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Research advances in ecosystem services in drylands under global environmental changes

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The ecosystem services (ES) provided by drylands are critical to human wellbeing (HWB). Maintaining ES sustainability and improving people's livelihood in drylands are crucial to global sustainable development as 90% of the dryland population belongs to the developing countries. Global environmental changes have greatly altered ecosystem structure and process of dryland ecosystems and have led to significant changes in ES provision, supply–demand relationship and trade-offs at multiple scales. We reviewed research advances and identified knowledge gaps on dryland studies in line with the 'structure–function–service–wellbeing' cascade framework. Focus was put on ES and their contributions to HWB. ES concept and methodology are highly useful in understanding natural-social linkages of drylands and informing decision making. More empirical studies are needed to apply the ES methods and make regional comparisons.

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Introduction

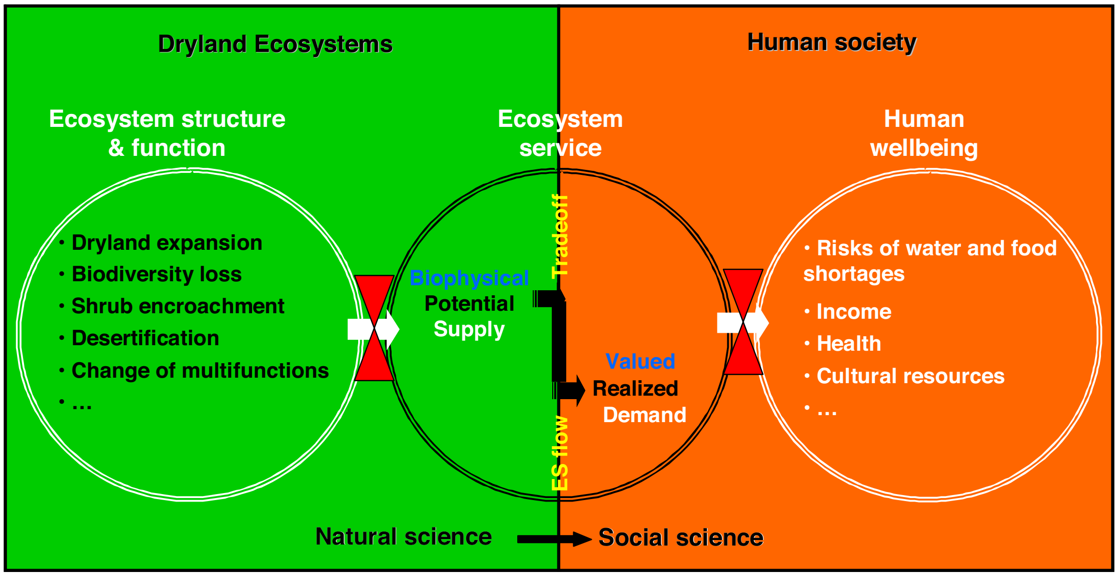
Drylands, usually defined as the regions with an Aridity Index (i.e. the ratio of annual precipitation to annual potential evapotranspiration) below 0.65, currently cover 41% of global land surface and are home to 38% of global population. Highly variable and small amount of precipitation but high evaporation result in periodic drought, which is the foremost constraint of ecosystem processes in drylands. Under the pressures of natural conditions and global environmental changes, these regions are usually at high risks of land degradation, natural hazards and water and food shortages [1]. At the same time, local people are highly dependent on the provision of goods and services by natural ecosystems as they have few other options to maintain livelihoods. Some of the local people are among the most ecologically marginalized populations on the globe and some even barely make to the survival line [2].

Drylands provide ecological-social complexes for both natural and social science. In the past few decades, increasing research projects and international initiatives are targeting at understanding dryland ecosystem changes, their driving forces and consequences. The establishment of ES concept and related methodology provided new insights in understanding the connections between natural and social systems [3•]. The ES frameworks depict the nature–society linkages, highlighting the foundation of ES (i.e. ecosystem properties) and the path to realize human wellbeing (HWB) (i.e. transformation of ES to human needs) [4]. The ES concept makes nonproductive services more visible and applicable. ES quantification, trade-off and supply–demand analyses from natural science perspectives together with ES valuation, payment for ES and natural capital accounting from social science perspectives can play important roles to inform land use planning, ecosystem management and decision making. However, relevant studies targeted to drylands are still lacking. Here, we review ES studies in drylands in line with the 'structure–function–service–wellbeing' logic flow (Figure 1). We aim to summarize the research advances and identify remaining research questions for drylands. The solutions would also provide valuable references to other ecologically vulnerable areas to find the way to achieve balance in nature–society relationship.

Global environmental change in drylands

Climate change, population growth, urbanization, grazing and desertification are the main drivers of ecosystem change in drylands [5]. In the past century, significant warming trend in drylands has occurred with stronger magnitude in comparison with that in other parts of the world. The extent of dryland is expected to expand by 11%

Figure 1



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The chain from ecosystem structure & function to ecosystem service (ES) to human wellbeing (HWB). ES is the interface in linking natural system to social system. Analyses of trade-offs, ES flows (from supply to demand), and ES valuation provide new analytical tools to connect natural science to social science.

(23%) before 2100 relative to 1961–1990 according to the climate projection RCP4.5 (RCP 8.5). That means that 50% (56%) of the total land surface would be covered in drylands [6,7•]. Land use was more flexible in history because people livelihoods especially the nomads were dependent on a mixture of movable hunting, cropping, collecting and livestock breeding. Comparatively, the population pressure now has led to higher tension between pastoral, cultivation and construction land uses as human demands for livestock product, grain yield and fixed living space are all increasing. Desertification is an umbrella term that covers all types of land degradation in drylands. Although the estimated range of desertification is uncertain, it is a consensus that desertification is occurring at a startling rate (exceeding 50,000 km^2 per year) [8,9]. Dryland expansion, along with rising temperature and desertification, poses severe threats to ecosystems and local inhabitants. Significant progress has been made in studying environmental change of drylands, but climatic process and desertification in these regions are very complex. Their causes and consequences vary at different spatial and temporal scales. Long term observations and improved models are required to promote research understanding the dynamic mechanisms of environmental changes as well as their ecological impacts at multiple scales [5].

Ecosystem structure and process/function

Experimental and modeling results show that global change has direct and indirect effects on dryland ecosystem structure and process [10•]. Changes in vegetation composition, coverage, greenness and spatial distribution are important structural changes [11–13]. One of the most widely occurred phenomenon in global drylands is the conversion from grassland to shrubland, that is, shrub encroachment [14]. Land surface characteristic indicators (e.g. patch size distribution of vegetation and biocrust) are found to be a new effective tool to identify the 'critical transition' in addition to plant and soil variables [15,16]. In addition, a study based on long-term site observation found that increasing variability of grass cover could also serve as a leading indicator of stochastically driven vegetation recovery [17]. These findings indicate that both space and time indicators are useful in identifying the change of state of the studied dryland ecosystems, but more evidences are needed from other regions of drylands.

The ecosystem structural changes have important consequences on biodiversity and ecosystem mass, energy and hydrological flows and consequently affect the quantity and quality of ES [18–22]. Generally, ecosystem studies have made progress in understanding dryland ecosystem processes and their driving forces, which provides important basis to underpin ES and their contributions to human society. However, many unique factors and processes of dryland ecosystems have caught limited awareness or still have not been well understood. For example, photo-degradation has been not well addressed