



# Above-belowground interactions in alpine ecosystems on the roof of the world

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Received: 27 October 2020 / Accepted: 30 October 2020  
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The Tibetan Plateau, known as the “Roof of the world”, is the highest plateau on Earth. It is the origin of major Asian rivers, and hence also called the “Asian Water Tower”. The plateau has unique ecosystems, characterized by low temperatures and low atmospheric pressure and oxygen concentrations. Despite extreme environmental conditions, the plateau exhibits a rich biodiversity. Over the past several decades, the plateau has experienced rapid climate change and intensified human activities. For instance, the mean annual air temperature has increased by about 0.4 °C per decade since the 1970s which is twice that of the global average (Fig. 1). The alpine ecosystems, including interacting plants, animals and microorganisms, and above- and

belowground components, are the results of long-term evolution and adaptation to the extreme environments. Understanding how the alpine environments shape above-belowground interactions and their responses to climate change remains a huge challenge.

In recent decades, extensive efforts have been made to examine the structure and functioning of Tibetan alpine ecosystems, including field observations, transect surveys, well-designed experiments, comprehensive meta-analyses, and literature reviews. Currently, we can draw the following conclusions:

- The alpine ecosystem is a relatively large carbon pool, especially the peat in alpine wetlands and soils

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Editorial Responsibility: Hans Lambers

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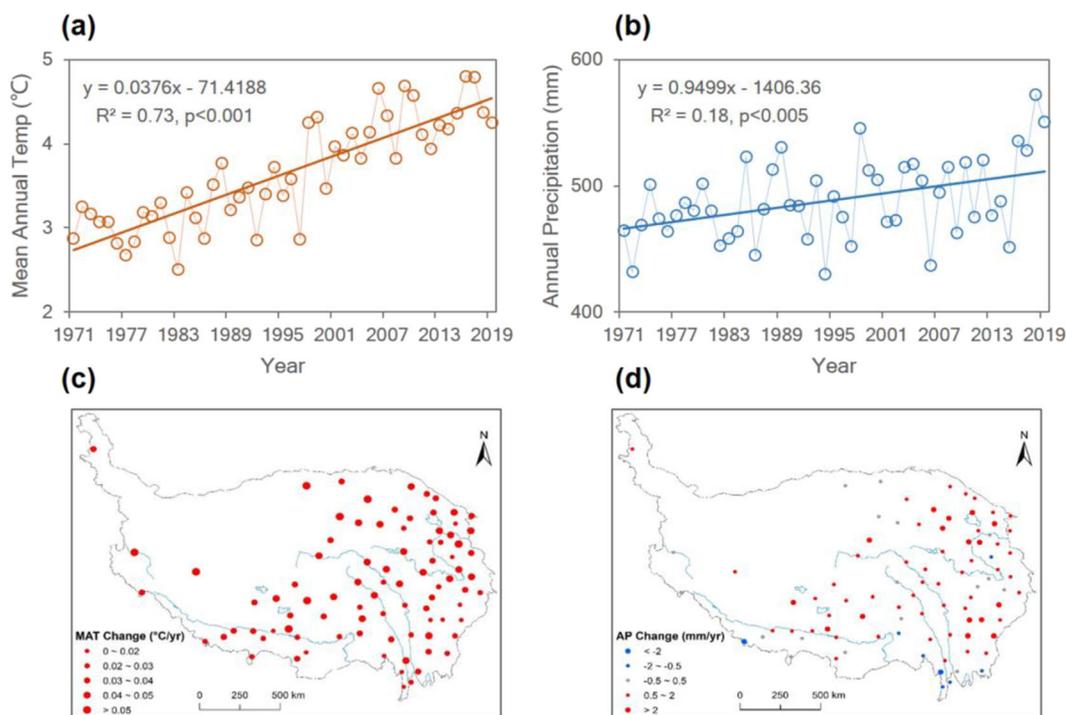
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**Fig. 1** Changes in mean annual temperature and annual precipitation from 1971 to 2019 on the Tibetan Plateau. From 1971 onwards, the plateau has experienced faster climate warming than the global average

