The contribution of ecosystem restoration to SDGs in Asian drylands: A literature review

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Abstract

The multiple effects of ecosystem restoration programs deserve attention. After reviewing the social-ecological effects of 23 ecosystem restoration programs in Asia's drylands, we find that these programs mainly contribute to SDGs synergistically, but the tradeoffs between social-ecological effects still exists. Among the five goals of SDG15 (Life on Land), SDG13 (Climate Action), SDG6 (Clean Water and Sanitation), SDG1 (No poverty) and SDG2 (Zero Hunger), 11 programs can synergistically achieve no less than three goals, especially grassland restoration and water diversion in China, as well as water management programs in Israel. However, the contribution of ecosystem restoration programs to SDG15 easily weakens SDG6, SDG1 and SDG2, indicating the competition of land and water between ecosystem restoration and agriculture. To reduce the trade-offs among SGDs caused by ecosystem restoration, we

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propose the social-ecological system research framework of "Dryland Boundary – Water, Food, Energy and Ecosystem Nexus - Meta-coupling – Nature-based Solutions" to guide the implementation of ecosystem restoration programs from four aspects: supply-demand matching, element matching, regional matching and local adaptation.

Keywords: Social-ecological effects; Dryland boundary; Water, Food, Energy and Ecosystem nexus; Meta-coupling; Nature-based Solutions

1 Introduction

Ecosystem restoration is a direct adaptive response to degraded and destroyed ecosystems worldwide (Aronson *et al.*, 2020; Waltham *et al.*, 2020; Zou *et al.*, 2020). Considering the importance of ecosystem restoration to sustainable development, the United Nations declared 2021-2030 the "Decade on Ecosystem Restoration" to tackle global ecosystem degradation and called for intensified efforts at the national level to achieve the Sustainable Development Goals (SDGs), especially the land degradation zero growth target (Aronson *et al.*, 2020; Cowie *et al.*, 2018; Dubey *et al.*, 2020; Lu *et al.*, 2019; Peng *et al.*, 2020). This plan aims to launch a global campaign to carry out extensive and in-depth ecological restoration work, curb land degradation and biodiversity loss (Ambe & Obeten, 2020).

Drylands account for 41% of the global terrestrial area (Feng & Fu, 2013) and support over 38% of the world's people (Huang *et al.*, 2017). Dryland systems are vulnerable due to low water availability, long-term drought stress and increasing human pressure (Fu *et al.*, 2021). Under the continuous influence of global climate change and human activities (Huang *et al.*, 2016), the sustainability of the social-ecological system in drylands faces multiple challenges, such as poverty, food shortages, water resource limits, and extreme climate and biodiversity losses (Fu *et al.*, 2021; García-Vega & Newbold, 2020; Reynolds *et al.*, 2007; Wang *et al.*, 2012). Thirty four percent of the world's drylands are located in Asia, accounting for nearly half area of this continent (Miao *et al.*, 2015). Asia experienced the largest increases in dryland areas, and water shortages in Asian dryland got worse (Prăvălie *et al.*, 2019). Asian drylands are distributed in 38 countries, and most of which are developing countries (Prăvălie, 2016). People are very dependent on land, while the land degradation problems in China, Iran and other countries have harmed the interests of local residents (Hashemimanesh & Matinfar, 2012; Qu *et al.*, 2007). In the past few decades, multiple pressures, such as regional climate change, the demand for food production and urban sprawl, have caused severe degradation of the ecosystem in Asian dryland, posing a major threat to regional sustainable development (Lal, 2002; Qi *et al.*, 2012). Therefore, it is necessary to explore the sustainable development in Asian drylands.

To restore deteriorating ecosystems, countries in Asia's drylands have carried out a series of ecosystem restoration programs involving forest restoration, grassland protection, combating desertification and securing water resources in recent years(Daeseob & Gyumi, 2016; Delang & Wang, 2013; Khalilimoghadam & Bodaghabadi, 2020; Tal, 2006; Yin *et al.*, 2019). These programs promote several SDGs. The forest coverage rate in the Three North Area of China increased from 5.05% in 1978 to 13.57% in 2018 benefited from Natural Forest Protection Program, which contribute to SDG15 (Li *et al.*, 2012). Water diversion brings water for production and for living in the southern Negev Desert, promoting regional industrial and agricultural development (Tal, 2006). The Grain for Green program in China transforms the land constraints on households and accelerates the transfer of labours to non-agricultural sectors (Uchida et al., 2009), and the average household income has increased by more than 250% (Yin et al., 2014). These ecosystem restoration programs are often designed for a single goal, either for grassland restoration or for water resource security, while this single goal may have positive or negative impacts on the other SDGs.

Previous evidence on the contribution of ecosystem restoration in Asia's drylands is not enough to judge the integrated contribution of ecosystem restoration to SDGs. Therefore, we propose the scientific question: what are the comprehensive effects of ecosystem restoration to SDGs from the perspective of synergy and tradeoff? We start with the following three points: first, sort out major ecosystem restoration programs in Asia's drylands by classification; second, summarize the positive or negative effects of ecosystem restoration on the SDGs; and finally, propose a coupled social-ecological system research framework to support the accelerated realization of the SDGs in Asia's drylands.

