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Climate-forced ecological changes over the Tibetan Plateau

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ABSTRACT

Effects of global warming on ecosystem have attracted lots of attention; however, ecological response to climate change has been hardly documented in alpine regions. Here we investigated climate warming induced ecological changes on the Tibetan Plateau (TP) over the past 50 years on the basis of a large amount of in situ field observation and remote sensing data. We found that climate warming up to 0.41 °C/10 a has greatly improved the heat conditions on the TP, thus exhibits a growth of 46,000 ha farmland during the past 30 years, with the largest growth rate by 19% which occurred above 4000 m. Terrestrial net primary productivity (NPP) has increased by 0.002 Pg C a^{-1}. Broad-leaved forest had the highest average NPP. Cultivated vegetation contributes most for causing NPP growth in the recent 30 years. We also found that seasonal frozen soil depth decreased as the consequence of climate warming. Increased snow-melting inflated lake and river areas, whereas swamp area decreased owing to reduced moisture in the root zone. Freeze-thawing erosion decreased because of the reduced annual range of temperature. Understanding the ecological effects of climate change on the TP is of great significance to improve environmental management and promote sustainable development.

1. Introduction

The global average temperature has increased by approximately 0.85 °C over the past 100 years, with the prominent periods of warming from 1976 onwards (IPCC, 2013). The rate of warming during the recent 35 years has been greater than that during the last 1000 years. Tibetan Plateau (TP) is located in southwestern China, covering an area of 1.2×10^6 km^2 or 1/8 of the whole Chinese territory (Kang et al., 2010). The mean elevation of TP is more than 4000 m above sea level, hardly influenced by anthropological activities, thus making itself an ideal place for inspecting ecosystem response and sensitivity to climate warming. Due to TP's potential impact on regional and global climate patterns, it has become a hot spot for research of global climate change and the corresponding ecosystem feedback (Beaumont et al., 2011; Wischnewski et al., 2011).

In the past centuries there have been various studies on alpine wetland area change in the headwater region of the Yangtze and Yellow Rivers (Zhang et al., 2011), glacier retreat in the Himalayas (Yao et al., 2012), the thickness change of the active permafrost layer in Qinghai–Tibet Plateau (Cheng and Wu, 2007; Wu et al., 2010), rangeland degradation in Northern Tibet (Gao et al., 2010), the change of NDVI in Qinghai–Tibet Plateau (Peng et al., 2012), dynamics of aeolian sandy land in the Yarlung Zangbo River basin of Tibet (Shen et al., 2012), weakened sensible heat flux and lake evaporation of Tibet (Yang et al., 2014), and the snow-free season change in the Lhasa River and Niyang River basin (Gao et al., 2012). However, most of these studies were at regional scales and their time scales were too short to develop a complete understanding of the ecological changes on the TP. This study aims at investigating the recent ecosystem response (i.e. alpine wetland, seasonal frozen soil, vegetation growth, agriculture and erosivity) to climate warming on the basis of comprehensive experimental observation and data analysis.

2. Materials and methods

2.1. Field investigation

Our research group conducted field survey in Tibet every June to September for the last 10 years. Investigations were carried out in 35 counties of the six regions (Lhasa, Nyingchi, Shannan, Nagqu, Ngari, Xigazê) of Tibet (Fig. 1). A large number of field experiments and sampling work were carried out to obtain first-hand information in order to comprehensively understand the natural environment in Tibet. Our fieldwork was authorized and supported by the Nature and Ecology Conservation Division, Environmental Protection Department of the Tibet Autonomous Region, China. The field survey routes were defined in non-protected land region to acquire first-hand information (such

