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# Climate change and its impacts on vegetation distribution and net primary productivity of the alpine ecosystem in the Qinghai-Tibetan Plateau

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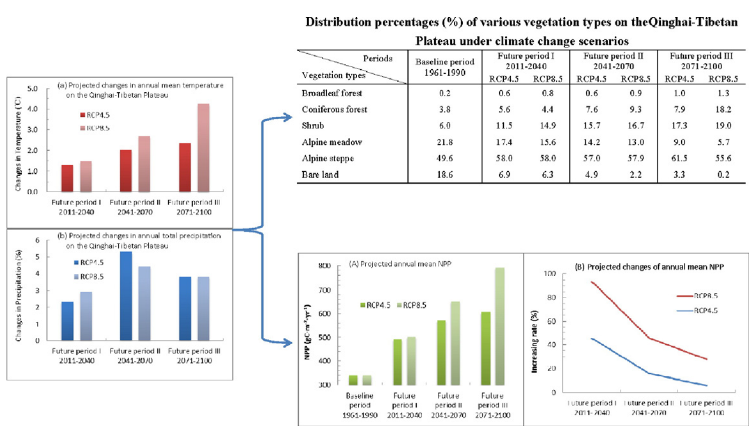
## HIGHLIGHTS

- The distributions of forests and shrubs will increase on the Qinghai-Tibetan Plateau.
- Alpine meadows will decrease and will be mainly replaced by shrubs in the future.
- Alpine steppes will expand and occupy the western and northern plateau.
- The net primary productivity of the alpine ecosystem will increase in the future.
- Productivity will show a gradual increase from the eastern to the western region.

## GRAPHICAL ABSTRACT




Distribution percentages (%) of various vegetation types on theQinghai-Tibetan Plateau under climate change scenarios

| Vegetation types \ Periods | Baseline period 1961-1990 | Future period I 2011-2040 | | Future period II 2041-2070 | | Future period III 2071-2100 | |
|---|---|---|---|---|---|---|---|
| | | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 | RCP4.5 | RCP8.5 |
| Broadleaf forest | 0.2 | 0.6 | 0.8 | 0.6 | 0.9 | 1.0 | 1.3 |
| Coniferous forest | 3.8 | 5.6 | 4.4 | 7.6 | 9.3 | 7.9 | 18.2 |
| Shrub | 6.0 | 11.5 | 14.9 | 15.7 | 16.7 | 17.3 | 19.0 |
| Alpine meadow | 21.8 | 17.4 | 15.6 | 14.2 | 13.0 | 9.0 | 5.7 |
| Alpine steppe | 49.6 | 58.0 | 58.0 | 57.0 | 57.9 | 61.5 | 55.6 |
| Bare land | 18.6 | 6.9 | 6.3 | 4.9 | 2.2 | 3.3 | 0.2 |

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## ABSTRACT

Changes in climate have caused impacts on ecosystems on all continents scale, and climate change is also projected to be a stressor on most ecosystems even at the rate of low- to medium-range warming scenarios. Alpine ecosystem in the Qinghai-Tibetan Plateau is vulnerable to climate change. To quantify the climate change impacts on alpine ecosystems, we simulated the vegetation distribution and net primary production in the Qinghai-Tibetan Plateau for three future periods (2020s, 2050s and 2080s) using climate projection for RCPs (Representative Concentration Pathways) RCP4.5 and RCP8.5 scenarios. The modified Lund-Potsdam-Jena Dynamic Global Vegetation Model (LPJ model) was parameter and test to make it applicable to the Qinghai-Tibetan Plateau. Climate projections that were applied to LPJ model in the Qinghai-Tibetan Plateau showed trends toward warmer and wetter conditions. Results based on climate projections indicated changes from 1.3 °C to 4.2 °C in annual temperature and changes from 2% to 5% in annual precipitation. The main impacts on vegetation

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Net primary production
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Dynamic Global Vegetation Model
Qinghai-Tibetan Plateau

distribution was increase in the area of forests and shrubs, decrease in alpine meadows which mainly replaced by shrubs which dominated the eastern plateau, and expanding in alpine steppes to the northwest dominated the western and northern plateau. The NPP was projected to increase by 79% and 134% under the RCP4.5 and RCP8.5. The projected NPP generally increased about 200 g C·m$^{-2}$·yr$^{-1}$ in most parts of the plateau with a gradual increase from the eastern to the western region of the Qinghai-Tibetan Plateau at the end of this century.



## 1. Introduction

In recent years, the climate change issue has caused widespread concerns around the world, and governments and scientists in many countries have been committed to research to resolve these problems (EBNCCA, 2011). According to current observations, global climate change, particularly increasing temperatures, has had a significant impact on many natural ecosystems (Field et al., 2014). Because the spatial distributions of different plant species are controlled by temperature, precipitation and other climatic factors, one of the major consequences of climate change is expected to be a change in the floristic composition of different areas, affecting land cover types and the community structure of ecosystems (Klein et al., 2007; Scholze et al., 2009). Changes in precipitation, temperature and other key environmental factors, coupled to increased carbon dioxide concentrations in the atmosphere, will influence the physiological, ecological, and other processes of species in ecosystems, including evapotranspiration, decomposition and photosynthesis. This will significantly affect ecosystem productivity (Niu, 2001; Lindner et al., 2010). Therefore, climate change will affect net primary production (NPP), water conservation, and other service values in ecosystems by altering their structures and functions (Xie et al., 2001; Schröter et al., 2005; Doherty et al., 2010).