2 Ecosystem restoration approaches in Asia's drylands

Many Asian countries, especially China, Mongolia, Iran and Israel, have carried out a series of ecosystem restoration programs in drylands (Fig 1, Table A1), we conduct literature search by searching "Asian", "dryland", "afforestation", "desertification control/ combating”, “water diversion/ safety”, “irrigation”, “ecosystem restoration”, “SDG”, “social-ecological effects”. More details about the ecosystem restoration programs are in Table A1.

2.1 Natural forest restoration programs

Forests play an important role in biodiversity richness, climate regulation, carbon storage, and the water cycle (Hansen *et al.*, 2013). The Chinese government implemented Natural Forest Protection (P13) in 1988 to ban or reduce natural forest logging (Bryan *et al.*, 2018; Delang & Wang, 2013; Liu *et al.*, 2008). Iran implemented the Zagros Forest Preservation Plan (P17) in 2003 (Beygi zHeidarlou et al., 2019), aiming to reduce forest destruction, protect habitats, improve the status of protected forests, and promote sustainable forest management (Heidarlou *et al.*, 2020). Due to the differences in local participation and acceptance, the Zagros Natural Forest Preservation Plan in Iran is far from reaching the expected ecological goals.

2.2 Planted forest construction programs

Planted forests are another important means of forest restoration. Israel's forestation program could date back to 1948 (P1), and Israel handed over all afforestation tasks to the Jewish National fund (hereinafter KKL) in 1961, which became the only afforestation agency in Israel (Amir & Rechtman, 2006; Stavi *et al.*, 2015; Tal & Gordon, 2010). Most of these forests are located in Galilee and northern Negev, this program provided a source of employment for settlers and have raised settlers’ incomes (Amir & Rechtman, 2006). In 1965, Iran initiated the wind and sand control program

(P7) for desertification combating by planting trees (Hashemimanesh & Matinfar, 2012). Mongolia started afforestation activities (P9) in 1971 (Tsogtbaatar, 2013) and carried out the Greenbelt Planation Project (P20) from the east to the west in southern Mongolia from 2007 to 2016 to reduce the damage to the environment by wind and sand, and this has made prominent contributions to desertification control (Daeseob & Gyumi, 2016). China implemented the Three North Shelterbelt (P11) in 1978 and Grain for Green (P14) in 1999 that greatly increased the regional vegetation coverage; the former program mainly aimed at wind prevention and sand control, and the latter focused more on regional water supply and soil conservation (Cao *et al.*, 2020; Deng *et al.*, 2014). Due to the differences in the original purposes of building plantations in various countries, the other social-ecological effects contributed by planted forests are regionally different. Specifically, P1 paid attention to the employment of settlers. Mongolia and Iran's afforestation contributed much for wind prevention and sand fixation, while China's Grain for Green focused on soil and water conservation.. Although the abovementioned plantation projects have significantly increased vegetation coverage and contributed to SDG15 and SDG13, they failed to slow or reverse biodiversity loss (Zhang *et al.*, 2020).

2.3 Grassland restoration programs

Overgrazing of destroyed grasslands has reduced the productivity and resilience of grasslands (Huang *et al.*, 2013) and further caused soil erosion and desertification (Wang *et al.*, 2018). To restore these increasingly degraded grassland systems, China, Iran and the Central Asian countries have implemented a series of grassland restoration programs. In 2003, China launched Returning Grazing Lands to Grasslands (P18), demanding that grazing be prohibited on severely degraded pastures (Hao et al., 2014). For the win-win achievement of grassland protection and the improvement of the lives of herders, China further implemented the Grassland Ecological Protection Award Policy (P22) in 2011, aiming at reducing the amount of livestock by subsidizing farmers (Yin *et al.*, 2019). In 2010, Iran launched the Restoration-rangeland Ecological Program (P21) that enclosed more than 2,000 hectares of dry pasture in Taftan and banned grazing to restore the regional pasture (Ebrahimi *et al.*, 2016). Currently, the mainstream approach of grassland restoration is grazing exclusion or rotational grazing, which may reduce the income of herders and cause problems such as secret grazing.

2.4 Desertification combating programs

The global desertification area accounts for 24.1% of the land area (Wang *et al.*, 2013), which seriously threatens the sustainability of regional social-ecological systems. In the past few decades, countries in Asia's drylands have implemented several combating methods, including vegetation sand control, chemical sand fixation, and engineering sand control. Vegetation sand control refers to combating sand by increasing vegetation coverage, mostly through forest restoration and grassland restoration. For example, after nearly 70 years of desertification combating in Mu Us Sand Land in China, 93.24% of the sand land has improved, the forest coverage rate has reached 34.8%, and the average annual desertification reversal rate has reached 1.62%

(Ding *et al.*, 2021). For chemical sand fixation, Iran carried out dune fixation (P3, P8) using petroleum products (Hashemimanesh & Matinfar, 2012) and that was then supplemented by vegetation restoration (Azoogh *et al.*, 2018; Khalilimoghadam & Bodaghabadi, 2020). In terms of engineering sand control, China used straw checkerboards to prevent near-surface sand flow by increasing surface roughness, reducing surface wind speed, and reducing sand transport intensity in the 1960s (P5) (Qu *et al.*, 2007; Zhang *et al.*, 2018b). Accordingly, chemical sand control and engineering sand control mainly stabilize quicksand and reduce the amount of sand in the air. In comparison, vegetation sand control reduces the sand transport capacity of wind by reducing the wind speed while making a positive contribution to vegetation coverage.

