0) model, WRF-Noah model, and an empirical Complementary Relationship (CR)—were applied by Xu et al. (2020-in this issue) to estimate regional evapotranspiration in the Agricultural-Pastoral Ecotone in Northwest China (APENC). Their results showed that the WRF-CLM4.0 model and the CR model are more applicable to the APENC than the WRF-Noah model. For regional applications, the CR model can capture the local characteristic and well-suited for data lacking, highly heterogeneous landscapes as the study region.

Finally, concerning the ES and policy implications, Dang et al. (2020-in this issue) used a sustainable livelihood approach and structural equation modeling to compare the livelihood of participants and non-participants of GFGP. According to a household survey, the authors found that GFGP participants suffered from a small reduction in natural capital due to a sharp decrease in their landholdings, but they had much more off-farm income, subsidies, and financial and social assets. The authors summarized the main factors influencing respondents' perceptions of GFGP and provided suggestions to decision-makers.

4. Open questions

Although ecological restoration effects on soil conservation, water resources, and ES have been extensively studied, unresolved questions remain, and new scientific challenges have emerged in the Loess Plateau. Unquestionably, Loess Plateau restoration increased ES regulation (e.g., soil retention, carbon sequestration) (Jiang et al., 2016, 2018). This increase produced a decline of some ES, such as water yield and food production (Feng et al., 2020a). Nevertheless, some questions are still not answered:

1) Both field and satellite, large scale vegetation restoration have taken a toll on the hydrological balance of Loess Plateau. The GFGP expanded vegetation cover, increasing evapotranspiration, reducing water yield reduction, and desiccating the soil. Currently, water demand from current vegetation over the Loess Plateau might have already exceeded the local water supply, and further revegetation might not be sustained (Feng et al., 2016; Ge et al., 2020). Further revegetation over the region is therefore controversial (Chen et al., 2015). At the local scale, GFGP brought some significant benefits such as carbon fixation and soil conservation. However, some trade-offs were observed, including water shortage and the formation of dried soul layers (Zhao et al., 2018). The formation of dry soil layers severely restricted vegetation growth, leading to vegetation degradation in some areas. How the hydrology would be impacted by further vegetation restoration and how much more vegetation could be sustained over the Loess Plateau? Neglecting the answers to these questions can be risky, for example, when assessing the upper threshold of vegetation density in the Loess Plateau (Feng et al., 2016; Zhang et al., 2018). Simulation results indicated that revegetation of the Loess Plateau decreased soil moisture. A large-scale increase in evapotranspiration due to larger leaf area, deeper roots, and higher aerodynamic roughness from planted forests may limit water available for human consumption,

agriculture, and industry. Hence, selecting suitable vegetation species and maintaining the current ecosystem's stability is critical to restoring degraded land. In the special issue, Zhang et al. (2020a-in this issue) proposed a strategy for suitable species selection from the perspective of plant functional traits. The results indicated that tall plants with small-leaves and shallow grass were beneficial for soil water conservation on flat topographies. Yang et al. (2020-in this issue) reported that apple cultivation might not be sustainable based on soil moisture monitoring. Overall, we must take drastic measures to conserve soil by selecting suitable vegetation species with minimal water consumption. Overall, it is very likely that GFGP had a transmutation effect. This hypothesis is based on the idea that the restoration carried out in Loess Plateau did not changed solely the ecological and the human processes, but also disturbed the human-nature coupled ecosystems at multiple scales. For instance, GFGP had positive effects on soil conservation, carbon fixation, and sediment transport. However, negative feedbacks were identified, such as the creation of a dried soil layer, water shortage, and wetland degradation. In this context, it is essential to consider the impacts of restoration practices at different scales to minimize the effects of the trade-offs (Zhao et al., 2018).

2) The increase in vegetation decreased soil erosion and led to reduced sediment transport into the Yellow River. Terracing, combined with revegetation, is among the effective ways to combat land degradation (Wei et al., 2016). The previous study quantified the factors affecting the reduction of sediment before. After ecological restoration, terrace farming and check dams contributed 33% and 21% of the total reduction of sediment, respectively, before GFGP and vegetation restoration dominated that after the GFGP, contributing 57% of the total reduction (Wang et al., 2016). As short-duration (sub-hourly to daily) extreme rainfall events are expected to intensify because of climate change, there are few reports on the response of vegetation and engineering measures to extreme precipitation events and the optimization of technique design is crucial to ensure long-term soil and water conservation (Feng et al., 2020b; Yu et al., 2019). More importantly, how the relationship between water and sediment in a river basin changes under extreme precipitation? Is there any threshold behavior of runoff response or sediment yield change under extreme rainfall conditions at multiple scales? There are still many questions that need to be detected and answered.

3) Vegetation restoration also improved ES (Lü et al., 2012; Li et al., 2016). A recent study reported that soil conservation in this area increased from 9.32×10^8 t in 1999 to 14.31×10^8 t in 2010. Similarly, carbon stock has increased by 79.26×10^4 t in the last ten years. Agricultural production conditions and other ecological construction programs, such as the construction of terraces and check dams, could improve the regional grain supply (Chen et al., 2017; Shi et al., 2020b). To promote the Loess Plateau's sustainable development, China is committing a further investment of around USD 33.9 billion until 2050 (Feng et al., 2016). Human has dramatically altered the landscape, leading to changes in ecosystems and their related services. The relationships among ES can be in the form of trade-offs or synergies. When the provision of one service is offset at the expense of the provision of another, a trade-off occurs. However, when multiple services are simultaneously reinforced, a synergy occurs. Bennett et al. (2009) highlighted that ES are interrelated because of (1) influences of common drivers, or (2) interaction of ES themselves. Slow rural industrialization in the Loess Plateau was the main reason for the decline in the primary industry. Industrial transfer created opportunities for the development of secondary industry, but energy consumption per unit output was about twice the national level. The decline of primary and secondary industries and the slow growth of the tertiary industry led to a decline in the proportion of GDP and GDP per capita. Therefore, sustainable economic growth is still an essential issue in the Loess Plateau.

In order to solve the current environmental problems, it is necessary to understand better the interactions between ES in order to guide policy-makers. To ensure the sustainability of ecological restoration and ES, we aim for the net benefits, or no net loss, at least, to both humans and nature. More effort will be needed to develop in-depth communication with local stakeholders further.

5. Final remarks

LDN is a crucial aspect in achieving sustainable development goals. Ecological restoration projects are an essential contribution to meet this goal. Although reversing land degradation is a critical aspect in sustainable goal 15 (Life on Land)[3] the multiple dimensions of land degradation link this phenomenon directly or indirectly with all the other goals. The next decade will be key to achieve this, and the implementation of the United Nations decade on ecosystem restoration (2021–2030) will have an important role. The aim is high "restoring 350 million of degraded ecosystems by 2030",[4] however, the participation of different actors (e.g., scientists, stakeholders, decision-makers) can make this happen and contribute to the "world that we want". "There is no more time to wait"; we need to reduce our footprint in the ecosystems and land degradation (Pereira, 2020b).

In the Loess Plateau of China, an area that turned green after extensive vegetation restoration, the benefits of restoration depend significantly on how the Loess Plateau is managed, which, at present, is an ongoing process. The articles published in his special number can help not only with the restoration strategies in the Loess Plateau but also with the global vision of environmental protection to achieve United Nations sustainable development goals.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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