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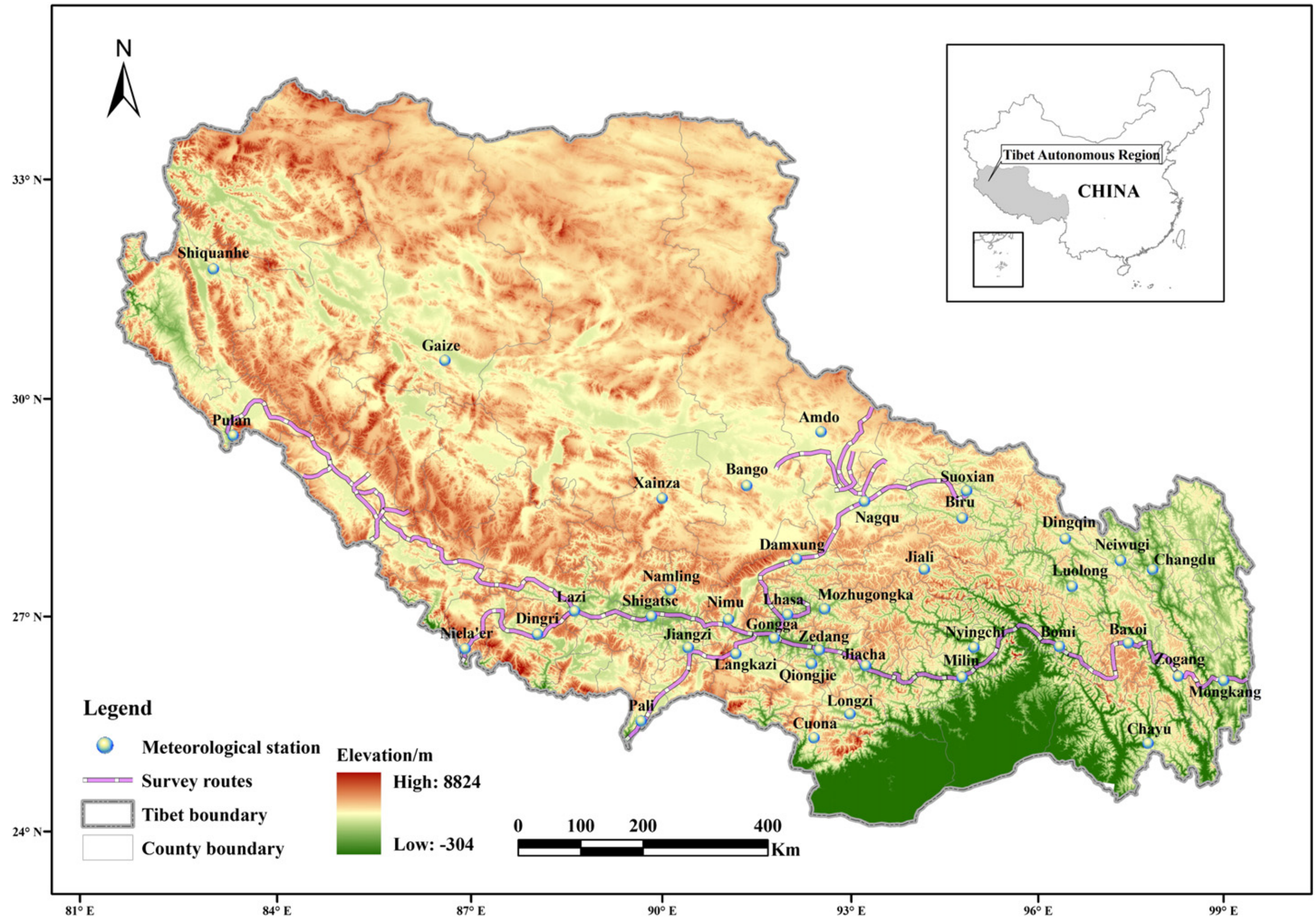

Fig. 1. Field surveyed and meteorological stations in the Tibetan Plateau.

as acquiring GPS of observed locations, and recording ecosystem boundary), which hence can be compared for remote sensing interpretation and establish interpretation marks. For alpine wetland, most investigation work was conducted in Nagqu, Xigazê and Lhasa. Seasonal frozen soil, erosivity data were acquired from meteorological stations and remote-sensing data, investigation data of which were used in establishing interpretation marks. For vegetation investigation, we collected vegetation (grasslands, shrubs, trees etc.) species and their distribution information along the No. 318 national road from Mongkong in the east to Pulan in the west part of Tibet, in order to compare with remote-sensing interpretation. Agriculture investigation was conducted in Lhasa, Nyingchi and Shannan. Under the permission of an agricultural landowner, we examined different agricultural productivity and measured the height, area of agricultural products. All the investigation observed data did not involved endangered or protected species.

2.2. Remote-sensing data

Using a large amount of field survey and observation data from the last 10 years, as well as remote-sensing data, the locations, distribution and area of alpine wetland, seasonal frozen soil, vegetation growth, agriculture and erosivity in Tibet were evaluated. The remote-sensing data were interpreted manually from the composite false-color images by means of a visually interactive interpretation method.

The remote-sensing data for interpretation used in this study included scenes of four sets of Landsat MSS and TM/ETM remote-sensing data in 1976, 1990, 2000 and 2010. The remote sensing data used in the year 1990 is TM images, and data used in the year 2000 is ETM images. The remote sensing data used in the year 2010 is HJ-1 images with spatial resolution of 30 m, and the data in 1976 is MSS images with a spatial resolution of 60 m. The MSS, TM, and ETM data were obtained from the International Scientific Data Service Platform which belongs to the Computer Network Information Center of the Chinese Academy of Sciences. The HJ-1 data was obtained from the Environmental Satellite Application Center of the Chinese Ministry of Environmental Protection. It was difficult to acquire cloud-free images of the whole study area within a given year due to the large geographical span of the study region. Consequently, some images from previous or subsequent years were used as replacements. ERDAS software version 9.3 was used to conduct pre-processing of the four sets of remote-sensing images.

2.3. Meteorological data

The daily air temperature, highest temperature, lowest temperature, surface ground temperature, extreme lowest temperature, precipitation, sunshine duration, and maximum depth of frozen soil data were recorded at 39 meteorological stations (Fig. 1) on the TP during the period of 1960–2010. All data were provided by the National Climatic Center of China Meteorological Administration.

2.4. Wetland interpretation

With reference to the Ramsar Convention, considering the actual situation of TP, a classification system for Tibetan wetlands was established which contained three major categories, i.e. river, lake, and swamp (Table 1).