2.5 Water resources security programs

Water shortages are a severe limiting factor for sustainable development in drylands (Huang *et al.*, 2016; Mohammadinezhad & Ahmadvand, 2020). To alleviate the negative impact of water shortages on the social-ecological system, countries in Asia's drylands implemented water diversion and water collection projects, as well as technological innovations to improve water resource utilization efficiency. In 1964, Israel carried out Water Transport (P6), which transported water from relatively wet northern Galilee to arid southlands. To restore the ecosystem downstream of the Heihe River and Tarim River in China, the Ecological Water Diversion Project (P15) in the Heihe River Basin, the Tarim River Basin Ecological Water Conveyance Project (P16) and the Comprehensive Management Program (P23) in the Tarim River basin were implemented in 2000, 2001 and 2011, respectively (Chen et al., 2011; Ling et al., 2016; Zhang et al., 2018). Since the 1980s, Israel has established 178 reservoirs (P12) throughout the country for rainwater harvesting that has increased the water supply (Tal, 2006). The Paddy Land-to-Dry Land program (PLDL) (P15) was implemented in 2006 to ensure water resource security in Beijing(Yang *et al.*, 2020). Technological innovation also plays a key role in water security, e.g., Israel vigorously developed wastewater reuse (P2) and drip irrigation (P4) to improve water use efficiency (Ouda, 2016; Tal, 2006). Water resources projects in Israel mostly address agricultural production goals, while the Heihe River and Tarim River water resources projects focus more on ecological restoration goals that mainly included improving vegetation coverage, increasing downstream water supply and reducing desertification (Ling *et al.*, 2019; Tan *et al.*, 2011; Zhang *et al.*, 2018a), and the water resources projects in Saudi Arabia and Beijing are more for production and living purposes. The differences in social and ecological purposes of water resource projects may cause differentiated SDG effects.

3 The effect of ecosystem restoration programs to the SDGs in Asia's drylands

The contribution of ecosystem restoration to SDGs has synergistic effects (Fig 2). Carbon sequestration effect of vegetation links SDG15 with SDG13, as vegetation restoration not only increases natural vegetation coverage but also alleviates the negative impact of the greenhouse effect. Water safety projects have positive impacts on the social-ecological system by increasing the water supply for ecological restoration and agricultural production, which is a synergy of SDG1, SDG6 and SDG15. In addition, ecosystem restoration can promote the realization of SDG1 and SDG2 by paying for ecosystem or eco-industry development.

However, there are also tradeoffs among SDGs in ecological restoration projects (Fig 2). The tradeoffs mainly include the conflict between ecological land and cultivated land, and the conflict between ecological water and agricultural water. On the one hand, the increase in ecological land reduces land available for agriculture, causing the constraints of SDG15 on SDG1 and SDG2. On the other hand, vegetation restoration projects, especially plantations, consume plenty of water that increases the water conflicts between food-energy-ecosystems.

3.1 Synergy effect of the ecosystem restoration program to SDGs in Asia's drylands

We summarize four main paths to promote the coordinated realization of SDGs in Asia's drylands based on ecosystem restoration (Table 1). The first is the integrated improvement of the social-ecological system based on water safety programs, showing the collaborative realization of SDG15-SDG13-SDG6-SDG1-SDG2. The second is the positive impact on the social-ecological system based on payment for ecosystem, reflecting the synergy effect of SDG15-SDG13-SDG1-SDG2. The third is socioeconomic promotion based on the development of water-saving agriculture, which indicates the collaborative realization of SDG6-SDG1-SDG2. The fourth is the positive effects of clean drinking water projects within the synergic contribution of SDG6-

SDG1.

3.1.1 Synergy achievement of SDG15-SDG13-SDG6-SDG1-SDG2 through eco-water projects

Since the 1980s, Israel launched rainwater harvesting (P12) to support agriculture, landscape irrigation and household cleaning(Al-Batsh *et al.*, 2019; Almazroui *et al.*, 2017). For 2010, the forest area in the Negev was approximately 23,000 hectares of which a considerable part is supported by rainwater harvesting(Stavi *et al.*, 2015). In addition, rainwater harvesting increased irrigation water, assisting to increase crop yields and income for local households (Al-Batsh *et al.*, 2019). The Ecological Water Diversion Project in the Heihe River Basin in China (P15) made 57.82% of the upstream water discharge downstream. Groundwater level downstream obviously increased, at the end of 2010, the terminal lake had gradually expanded to 50 km^2, and forest areas in the middle and lower reaches had increased by 13.2 km^2, 4.62 km^2, respectively (Zhang et al., 2018). The arable land downstream increased from $1.09×10^3$ to $4.45×10^3$ ha between 2000 and 2007, which promoted regional crop yields and contributed to SDG2 (Zhang et al., 2018). The added value of the secondary and tertiary industries increased from $1.02×10^8$ CNY in 2000 to $39.4×10^8$ CNY in 2015, which promoted the realization of SDG1. In China's Tarim River basin, P16 and P23 direct 350 million cubic metres of water flow downstream (Ling *et al.*, 2016). From 2010 to 2016, the GDP of the headwaters of the Tarim River and the mainstream areas increased by 15.8% and 6.0%, respectively(Ling *et al.*, 2019). Due to the increase in water supply, and the coordinated development of SDG15, SDG13, SDG6, SDG1, and SDG2 has been achieved.

