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Commentary

Current status and future directions of the Tibetan Plateau ecosystem research

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The Tibetan Plateau (TP) encompasses Xizang and Qinghai and parts of northern Yunnan and Sichuan provinces, with a total area of circa 2.6 millions km^2. The 2013 satellite data showed that grasslands, forests, wetlands, agricultural lands, and deserts account for 60%, 7.7%, 1.4%, 0.3%, and 30%, respectively, of total TP land [1]. Due to its existence in dry, high altitude and cold environments, the TP ecosystem is extremely vulnerable to global climate change and studies on the TP ecosystem can be utilized as a pre-warning for other ecosystems. As a key factor driving ecosystem dynamics, temperature in the past decades has been increasing at a faster rate in the TP than in the Northern hemisphere on average. At the same time, the social-economy of the TP has developed continuously since the 1950s [2]. Aided by favorable climatic conditions and protection measures from governments, vegetation growth on the TP has strengthened in the past 40 years. Forest land experienced an area shrinkage from 1950 to 1986, followed by a slow recovery from 1986 to 1998, and then a rapid recovery after 1998 [3,4]. Since the 1980s, grassland phenology has exhibited a pattern of advanced (i.e., earlier) start and postponed (i.e., later) end to the growing season [5]. Grassland productivity has also significantly increased [6]. Recovered vegetation and enhanced protection measurements have also contributed to substantial growth in wildlife populations on the TP since the 1990s [7].

Prior to 1973, some preliminary and multidisciplinary scientific surveys had been carried out for the TP, focusing primarily on agriculture and forestry in Qinghai, Gansu, West Sichuan, northwest Yunnan and central Tibet. The first comprehensive and large-scale series of scientific expeditions for the TP was initiated in 1973 and concluded in 1992. This was focused mainly on geology and the effects of a geological uplift on climate and plant evolution (Fig. 1). With respect to ecosystems, most data collected pertained to vegetation distribution [8]. On the basis of this extended expedition, a series of monographs, photographic albums and films were recorded and published. International scholars and societies have also actively participated in studies related to ecology, natural resources, and geology on the TP by cooperating with scientists from China and neighboring counties of India, Nepal, and Pakistan.

Along with the extended comprehensive expedition, a series of long-term ecological stations have been gradually established on the TP. The earliest one was set up in the Haibei alpine meadow ecosystem in 1976. As of today, a number of national stations and Chinese Ecosystem Research Network (CERN) stations have been established, as well as numerous research stations operated by individual institutes or universities (Fig. 2). Each ecological station addresses a typical ecosystem on the TP and provides a platform for monitoring ecosystem status and dynamics, while also serving as a locus for ecological experimentation. Multiple sampling transects are in the process of being laid out along climate gradients. Field samplings along the transects and manipulative experiments have accumulated substantial data about TP ecosystems and environments, and significantly advanced our understanding of the driving factors, mechanisms and spatial pattern of ecosystem dynamics.

Literature analysis reveals that over 8,000 Science Citation indexed papers have been published in the field of TP ecology from 1995 to 2018. Prior to 2000, approximately 20 papers were published each year. Particularly swift growth occurred after 2015. Among the circa 8,000 papers, the most frequently used keywords are climate change and warming (Fig. S1 online).

Intensified human activities and accelerated climate change are fundamentally changing the TP ecosystem. Besides its ecological hurdle function, the TP and the adjacent central Asia plateau also lie in the core zone of the "One Belt, One Road" initiative, which is an international cooperative development plan launched by China for re-vitalizing trade along the ancient Silk Road and elsewhere. To relieve the pressures on ecosystems caused by global climate change, as well as to provide scientific support for meeting national needs, improved understanding on the status and changes of the TP ecological environment is essential. The first scientific expedition series and recent researches have significantly advanced TP ecosystem studies. But the overall body of research is still weak relative to other regions of China. Recently developed research technologies, especially remote sensing, provide an unprecedented impetus for enhanced TP ecosystem studies. In meeting these needs, a second scientific expedition series and set of research projects has been initiated, as well as a strategic frontier research plan. The overall objectives of these major scientific projects are to apply new research techniques in investigating eco-

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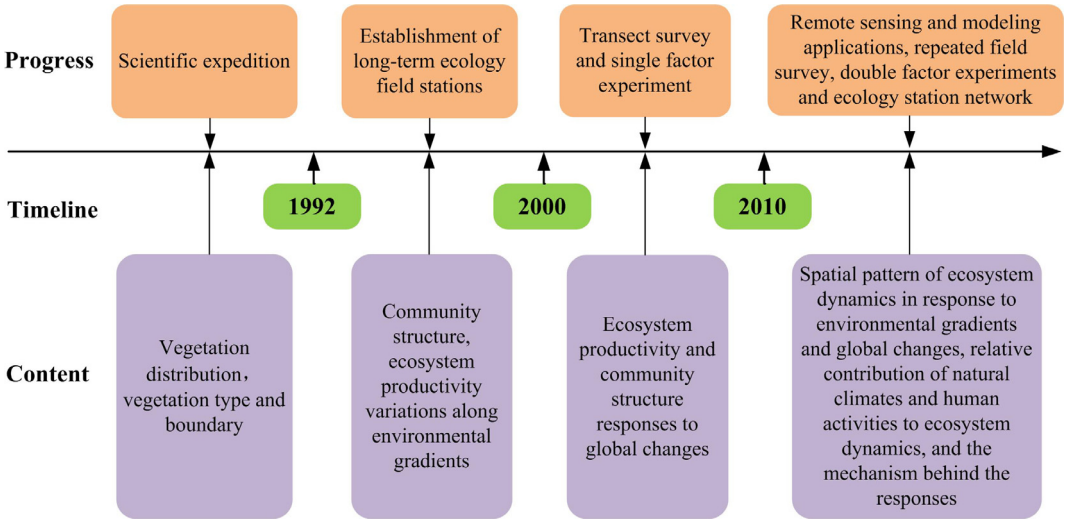

Fig. 1. The research stages on ecosystem of the Tibetan Plateau in the past 40 years.

