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The spatiotemporal patterns of vegetation coverage and biomass of the temperate deserts in Central Asia and their relationships with climate controls

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ABSTRACT

More than 80% of the world's temperate deserts are located in Central Asia. Knowledge of the desert biomass distribution and its dynamic related to the climate controls are vital for the development of adaptation strategies to meet the challenge of climate changes in the 21st century. However, due to the lack of field observations and the difficulties in retrieving vegetation fractional coverage (VFC) of sparsely vegetated lands across large areas from satellite imagery, the amount of desert biomass and its spatiotemporal patterns in Central Asia are still unclear. Based on 168 field observations and the Moderate Resolution Imaging Spectroradiometer (MODIS) data, we developed the VFC and biomass maps of the temperate deserts in Central Asia for the early 2000s (2000–2004) and early 2010s (2010–2014) and investigated the relationship between climate drivers and biomass distribution in the first decade of the 21st century. Our results showed the mean VFC (±SE) and biomass density (±SE) of the temperate desert, which covers an area of 3.6×10^6 km^2 in Central Asia, were 19 ± 14% and 280 ± 190 g m^{-2} respectively. The total desert biomass amounted to 1.00 Gt, about 36% of which was contributed by the temperate semi-shrub and dwarf semi-shrub. Precipitation, aridity, and growing season temperature were the major control factors on the biomass. Following the precipitation gradient, the western Central Asia had higher biomass density than the east, and relatively high biomass density was found on the windward slopes of the mountains. Large areas in the western Central Asia desert lost biomass due to the prolonged drought since the late 1990s. The differences in climate sensitivities among that desert vegetation types were noteworthy, indicating the future climate change may trigger vegetation succession.

1. Introduction

Deserts cover over 19 m km^2 or 15% of the global land surface, and are home to some 144 million people (Ezcurra, 2006). About 23% of the global deserts are temperate deserts, more than 80% of which are in Central Asia including the arid lands of northwestern China, southwestern Mongolia Republic, and the five Central Asia states of the former Soviet Union — Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan (Cowan, 2007) (Fig. 1). Plant biomass per unit area of the temperate desert is relatively low, but the large surface area of the Central Asia dryland gives it a global significance in carbon cycle research (Ahlström et al., 2015; Li et al., 2015). At the local scale, the desert vegetation not only supports the wild and domestic animals in the dryland ecosystems, but also provides important ecological services such as soil protection (Lioubimtseva, 2015; UNDP, 2005).

The sustainability of the temperate desert vegetation, however, is under the threat of the dramatic climate change in Central Asia (de Beurs, Wright, & Henebry, 2009; Lioubimtseva & Henebry, 2009), which was among the regions experiencing the fastest warming (0.4 °C decade^{-1}) of the world in the recent decades (Hu, Zhang, Hu, & Tian, 2014; Ji, Wu, Huang, & Chassignet, 2014). Prolonged drought stress in the 2000s made the northwestern Central Asia one of the most conspicuous vegetation browning hot spots in the world (Gessner et al., 2013; Piao et al., 2011). Despite its importance and sensitivity to climate change, large uncertainties exist regarding the desert biomass and its responses to climate controls (Trumper, Ravilious, & Dickson, 2008). Regional studies on temperate deserts' biomass are particularly rare because most studies have focused on hot deserts located in tropical/subtropical regions (Wu, 2001). Using the selection criteria "desert/dryland" and "carbon/biomass" for the title, abstract, and

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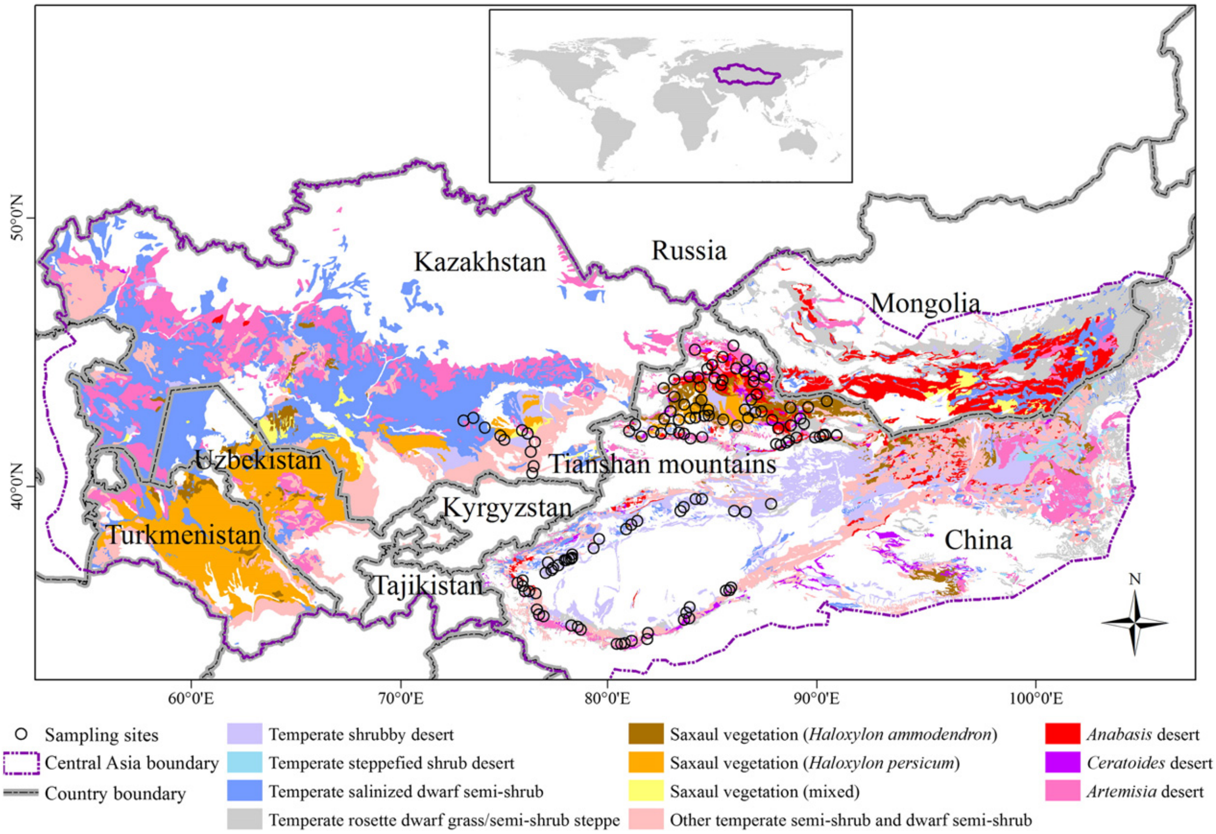