3.1.2 Synergy achievement of SDG15-SDG13-SDG1-SDG2 through payment for ecosystem

After Grain for Green (P14) was implemented in the Loess Plateau of China, 16000 km^2 of rain-fed farmland was converted into woodland or grassland from 2000 to 2010, which increased the vegetation coverage by 25%(Feng *et al.*, 2016), and positively contributed to carbon sequestration(Feng *et al.*, 2013). In terms of farmers possessing farmland at high altitudes and with steep slopes, the subsidy is higher than the direct income on sloped farmland (Liu *et al.*, 2009). Thanks to agricultural technological advancement, from 1998 to 2014, food crop production in the entire Loess Plateau increased by 1.71% per year on average (Lyu & Xu, 2020). In addition, the Chinese government is actively increasing residents' income through payment for ecosystem. From 1999 to 2008, China invested more than 430 billion CNY, directly benefiting 120 million farmers in 30 million households across the country (Liu *et al.*, 2008; Liu, 2020; Shi & Wang, 2011).

Returning Grazing Lands to Grasslands (P18) and the Grassland Ecological Protection Award Policy (P22) accelerated the co-realization of SDG15, SDG13, SDG1, and SDG2. On the one hand, carbon sequestration has increased through vegetation restoration. In the process of grassland restoration in Inner Mongolia, northern China, vegetation coverage increased by 52% (Xiong *et al.*, 2016). The total NPP of the Inner Mongolia grassland increased by 29,432.71 Gg C yr^{-1} during 2001–2009, and 80.23%

of that benefit was from human management (Mu *et al.*, 2013). On the other hand, regional income levels and crop yields have increased through payment for ecosystem. During the Twelfth Five-year Plan Period, the central government invested 77.4 billion CNY and entered the first phase of grassland payments (Zhang *et al.*, 2019). In grazing exclusion areas, intensive corn production has increased crop yields and eliminated the negative effects of grazing exclusion on animal husbandry, promoting SDG2 (Dai, 2010).

Benefiting from the afforestation project (P1), as of 2006, Israel's planted forests covered an area of 90,000 hectares, accounting for 4.2% of the country's area (Amir & Rechtman, 2006), mitigating the greenhouse effect (Rotenberg & Yakir, 2010; Tal & Gordon, 2010). Since Israel widely carried out afforestation, unemployed residents have been hired to work in tree planting and forest maintenance. Available job opportunities significantly increased the income level of poor people (Rueff *et al.*, 2008), promoted regional SDG1 (Tal & Gordon, 2010).

3.1.3 Synergy achievement of SDG6-SDG1-SDG2 through agricultural development

Wastewater Reuse (P2) and Water Transport (P6) in Israel increased the supply of fresh water for agricultural development. As of 2015, nearly 86% of wastewater was treated and used for agricultural irrigation, providing 50% of the country's irrigation and contributing to the increase in arable land and crop yields water (Tal, 2016). Drip irrigation (P4) has greatly improved the productivity per unit of water (Orlovsky, 2008), helping to obtain higher potato yields in the Arava Desert, Israel (Trifonov *et al.*, 2017).

Drip irrigation improved the value of local agricultural products by 160%, increasing household income (Tal, 2016). The development of water-saving agriculture has promoted organic and greenhouse agriculture in the Negev Desert, Israel, contributing to regional income (Fleischer *et al.*, 2008; Orlovsky, 2008; Rohit Katuri *et al.*, 2019; Shelef *et al.*, 2016). In summary, technological advances facilitated the synergy of SDG6, SDG1, and SDG2 through the development of water-saving agriculture.

3.1.4 Synergy achievement of SDG6-SDG1 through clean drinking water and payment for ecosystem

To ensure the quality and quantity of the water supply for Beijing, China, Paddy Land-to-Dry Land (P19) was implemented in 2006. Benefiting from this project, the irrigation water consumption upstream of the Miyun Reservoir dropped obviously, and the water storage of the reservoir gradually increased, reaching 1.214 billion m^3 in August 2013 (Yang *et al.*, 2020; Zheng *et al.*, 2013). To compensate for the loss of agricultural income of upstream farmers due to the decrease in rice production, PLDL project provided ecological payments to participators from 450 CNY per mu per y in 2006 to 550 CNY per mu per y in 2008 (Zheng *et al.*, 2013). This program achieved a win-win situation between SDG6 and SDG1.

3.2 Tradeoff effect of ecosystem restoration programs to SDGs in Asia's drylands

Ecosystem restoration programs have multiple tradeoff effects on the SDGs. Here, we summarize two principal cases. One is land-use conflicts, which is reflected in the negative relationship between SDG15 and SDG2, as well as between SDG15 and SDG1.