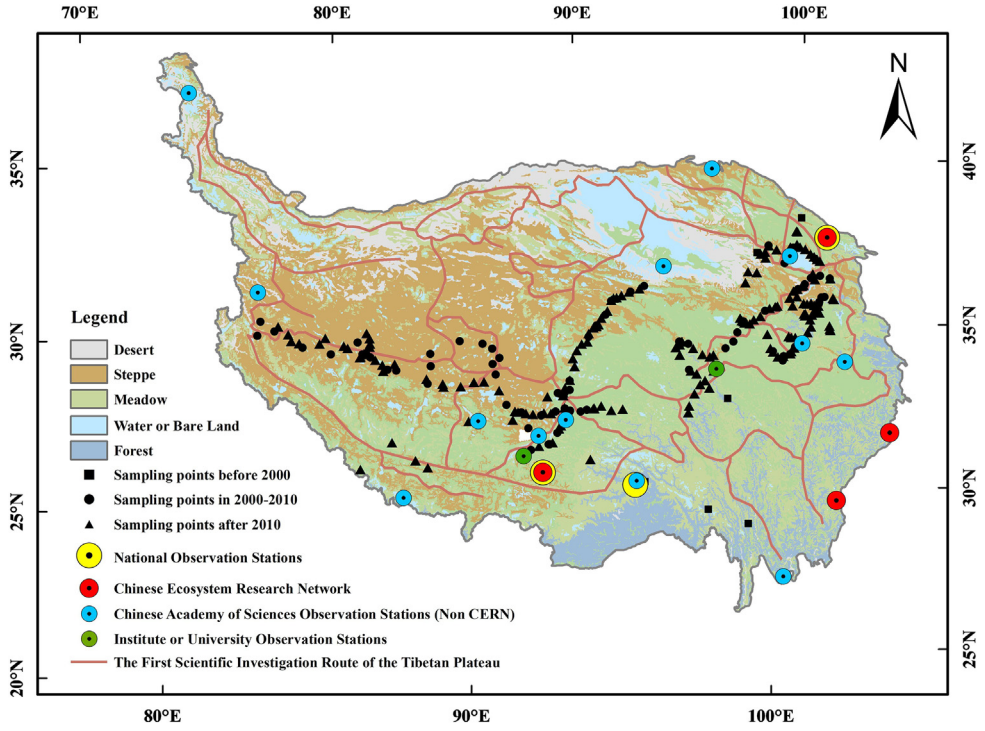

Fig. 2. Different levels of ecology research stations and field transects on the Tibetan Plateau.

logical and environmental changes on the TP. Based on national strategic needs and current research gaps, the following foci for ecological and environmental research have been identified:

(1) Strengthening interdisciplinary study: the TP is a typical region where cryospheric system, biospheric system, hydrospheric system, and ecosystem interact [9]. Investigation centered exclusively on one systemic dimension is inadequate to explain the core processes and mechanisms defining the TP. Only interdisciplinary study can advance our understanding on the interactions between ecosystems and climates.
(2) Differentiating the relative contribution of human activities and natural climate change to ecosystem dynamics. Increased attention to socioeconomic development in the region and its impacts on the TP ecosystem is clearly warranted. For natural climate effects dominated systems, we can only adopt measures to adapt to nature. If human socio-economic activities play a dominant role, actions to lessen pressures of human activity on the TP ecosystem are essential. With regards to natural climates, consequences of extreme events entail mounting attentions. Potential effects of wildlife on vegetation have been mostly overlooked in previous studies. Recently, enhanced environmental protection and recovery measures are creating conditions favorable to wildlife recovery. However, studies on wildlife effects on vegetation severely lag behind their actual population growth in the region.

(3) Integrating the variety of research methods relevant to understanding the TP ecosystem. Observations need to be structured from field to low sky and then to high sky by effectively integrating remote sensing with field observations. In the field site, current manipulative experiments have focused upon individual climate change factors, such as temperature, precipitation or nitrogen. Interacted effects have been explored by using remote sensing data at regional scales [10]. Future experiments need to shift emphasis more to some rarely considered factors such as increased CO_2 concentration effects on natural ecosystems, as well as interactions of two or more factors. The field manipulative experiments can yield information about ecosystem response mechanism, and also optimize model parameters for the TP ecosystem, whose unique environmental and ecological features suggest its parameter values possess distinct traits from other systems. Only with regionally optimized model parameters and model-data assimilation, can we improve model performance. For regions with sparse field stations and measurements, such as the extensive western and northern TP, extraordinary efforts are required. Among the key ecosystem components of water, soil, atmosphere and life, special attentions are entailed for the belowground soil and microbes.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scib.2019.03.009.

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