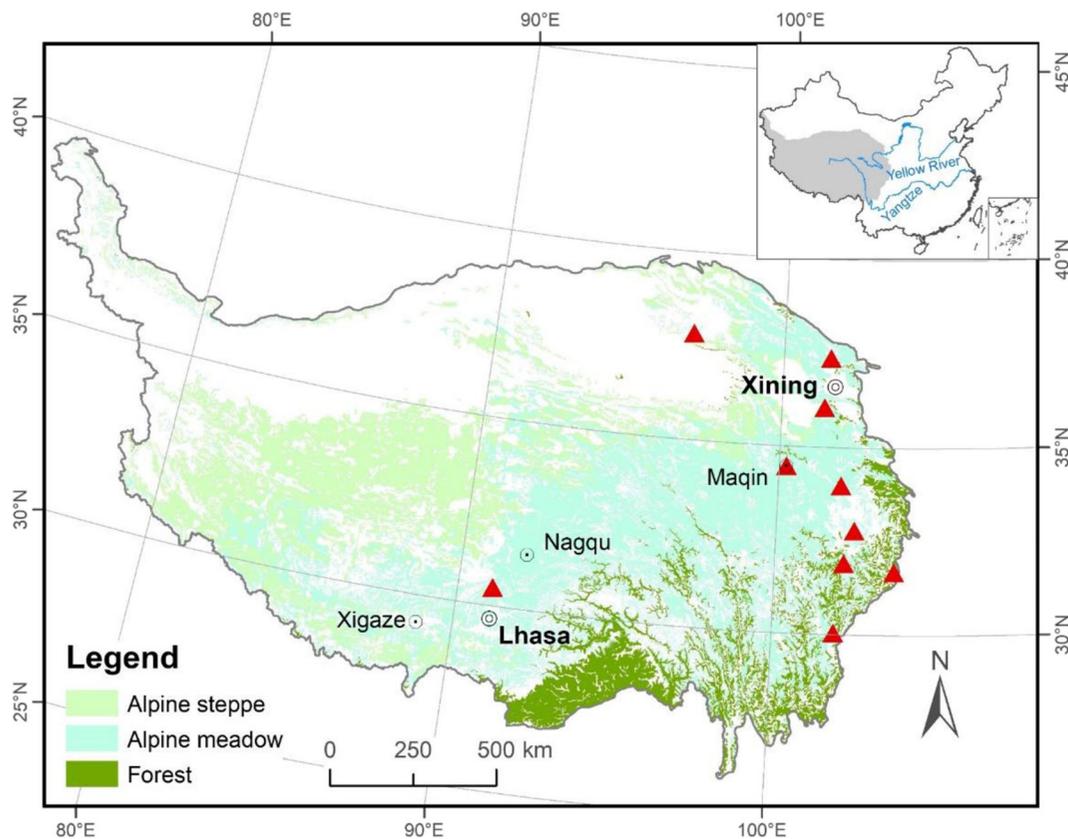
in alpine meadows. Alarming, this carbon pool is threatened by global warming and permafrost melting (Ding et al. 2016; Tang et al. 2018; Chen et al. 2019; Kou et al. 2020).

- The alpine grasslands, occupying more than 50% of the total area of the Tibetan Plateau, have shown an increasing trend in vegetation growth in the past several decades. This greening trend is mainly caused by climate change, and to a lesser extent by ecosystem restoration projects (Zhang et al. 2015; Shen et al. 2015; Liu et al. 2019).
- Data from long-term monitoring, remote sensing, and controlled experiments indicate that climate change is altering and reshaping patterns of vegetation growth, and these changes will have cascading effects on the structure and functioning of alpine ecosystems (Li et al. 2016; Ma et al. 2017; Liu et al. 2018; Wang et al. 2020a).
- The biogeographic patterns of soil microbial communities on the Tibetan Plateau are determined by above- and belowground parameters, such as vegetation type, soil pH, and moisture, and strongly influenced by climate changes (Jing et al. 2015;

Zhang et al. 2016; Ladau et al. 2018; Jiang et al. 2018).

- Although the overall vegetation growth on the Tibetan Plateau is increasing, the grassland ecosystems in some areas are still severely degraded (Dong et al. 2020). Preserving the pristine condition of the typical alpine vegetation and restoring the integrity of degraded ecosystems to achieve sustainable and environmentally-sound ecosystem management are the main on-going research topics (Bai et al. 2020; He et al. 2020).

Despite remarkable knowledge gains, there are still some areas that require in-depth research, such as the above-belowground interactions of alpine ecosystems. It is particularly important for this system for the following reasons: (1) A large part of the alpine ecosystem resources is allocated belowground. This may be more than 80% in alpine grassland. (2) Under extreme environmental conditions, plants may rely more on symbiotic associations with microorganisms. (3) The rapid climate change of the Tibetan Plateau may have a significant impact on above- and belowground interactions.



**Fig. 2** A vegetation map of the Tibetan Plateau, showing the research sites used for studies described in this *Special Issue*

To advance our understandings of the above-belowground interactions in the alpine ecosystems, we organized a *Special Issue* entitled “**Above-belowground interactions in alpine ecosystems on the roof of the world**”. This *Special Issue* comprises 19 articles, spanning multiple alpine ecosystems, including forests, shrublands, meadows, steppes, and marshes, across the eastern and southern parts of the Tibetan Plateau (Fig. 2), and covering diverse ecological processes.

Three papers in this *Special Issue* discuss the changes in above- and belowground ecological processes along altitudinal gradients. Specifically, Cui et al. (2020) explored the characteristics of microbial metabolic limitations along an altitudinal gradient. Hou et al. (2020) assessed the patterns of soil organic matter stability along two altitudinal gradients, and found that the soil organic matter stability was jointly controlled by edaphic, vegetation, and climatic factors. Yao et al. (2020) found that the quantity and quality of soil organic matter, in addition to leaf cuticular waxes, varied with altitude.