Second is the increase in ecological water consumption, causing the decrease in agricultural and domestic water supply, causing a negative impact of SDG15 on SDG6, as well as SDG15 on SDG2.

3.2.1 Tradeoff effects of the SDGs caused by land use conflicts

The transformation of agricultural land to ecological land in ecosystem restoration may have some negative impacts on rural livelihoods. Farmland sloping at greater than 15° covered 2.52 Mha on the Loess Plateau, which qualified under the Grain for Green restriction, while vegetation restoration reached 4.83 Mha by 2008(Chen *et al.*, 2015).The rapid reduction in cultivated land would inevitably affect the local food. After grazing exclusion, forage prices increased from 200 to 450 CNY per bale, increasing the cost of animal husbandry in northern China (Lan *et al.*, 2020), indicating the negative effect of SDG15 on SDG1. The poorer farmers and herdsmen are, the more likely their income is to be negatively affected (Cao *et al.*, 2010). Therefore, successful and sustainable ecosystem restoration should not only improve the environment but also increase the well-being of rural households (Yang *et al.*, 2020). A comprehensive consideration of multiple geographic processes, including natural and social processes, is required to promote the integrated sustainable development of the social-ecological system (Fu, 2020).

3.2.2 Tradeoff effects of the SDGs caused by water resource conflicts

The available water in drylands supporting food production, energy processing, economic development and ecosystem stability is limited. Vegetation restoration, especially plantation forests, consume large amounts of water that may enhance the water conflict between different sectors. Farley *et al.*, (2005) emphasize that afforestation of grasslands and shrublands could reduce runoff and may be most severe in drier regions. In Israel, the water yield of unforested areas in the arid and semiarid areas was 69 mm, while afforestation reduced the water yield by 51 mm (Rohatyn *et al.*, 2017). The average consumption rate of terrestrial water storage by ecosystem restoration in the Mu Us sandy land is 16.6±5.0 mm yr^{-1}(Zhao *et al.*, 2020), which represents the constraint between SDG15 and SDG6. Due to the increase in downstream of Heihe River ecological water consumption, the average groundwater level has continuously declined by a total of 5.8m from 2000 to 2010 in the middle reaches, which reduced the water available for production and life (Zhang *et al.*, 2018a). Feng *et al.*, (2016) estimated a threshold of NPP of 400 ± 5 g Cm^{-2} yr^{-1} above which the population would suffer water shortages in the Loess Plateau. In addition, forests compete for limited water resources for food production, threatening regional food security (Rohatyn *et al.*, 2017), which is the negative effect of promoting SDG15 on SDG2. Insufficient surface water causes a drop in the groundwater level, which threatens the sustainability of regional water resources.

4 Perspectives in achieving the SDGs in Asia’s dryland ecosystem restoration projects based on social-ecological system research

To reduce land use conflicts and water resources conflicts and promote the realization of multi-goals of SDGs contributed by ecosystem restoration programs in drylands, we proposed a research framework based social-ecological system that comprehensively considered the “Dryland boundary - Water-Food-Energy-Ecosystem (WFEE) nexus - Meta-coupling – Nature-based Solutions (NbS) (Fig 3)”. The Dryland boundary requires determining the upper limit of the resource supply in drylands, controlling the size and intensity of ecological restoration within the capacity of dryland systems from the supply-demand match. WFEE requires the coordinated achievement of the SDGs from the matching of the elements based on ecosystem restoration. Meta-coupling encourages ecosystem restoration to make positive contributions to the SDGs at multiple spatial scales. The positive effects on SDGs at a certain spatial location should minimize the negative impact on the SDGs at the near or far places connected to it. Dryland boundary conveys thinking about matching supply-demand, which is the threshold basis for matching the multi-elements in WFEE and multi-places in meta-coupling. WFEE clarifies the multielement match requirements for the Dryland boundary and meta-coupling. Meta-coupling puts forward multi-spatial scale match requirements on the Dryland boundary and WFEE. NbS requires the implementation of ecological restoration in drylands based on natural conditions and emphasizes the native adaptability of ecosystem restoration, that is, the suitability of ecosystem restoration to local ecosystems and the acceptance of ecosystem restoration by local society. Considering the local differences in the structure and function of the social-ecological system in drylands, the spatial heterogeneity in Dryland boundary, WFEE, and meta-coupling in drylands is obvious. NbS is a sustainable local practice under the scientific basis of the Dryland boundary, WFEE, and meta-coupling.

4.1 Dryland boundary

Planetary boundaries define the "safe operating space" for humans, identifying levels of anthropogenic perturbations below which the risk of destabilization of the Earth system is relatively low (Steffen *et al.*, 2015). Because of the vulnerability of dryland, it is very important to identify dryland boundary, which is the up limits of ecosystem restoration. First, to identify the freshwater use boundary. Ecosystem restoration should fully consider the regional freshwater supply capacity, treating SDG6 as the basis for the other SDGs in drylands(Falkenmark, 1997). Second, to identify the land-use boundary, including land suitability and capacity. The ability of the land to provide services for the social-ecological system is finite, especially when water and nutrients are relatively insufficient. Going beyond the land resource capacity will cause land degradation in drylands. The amount of land suitable for forests, grasslands, shrubs, construction, and farmland is dynamically balanced within a certain range in Asia's drylands, while quantifying the upper limits of land suitable for each land type is a major difficulty(Zhao *et al.*, 2006). The third is to clarify the CO_2 boundary. Since there is a large annual change in global carbon sinks in drylands(Yao *et al.*, 2020), the role of drylands in the global carbon neutrality goal is still unclear. Quantifying the carbon budget in Asia's drylands will be a major challenge in promoting SDG13 based on ecosystem restoration. In summary, clarifying the boundaries of water, land, and CO_2 in drylands from the perspective of supply and demand, assists ensuring that ecosystem restoration is carried out within the safe operation space of drylands.

