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The impacts of climate change and human activities on alpine vegetation and permafrost in the Qinghai-Tibet Engineering Corridor

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ABSTRACT

The Qinghai-Tibet Engineering Corridor (QTEC) in China may reflect the changes in the alpine ecosystem of the Qinghai–Tibet Plateau (QTP) that are driven by global climate change combined with intensive human activities. We used the normalized difference vegetation index (NDVI) as an indicator of alpine vegetation activity and the permafrost active layer thickness (ALT) as an indicator of permafrost dynamics to understand the impacts of climate change, human activity, or their combination on the alpine ecosystem in the QTEC. Based on the types of frozen ground, we separated the QTEC into northern, permafrost, and southern zones. The surface air temperature increased by 0.28 °C per decade from 1982 to 2010, and the rising trend of air temperature was most prominent in the permafrost zone ($P < 0.05$); the total precipitation exhibited a significant increase of 15 mm per decade ($P < 0.05$). The level of human activity in the QTEC rose slowly before 2000 and rapidly after 2000. The NDVI trends over the QTEC increased over the past thirty years, but the NDVI declined in some areas from 2001 to 2010, especially in the southern QTEC. The permafrost in the QTEC continued to thaw, and the ALT increased. Our results indicated that the QTEC experienced a significant warming and wetting trend. The increased precipitation improved the alpine vegetation activity across much of the QTEC, and the increased air temperature accelerated the thawing of permafrost. However, the construction and operation of the Qinghai–Tibet Railway since 2001 and 2006 promoted an influx of residents and tourists, boosted the local economy, and resulted in the deterioration of the alpine vegetation, particularly in the southern QTEC. Moreover, our results suggested that improvement of alpine vegetation cannot necessarily prevent permafrost degradation caused by warming.

1. Introduction

Climate change and human activities can significantly impact the underlying permafrost via vegetation and the active layer (Chen et al., 2014; Guglielmin et al., 2014). Climate-induced warming of the near-surface atmosphere and the corresponding rise in ground temperatures will lead to substantial changes in the water and energy balance in areas underlain by permafrost (Hilbich et al., 2008). Human activities cause additional disturbances, including overgrazing, numerous engineering projects, and the rapid growth of the population. In particular, the construction and operation of engineering infrastructures can change the original ground surface conditions in permafrost regions, causing degradation of the permafrost and the associated ecological environment (Jin et al., 2008).

Vegetation is the medium for heat exchange between the atmosphere and the lithosphere, and, as a result, changes to vegetation and the associated areas can directly impact permafrost (Guglielmin et al., 2014; Royleveillee et al., 2014; Runyan and D'Odorico, 2012; Yi et al., 2014). Vegetation can control soil temperature, the amount of water reaching the permafrost active layer (Runyan and D'Odorico, 2012),

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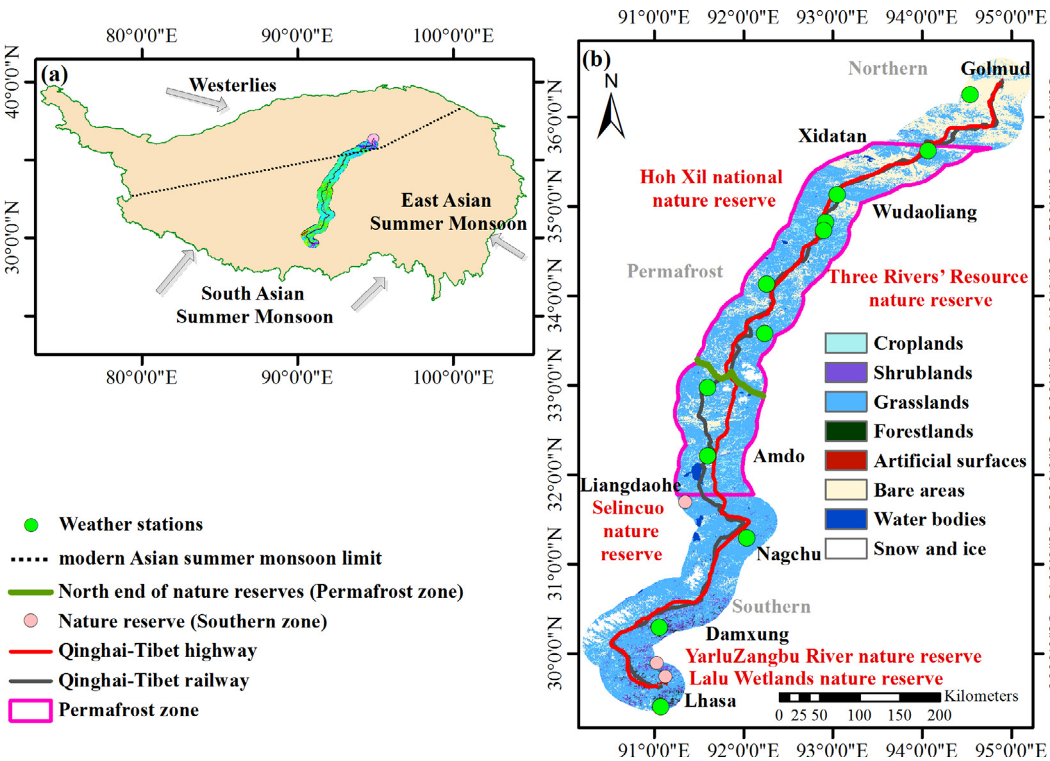