The characteristics of ecosystems, such as their complex bioclimatic mechanisms, interacting environmental factors, and their distributions on both temporal and spatial scales, dictate that research into the impact of climate change on them requires not only experiments and field observations, but also model simulation (Rustad, 2008). Many models have been used to evaluate the influence of climate change on terrestrial ecosystems, and these models differ in their focus and their specific advantages and disadvantages. Dynamic vegetation models can describe the compositions and functions of terrestrial surface ecosystems according to (i) the carbon, nitrogen, and water exchange in terrestrial ecosystems on different temporal scales, and (ii) all the dynamic processes that occur between different vegetation types (Wang et al., 2009). The Lund-Potsdam-Jena Dynamic Global Vegetation Model (LPJ model) can predict the distributions of regional vegetation types and other structural characteristics, and estimate the NPP of the vegetation and other functional characteristics under the impact of climate change (Smith et al., 2008). Based on simulations of the ecological and physiological adaptability of vegetation to the environment and the competition between plants for resources (Sitch et al., 2003), the LPJ model describes the temporal and spatial characteristics of regional vegetation and can effectively simulate the responses of vegetation pattern and functions to global changes (Schröter et al., 2005; Bondeau et al., 2007; Liu et al., 2009).

As one of the most sensitive areas to global climate change (Liu and Chen, 2000), the changes on the Qinghai-Tibetan Plateau exceed those in the rest of the northern hemisphere and even the world (Feng et al., 1998; Liu and Yin, 2002). In particular, the Qinghai-Tibetan Plateau shows a clear warming trend and increased precipitation (Niu et al., 2004; Wu and Yin, 2007). The climate conditions on Qinghai-Tibetan Plateau are extremely harsh and variable, and its ecosystems are relatively unstable (Zheng, 1999). Therefore, external disturbances can easily alter ecosystem patterns, processes, and functions. Consequently, climate change could greatly affect the ecological environment of the Qinghai-Tibetan Plateau (Tang et al., 1998; Du et al., 2004; Klein et al., 2004). Research, including field observations, remote sensing, and model simulations, has been directed toward the alpine ecosystems of the Qinghai-Tibetan Plateau and their responses to climate change (Klein et al., 2007; Ding et al., 2010; Gao et al., 2010a, 2010b; Huang, 2011). However, there has been little systematic, integrated research and some results are conflicting (Yu and Xu, 2009). Therefore, the comprehensive impacts of climate change on the structures and functions of these alpine ecosystems must be evaluated urgently, to understand the influence of climate change on the alpine ecosystem of the Qinghai-Tibetan Plateau, and to provide a scientific basis for its sustainable development and adaptation to climate change.

The objectives of this study were 1) to modify the climate, vegetation, and plant physio-ecological parameters of the LPJ model to make it appropriate it to the Qinghai-Tibetan Plateau, based on field observations and other modeling results from previous studies; and 2) to predict the influence of future climate change on the vegetation distribution and NPP of alpine ecosystem on the Qinghai-Tibetan Plateau with the Representative Concentration Pathways (RCP) recommended by the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Our results will provide a theoretical basis for future adaptations to climate change in the alpine ecosystem on the Qinghai-Tibetan Plateau.

## 2. Material & methods

### 2.1. Study area

The Qinghai-Tibetan Plateau exceeds 4000 m in average altitude, is the largest high-altitude area on Earth (Fig. S1), and is called the “Third Pole of the Earth”, after the Antarctic and Arctic (Yao and Wang, 1997; Wu and Yin, 2007). It is one of the areas with the greatest diversity in climate, species, and ecological types in the world (Fu et al., 2010). The continental circulation system controls the climate on the Qinghai-Tibetan Plateau, and in turn, the biological processes there and also affect the climate of the surrounding areas. The continental circulation also restricts the global atmospheric circulation to some extent, thereby affecting the advancing and retreating movement of the Asian monsoons (Zheng, 1999; Mo et al., 2004). The Qinghai-Tibetan Plateau is the source of the Yangtze, Yellow, Salween, Mekong, and other major rivers, and the amount of ice on the plateau is exceeded only by those in Antarctic and Arctic. About 37% of the surface water runoff in China is from the Qinghai-Tibetan Plateau (ECENRTR, 2002). It is covered with large areas of alpine steppes and alpine meadows, and shrubs are mainly distributed in the southeast, whereas coniferous and broadleaf forests occur mainly in the south and southeast of the plateau. A large area of bare land exists in the northwest. The Qinghai-Tibetan Plateau provides a range of ecosystem services, including economic, social and environmental services, to Asia and the world.

### 2.2. Model modifications and accuracy test

The LPJ model has been widely applied to predict dynamic changes in terrestrial ecosystem structure and functioning and its response to climate change based on the plant physiological and ecological principles, generalized empirical equations and characteristic parameters (Hickler et al., 2006). The LPJ model accounts the variety of structure and function among plants by representing vegetation as a mixture of plant functional types (PFTs, Hickler et al., 2006). The PFT is a general