Feng et al. (2016) pointed out that revegetation on the Loess Plateau is approaching sustainable water resource limits. The research viewpoint is that afforestation led to an increase in NPP and evapotranspiration (ET), further causing reductions in soil water, groundwater, and runoff. Since most restoration policies have not considered dryland boundaries as restrictions on ecosystem restoration in Asia's drylands, Feng's study provided a solution and method to estimate water boundaries in drylands.

4.2 Water-Food-Energy-Ecosystem nexus

The increasing population in drylands has great demands for water, food and energy and high requirements for ecosystem services, making the connections among water, food, energy, and ecosystems closer (Grizzetti *et al.*, 2016; Martinez-Hernandez *et al.*, 2017). The water-food-energy-ecosystem nexus concurrently considers multiple sectors and their internal connections (Strasser *et al.*, 2016), contributing to avoiding mutual restrictions between departments. To clarify the internal relationship among the water-food-energy-ecosystem in drylands, we consider the following two aspects. The first is to quantify the water demands for ecosystem, food, and energy in drylands, which deserves further attention and discussion. The second is to identify the equilibrium point among ecosystems, food production, and domestic water consumption to integrate and meet social and ecological needs. The relationships among ecosystems, food, and energy water are likely a seesaw; we should identify balance points and priorities. Carrying out ecosystem restoration based on WFEE while focusing on the water conflicts among ecosystem, food and energy, can contribute to the synergy among SDG1, SDG2, SDG6, and SDG15. The multielement equilibrium of water, food and energy is often identified in models. For example, Vinca et al., (2020) applied the NExus Solutions Tool (NEST), which integrates multiscale energy, water, and land resource optimization with distributed hydrological modelling in the Indus River basin to avoid counterproductive interactions among the sectors. The NEST model clarifies the conflict between ecosystems and agricultural production based on the water connection. Although the study has not quantified the equilibrium points of water consumption, it provides a model reference for ecosystem restoration to promote multielement matches in drylands.

4.3 Meta-coupling

Ecosystem restoration affects social-ecological systems at multiple scales through the form of material flow, information flow and energy flow. Clarifying the multispatial scale effects of ecosystem restoration in drylands is the key to achieving the synergy of the SDGs across regions. For example, water delivery in drylands may increase the water supply downstream while reducing the water supply midstream and upstream (Zhang et al., 2018). The development of greenhouse agriculture in the desert of Israel is remotely connected to Europe and Africa through trade chains (Fleischer *et al.*, 2008). Meta-coupling is helpful to grasp the comprehensive effects of ecosystem restoration on internal systems, peri-systems, and tele-systems. It provided a way to avoid the spatial tradeoffs of ecosystem restoration effects, and had the potential to promote the synergy of the SDGs on multiple spatial scales (Liu, 2017). We introduce meta-coupling thinking to research the inner connection of social-ecological systems in drylands. The meta-coupling framework, including intra-coupling, peri-coupling and tele-coupling, can help reveal hidden system connections at multi-spatial scales, such as spillover effects and feedback (Liu, 2017; Liu *et al.*, 2007). The intra-coupling refers to human and natural interactions in a coupled social-ecological system, reflected as farming, grazing, fuelwood collection, human settlements, and freshwater access. For example, the effect on grazing by grassland restoration and the impact of wind-sand control on human settlements. Peri-coupling and tele-coupling are defining according the distance to the inner system, such as herdsman migration, payment for desertification control, virtual water in trade, dust flow, water transfer, and cross-border investment in a river basin. For example, the carbon sequestration of vegetation restoration affects global carbon concentration through atmospheric circulation.

4.4 Nature-based Solutions

Nature-based Solutions are defined as actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham *et al.*, 2016; Zheng *et al.*, 2019). Human-induced ecosystem restoration is used as an external input to the original ecosystem. How to assist the restoration integrate into the natural system is the key to the success of program. We introduce Nature-based Solutions to ecosystem restoration in drylands, including two aspects: local suitability and participation of local residents.