Fig. 1. The study area, the desert vegetation map developed in this study, and the sampling sites.

keywords, we searched scientific publications during 1993–2013 in the scholarly databases Web of Science (http://apps.webofknowledge.com) and Google Scholar (http://scholar.google.com) and found that less than 16% of the studies focused on cold/temperate deserts/drylands. Therefore, it is important to assess the total amount and the spatiotemporal pattern of the desert biomass in Central Asia, and understand its relationship with the climate controls (Hu et al., 2014; Lioubimtseva & Henebry, 2009).

Some previous studies directly used site-level observations to estimate biomass or carbon storage at a regional scale (Li et al., 2015). This approach ignores the strong spatial heterogeneity in dryland biomass, and is unable to analyze the climate controls on the biomass distribution. Furthermore, due to the difficulties in conducting field studies in the remote deserts, the sampling sizes in these studies were usually small and the sampling sites tended to be located close to human settlements or farms where the growth of the sampling plants was affected by the high groundwater level and elevated nitrogen deposition due to agricultural managements (irrigation and fertilization). Other studies directly linked remote-sensing derived vegetation indices, e.g., the normalized difference vegetation indices (NDVI), to biomass (Ma, Fang, Yang, & Anwar, 2010; Piao, Fang, Zhou, Tan, & Tao, 2007), or estimated biomass based on ecosystem structural variables such as the vegetation fractional coverage (VFC) (Franklin & Hiernaux, 1991; Thevs, Wucherer, & Buras, 2013). Because green vegetation cover is not continuous (horizontally homogeneous) in dryland, the cover or canopy area of vegetation, estimated using remote sensing, may be directly related to biomass (Franklin, Duncan, & Turner, 1993). However, the combination of the reflectance spectra of bright desert soils and the relatively weak spectral response of sparse vegetation, esp. the nonphotosynthetic vegetation, make it difficult to retrieve the VFC across large areas using remote sensing data (Meyer & Okin, 2015; Okin, 2010; Okin, Clarke, & Lewis, 2013).

This study aims to (1) develop 500-m resolution VFC and biomass maps for the early 2000s (2000–2004) and early 2010s (2010–2014) for the temperate deserts of Central Asia, (2) locate the hotspots of biomass change in the first decade of the 21st century, and (3) investigate the correlations between the climate factors (temperature, precipitation, aridity index, etc.) and the biomass of the temperate desert vegetation.

2. Study area

Central Asia includes the vast dryland of the northwestern China (NW-China), southwestern Mongolia Republic (SW-Mongolia), and the five Central Asia states of the former Soviet Union (CAS5) — Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, with a total area $> 1 \times 10^7$ km^2 (Cowan, 2007) (Fig. 1). Sitting in the middle of Central Asia, the Tianshan Mountain divides the study area into the western (the CAS5 countries) and the eastern parts (the NW-China and SW-Mongolia). Because the land is located deep inside the Eurasian continent and because the basins in the area are in the rain shadows of high mountains, the climate in Central Asia is arid (Lioubimtseva & Cole, 2006). Taking up about 1/3 of the dryland area, the low-lying deserts are typically at elevations from −100 to 400 m above sea level. These deserts have an extremely arid climate with cold winter. The precipitation is generally less than 150 mm y^{-1}, 1/5 to 1/3 of which is in the form of snow; the potential evaporation is higher than 2000 mm y^{-1}; mean annual temperature is 5–9 °C. The study area has experienced rapid and accelerated warming in recent decades, about twice the warming rate of the global land's mean (Hu et al., 2014). Changes in precipitation have varied from place to place, with decreased precipitation found in the CAS5 region (Lioubimtseva & Henebry, 2009) and increased precipitation observed in the NW-China (Chen & Luo, 2013). About 80–90% of the world's temperate deserts