Fig. 1. Geography of the QTEC area. (a) Location of the QTEC (central area). (b) Some of the related weather stations (green points), Qinghai-Tibet Railway (black line), Qinghai-Tibet Highway (red line), permafrost zone (pink box), and the southern end of the nature reserves (green line), and the northern end of the nature reserves (the top of the pink box). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and snow accumulation (Royleveillee et al., 2014). Vegetation affects the energy balance of the soil; thus, changes in vegetation can provide feedback to the active layer thickness (ALT) and the temperature at the top of the permafrost (Guglielmin et al., 2014). The presence of different vegetation types helps preserve the permafrost layer by maintaining low soil temperatures. Different vegetation types produce different organic layer thicknesses (Royleveillee et al., 2014), and the organic layer of vegetation provides an insulating effect on the ground-surface temperature, which can slow permafrost degradation (Guglielmin et al., 2014; Runyan and D'Odorico, 2012). Permafrost degradation affects the hydrology and biogeochemistry of ecosystems and the engineering infrastructures above the permafrost (Jin et al., 2008). Active layer thickening and permafrost warming result in general decreases in the groundwater content (Guglielmin et al., 2014; Jin et al., 2008; Runyan and D'Odorico, 2012; Yi et al., 2014) and the numbers of families and species of plants (Yang et al., 2013); moreover, these changes profoundly enhance vegetation succession (Jin et al., 2008; Yang et al., 2013).

As the sole and highest physiographic unit of average elevation on Earth, the Qinghai–Tibet Plateau (QTP) is called the "Third Pole" and plays a key role in the Asian summer monsoon (Liu et al., 2012; Wu et al., 2015a). The QTP is of utmost relevance for the atmospheric circulation that is mainly controlled by the mid-latitude westerlies and the Asian summer monsoon (ASM), including the South Asian summer monsoon (SASM) and East Asian summer monsoon (EASM) (Bothe et al., 2011). The linkage of the Iranian Plateau to the QTP substantially increases precipitation over the Arabian Sea and the north Indian subcontinent, effectively contributing to the development of the SASM (Liu et al., 2012). The changes in the thermal forcing, precipitation, and surface pressure over the QTP are closely correlated with the changes in the ASM (Bothe et al., 2011; Liu et al., 2012). The air temperature over the QTP has increased by 0.28 °C per decade over the past 50 years (Li et al., 2010; Shen et al., 2015), and the precipitation has also shown an overall slight increase (Chen et al., 2013). Before 1990, the overall scale of human activities was small, and the impacts of human activities on the ecosystems were also less pronounced. Negative effects of human activities on the environment in the area occurred simultaneously and intensively from 1990 to 2000. After 2000, the scale of human activities increased with the construction of the Qinghai-Tibet Railway (QTR) (Fan et al., 2015). The increases in climate warming and total precipitation and the intensification of human activities across the QTP over the past several decades (Li et al., 2010) have resulted in vegetation improvements in most of the region (Chen et al., 2014; Cuo et al., 2016; Zhang et al., 2013), permafrost warming, and active layer thickening (Cheng and Wu, 2007; Harris, 2010; Jin et al., 2008; Wu et al., 2015b; Wu and Zhang, 2010). However, the vegetation has worsened in some areas (Shen et al., 2015).

The Qinghai–Tibet Engineering Corridor (QTEC) is situated in the central QTP and is classified as a critical engineering and transportation corridor that connects the inland of China and the Tibetan Plateau (Luo et al., 2017). Most previous studies focused on the impacts of climate change on the ecologically important QTP, and little attention has been paid to the much smaller area of the QTEC (Chen et al., 2014; Li et al., 2010; Wu and Zhang, 2010; Zhang et al., 2013). However, the QTEC is a typical indicator of the current climate conditions and human impacts that reflect the ecosystem changes in the QTP because the QTEC is affected by global climate change combined with environmental disturbances from human activities. We divided the study duration into two periods to evaluate the impacts of human activities on the changes in vegetation because human activities increased around 2000, especially with the construction of the QTR. To further understand the impacts of global climate change and human activities on the changes in alpine vegetation and permafrost over the QTEC, we 1) explored the spatiotemporal patterns of vegetation and climate factors in three different frozen soil zones, 2) evaluated the effects of human activities on the changes in vegetation, especially in the last decade when the level of human activities increased, and 3) analyzed the effects of vegetation on permafrost.