Local suitability emphasizes that the structure, and functions of ecosystem restoration should match the natural conditions of the local ecosystem.. For example, compared with large-scale plantations, natural forest protection is more suitable for natural ecosystem restoration in drylands (Ren *et al.*, 2015). The introduction of pioneer species in response to desertification control may lead to local natural vegetation degeneration and destroy local natural ecosystems(Cao *et al.*, 2010). Such restoration did not help original system more adaptable and resilient. The participation of local residents referred to pay attention to the role of local residents in ecosystem restoration. Ignoring the participation of local residents in ecosystem restoration often results in conflicts between ecological restoration and residents' livelihoods so that ecosystem restoration cannot achieve the expected goals. For example, preservation in the Zagros Forest of Iran has not achieved the expected protection goals: after conservation in 2003, the deforestation rates were 0.4% and 0.5% from 1993 to 2002 and from 2003 to 2017, respectively (Heidarlou *et al.*, 2020). The deforestation of forests closer to rivers, cities, and roads was more severe because the implementation of the conservation project could attract the participation of local people, and illegal logging by local residents for timber and grain was serious (Heidarlou *et al.*, 2019).

Achieving regional and local ecosystem restoration goals should take the potential needs of people for residing, producing, living, and obtaining natural resources into account. Nature-based solutions advocate leaving space for the adaptability and resilience of a social-ecological system, which strengthens the following two aspects of dryland research. First, strengthen research on the structure and function of the social-ecological system in drylands. Affected by the availability of local water, the structures (such as landscape patterns and livelihood models) and functions (such as ecosystem services and social communication) of drylands vary in different geographical locations (Fu *et al.*, 2021). Clarifying these regional differences can inform ecosystem restoration depending on local conditions and finally build a social-ecological system with certain resilience and stability from ecosystem restoration. Second, strengthen the research on the relationship of supply and demand of ecosystem services in drylands under the changing nature and society (Fu *et al.*, 2013). In summary, relying on ecosystem restoration with NbS thinking is a chance to break the vicious circle between ecological degradation and poverty in drylands and contribute to integrated sustainable development in social-ecological systems.

5 Conclusion

Drylands in Asia are concentrated and contiguous, with the total area ranking first on all continents in the world. It is necessary to reverse the degradation of ecosystems and enhance human well-being based on systematic ecosystem restoration in these regions. By combining the contributions of ecosystem restoration to the SDGs in Asia's drylands, we found that ecosystem restoration improved vegetation coverage, desertification, and regional water shortages, which contributed to SDG15, SDG13, and SDG6. Moreover, ecosystem restoration improved the income level and food security of participants through intensive agriculture and technological advancement, promoting the realization of SDG1 and SDG2. However, the decreases in production and income due to land-use conflicts result in tradeoffs between SDG15 and SDG2, as well as between SDG15 and

SDG1. In addition, ecosystem restoration caused a decrease in water for production and domestic supply, which was reflected in the negative impact of SDG15 on SDG6 and of SDG15 on SDG2. To minimize the tradeoffs in multi-SDGs affected by ecosystem restoration, we proposed a framework of “Dryland boundary – WFEE - Meta-coupling – Nature-based Solutions” to promote social-ecological system research in drylands. The tradeoff and synergy analysis of SDGs presented in this study can also be extended to combine global dryland SDG relationships in future research. By strengthening the research on the social-ecological system to support future ecosystem restoration work in drylands, it is expected to achieve a win-win situation of ecosystem health and social development.

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Table 1. Synergy effect of SDGs in ecological restoration programs

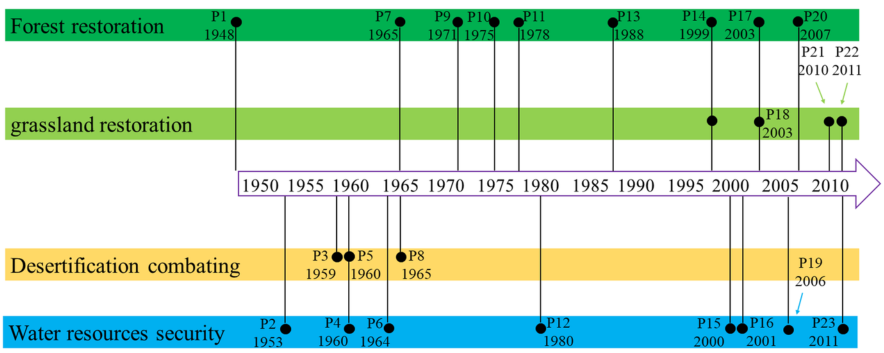
Synergy effects among SDGs	Program
SDG15-SDG13-SDG6-SDG1-SDG2	P12, P15, P16, P23
SDG15-SDG13-SDG1-SDG2	P1, P14, P18, P22
SDG6-SDG1-SDG2	P2, P4, P6
SDG6-SDG1	P19

Note: P1 Afforestation of KKL in Israel. P2 Wastewater Reuse in Israel. P4 Drip irrigation in Israel. P6 Water Transport in Israel. P12 Rainwater Harvesting in Israel. P14 Grain for Green Program in China. P15 Ecological Water Diversion Project in Heihe River Basin, China. P16 Tarim River Basin Ecological Water Conveyance Project in China. P18 Returning Grazing Lands to Grasslands in China. P19 Paddy Land-to-Dry Land program (PLDL) in China. P22 Grassland Ecological Protection Award Policy in China. P23 Comprehensive Management Program in the Tarim River basin, China.