Several papers in this *Special Issue* assess the effect of climate change on above- and belowground ecological processes. Liu et al. (2020) found that experimentally simulating a warmer and drier climate enhanced root production, but reduced root decomposition in an alpine grassland. Wang et al. (2020b) found in a field that precipitation mediated the warming effects on soil respiration. Chen et al. (2020) found that long-term nitrogen deposition decreased the less-protected particulate organic carbon, while the mineral-associated organic carbon was less vulnerable. Zhong et al. (2020) found that altered precipitation and foliar endophytes jointly affected root-associated arbuscular mycorrhizal fungal diversity for a common alpine grass species, *Achnatherum inebrians*.

The Tibetan Plateau is home to one of the most extensive rangelands in the world. Livestock grazing, as the common practice in this ecosystem, is largely shaping community structure and ecosystem functioning. Mipam et al. (2020) found that the plant and soil nutrients stoichiometry did not covary under different grazing intensities. Sun et al. (2020) found that

the plants tended to allocate more biomass belowground under moderate grazing intensity than under light and heavy grazing intensities, supporting the optimal biomass partitioning hypothesis, rather than the isometric allocation hypothesis. Tian et al. (2020) showed that plant diversity and soil carbon sequestration were differently affected by warm- and cold-season grazing, highlighting the importance of considering the grazing strategies in maintaining ecosystem sustainability. Zhang et al. (2020) found that clipping increased ecosystem carbon sequestration in an alpine meadow, and clipping could modulate carbon sequestration in response to changes in precipitation. In parallel, Yin et al. (2020) found that 10 years of preventing grazing was not beneficial to community structure of functional microorganisms. In agreement with Yin et al. (2020), Wu et al. (2020) also found that long-term enclosure fencing decreased plant diversity and soil organic carbon sequestration.

The burrowing activities from small rodents such as plateau pika (*Ochotona curzoniae*) are considered one of the main reasons for grassland degradation on the Tibetan Plateau. Qin et al. (2020) found that vegetation growth and soil carbon were susceptible to foraging and burrowing activities of pikas. Similarly, Zhao et al. (2020) found that ecosystem respiration was lower in the bare soil caused by burrowing activities of pika than in vegetated soil. Dai et al. (2020) found that the deteriorated soil structure caused by grassland degradation affected soil water retention. Xu et al. (2020) showed that ectomycorrhizal and rhizosphere fungal communities responded differently during forest restoration.

Two articles reveal interesting phenomena in this unique ecosystem. Wang et al. (2020c) found that N<sub>2</sub>-fixing plants improved the resource status and were beneficial for establishing neighboring plants in a newly formed glacier floodplain. Wang et al. (2020d) found that the deciduous tree species tended to release more root exudates than evergreen tree species, and consequently led to greater microbial feedback on nutrient cycling.

Although some results on the ecology of the Tibetan Plateau may still be somewhat preliminary, all studies included in this *Special Issue* have undoubtedly improved our understanding of the above-belowground interactions in these alpine ecosystems. Some important questions remain. One major hot topic in recent years has been the structure and functioning of aboveground and belowground food webs and their responses to

climate change. This is very important for alpine ecosystems, because the interdependence and interactions among organisms in extreme environments are fragile, and they are most vulnerable to climate change and human activities. Unfortunately, we know very little, and have almost no empirical evidence in this respect. Another focus comes from some special features on the Tibetan Plateau, such as glaciers, permafrost, and seasonally-frozen soils associated with low temperature and high elevations. As climate warming continues, how retreating glaciers, rising snowlines, and thawing permafrost will affect above- and belowground interactions needs special attention. In addition, the majority of the studies included in this *Special Issue* were conducted at the eastern side of the Tibetan Plateau, where the influence of human activity is relatively stronger. Thus, further explorations need to focus on the western side of the Tibetan Plateau, where some pristine ecosystem types dominate. With the advancement of science and technology, such as unattended observation equipment, internet in remote areas, molecular technologies such as meta-genomics, -transcriptomics, -proteomics, and -metabolomics, the study of aboveground-belowground interactions of ecosystems in extreme environments is expected to make great progress soon.

**Acknowledgments** The idea of organizing this *Special Issue* originated at an international conference held in Lanzhou in 2018. Dr. Hans Lambers was an invited speaker at the plenary session of the conference. During the meeting, many studies focused on above- and belowground interactions of the alpine ecosystem on the Tibetan Plateau, which interested Dr. Hans Lambers, who offered help towards this *Special Issue*. We would like to thank all authors, reviewers, and Editors, whose great efforts have made this *Special Issue* possible. Huiying Liu and Qisheng Feng helped to prepare the figures and organize part of the text. JSH is supported by Lanzhou University and funding agencies: Key R&D Projects of the Ministry of Science and Technology of China (2019YFC0507701) and National Natural Science Foundation of China (Grants No. 31630009).

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