Figure 1. Ecosystem restoration programs for forests, grasslands, water and desertification in Asia's drylands. P1 Afforestation of KKL in Israel. P2 Wastewater Reuse in Israel. P3 Desertification combating in Khuzestan, Iran. P4 Drip irrigation in Israel. P5 Straw Checkerboards in China. P6 Water Transport in Israel. P7 Afforestation in Iran. P8 Petroleum Mulching-Biological Fixation (PM-BF). P9 Afforestation in Mongolia. P10 Reforestation and Protection in Iran. P11 Three North Shelterbelt Project. P12 Rainwater Harvesting in Israel. P13 Natural Forest Protection Program in China. P14 Grain for Green Program in China. P15 Ecological Water Diversion Project in Heihe River Basin, China. P16 Tarim River Basin Ecological Water Conveyance Project in China. P17 Zagros Forest Preservation Plan (ZFPP) in Iran. P18 Returning Grazing Lands to Grasslands in China. P19 Paddy Land-to-Dry Land program (PLDL) in China. P20 Greenbelt Planation Project in Mongolia. P21 Restoration-rangeland Ecological Program in Iran. P22 Grassland Ecological Protection Award Policy in China. P23 Comprehensive Management Program in the Tarim River basin, China.

Figure 2. Effect of ecosystem restoration program on the SDGs Asia's drylands. The red solid line indicates the positive effects, and the red dotted line indicates the negative effects. The green circle represents the ecosystem, and the grey circle represents the social system. The blue dotted arrow indicates the overflow effects of the ecosystem restoration programs. "synergy effect" is defined as an ecological restoration project that has a positive effect on two or more SDGs; "trade-off effect" is defined as an ecological restoration project that promotes one or some SDG(s) but restricts other SDGs.

Figure 3. The framework of social-ecological system research with minimum tradeoffs and maximum synergy for the SDGs achieved by ecosystem restoration projects in Asia's drylands.



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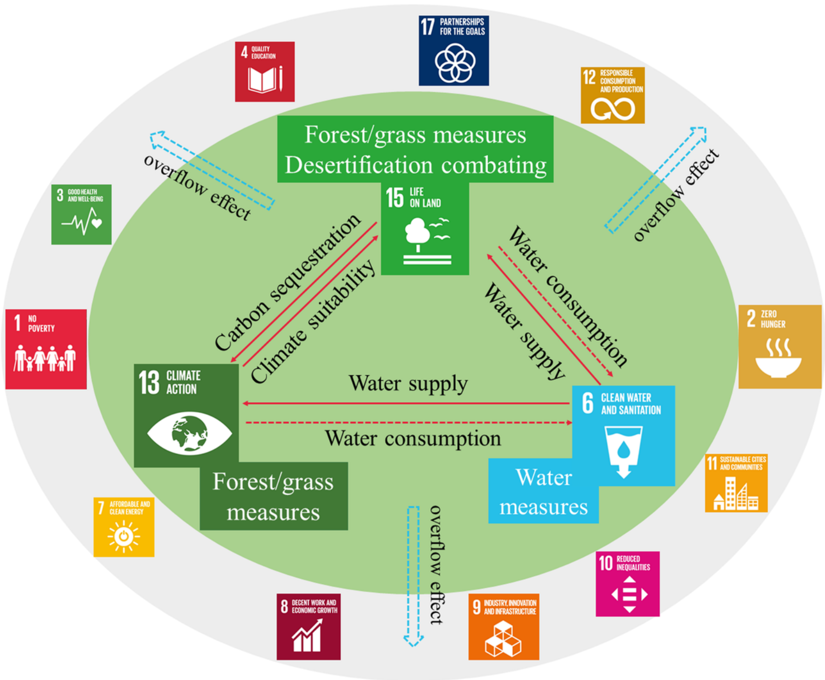

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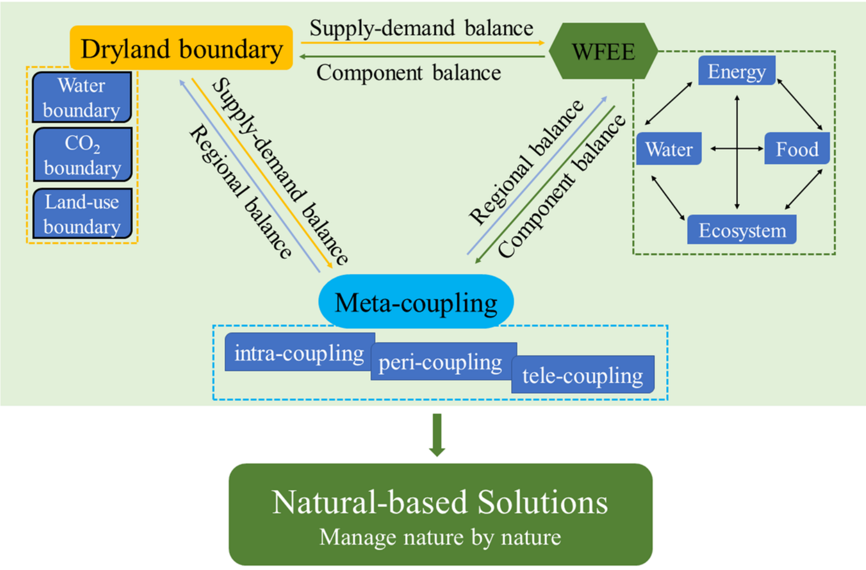

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