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Multi-factor modeling of above-ground biomass in alpine grassland: A case study in the Three-River Headwaters Region, China

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ABSTRACT

In this study, we evaluate various methods for estimating the above-ground biomass (AGB) of alpine grassland vegetation using Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation indices, in combination with long-term climate and grassland monitoring data collected at 15 site-specific stations, in the pastoral area of southern Qinghai Province (i.e., the Three-River Headwaters Region) of China. The results show that (1) over the past 12 years, there were considerable spatial variations in the grassland AGB and NDVI, with the average AGB in the peak period of grassland growth in the range of 329–3653 kg DW/ha, corresponding to an average NDVI of 0.25–0.72; (2) Grassland AGB is affected by various factors, such as geographic location, topography, climate, soil, and grass types. Single-factor AGB models only account for 15–49% of the variations in the grassland AGB during the peak period of grass growth, with NDVI-based AGB model to be the best (46%) among all linear remote sensing models we tested; and (3) although the multi-factor model (based on latitude, longitude, and grass cover and height) performs the best (70%) in estimating the AGB, it is not possible for operation due to the current difficulty of grass height modeling. The alternative and operational multi-factor model f(x,y,c) (latitude, longitude, and grass cover) can achieve reasonable estimation of AGB (63%), with the grass cover modeled from the MODIS reflectance, which would be further improved in conjunction with unmanned aerial vehicle technology in the future. Using this model f(x,y,c), the root-mean-square error (*RMSE*) of AGB estimation is reduced by 20% (i.e., 151 kg DW/ha) as compared with the best single-factor model based on the NDVI (*RMSE* of 887 kg DW/ha).

Above-ground biomass (AGB) is not only an important indicator of regional carbon cycling, but also serves as a critical indicator for both health assessment of grassland ecosystem and sustainable utilization of grassland resources. Therefore, developing high accurate AGB estimation model is of great importance for grassland management, grassland-livestock balancing analysis, and grassland growing status assessment and eco-environmental protection (Xu et al., 2013; Gao et al., 2013; Xu and Guo, 2015). Currently, ground-based measurements and remote sensing (RS) are the two primary methods for monitoring grassland AGB. Ground-based measurements, in sampling plots, are often time-consuming and can be affected by topography, accessibility, and regional environment (Lu, 2006). Remote sensing method is based on the strong spectral signatures of plant canopy foliage in the visible and near infrared bands (Craine et al., 2012; Edirisinghe et al., 2012; Li et al., 2014). One of commonly used methods is to utilize vegetation indices (VIs), such as the normalized difference vegetation index (NDVI), to indirectly estimate AGB in various spatial and temporal scales (Tucker, 1979; Tucker et al., 1986; Ullah et al., 2012; Li et al., 2014). Because the NDVI has been used to study natural grassland since the 1970s, a historical record spanning several decades is available for studies on VI- and RS-based monitoring of natural grassland biomass (Tucker, 1979; Tucker et al., 1986; Ullah et al., 2012; Li et al., 2014). Dozens of VIs have been proposed to address certain issues, such as the soil background effect on the NDVI-based biomass inversion model and NDVI saturation occurring at a leaf area index > 2.0–2.5 (Baret and Guyot, 1991; Huete et al., 2002). Besides the NDVI, other VIs have been used, including but not limited to, the soil-adjusted vegetation index (SAVI) (Huete et al., 1985; Huete, 1988), modified soil-adjusted vegetation index (MSAVI) (Qi et al., 1994), optimized soil-adjusted vegetation index (OSAVI) (Steven, 1998), soil adjusted total vegetation index (SATVI) (Marsett et al., 2006), enhanced vegetation index (EVI) (Huete et al., 1994; Rondeaux et al., 1996), and narrow-band vegetation index (Mutanga et al., 2004; Jacques et al., 2014; Xu

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et al., 2014). Among these VIs, the NDVI is the most widely used index (Craine et al., 2012; Li et al., 2014). However, natural grassland is characterized by complex grass species, wide geographical distributions, and high spatial heterogeneity. Regardless of the type of VIs used, the form and accuracy of natural grassland biomass monitoring models solely based on VI are likely to present regional differences. RS inversion models of grassland biomass have low accuracy, poor stability, and considerable spatial variability in many regions. For example, Ullah et al. (2012) investigated natural grassland biomass in the northern Netherlands and reported that the SAVI ($R^2 = 0.54$), TSAVI ($R^2 = 0.52$), and NDVI ($R^2 = 0.51$) have comparable predictions of grassland biomass (only 51–54%). Porter et al. (2014) studied grassland biomass in the central Montana, USA and found a better estimate ($R^2 = 0.63$–0.64) of biomass during the peak period of grassland growth using Landsat-derived NDVI. Reddersen et al. (2014) reported a poor relation ($R^2 = 0.01$–0.34) between grassland biomass and field spectrometer-derived NDVI and SAVI, for the central Germany study. Xu et al. (2014) investigated natural grassland of southern Saskatchewan, Canada, and found a significant correlation ($R^2 = 0.48$, $p < 0.1$) between biomass and the Landsat image-derived NDVI, when with <20% dead grass cover, and no correlation ($R^2 = 0.03$, $p > 0.1$) when with larger than 20% dead grass cover.

The major objectives of this study are the following: (1) to examine MODIS VIs for the suitability for estimating alpine grassland AGB in the pastoral area of southern Qinghai; (2) to identify critical factors, such as geographic location, topography, climate, soil, vegetation biophysical indicators, and the MODIS VIs, in estimating AGB of natural grassland vegetation; and (3) to establish multi-factor models for monitoring AGB of natural grassland and to assess model uncertainties.

1. Data and methods

1.1. Study area

The study area (N31°38′–36°20′, E89°31′–102°14′) is located in the southern Qinghai Province in the hinterland of the Qinghai-Tibet Plateau (Fig. 1a), and it is the headwater source of the three largest rivers in China: Yellow River, Yangtze River, and Lancang River. The area has average elevation of over 4000 m, average annual temperature of −5.6–4.9 °C, and the ≥0 °C annual accumulated temperature of

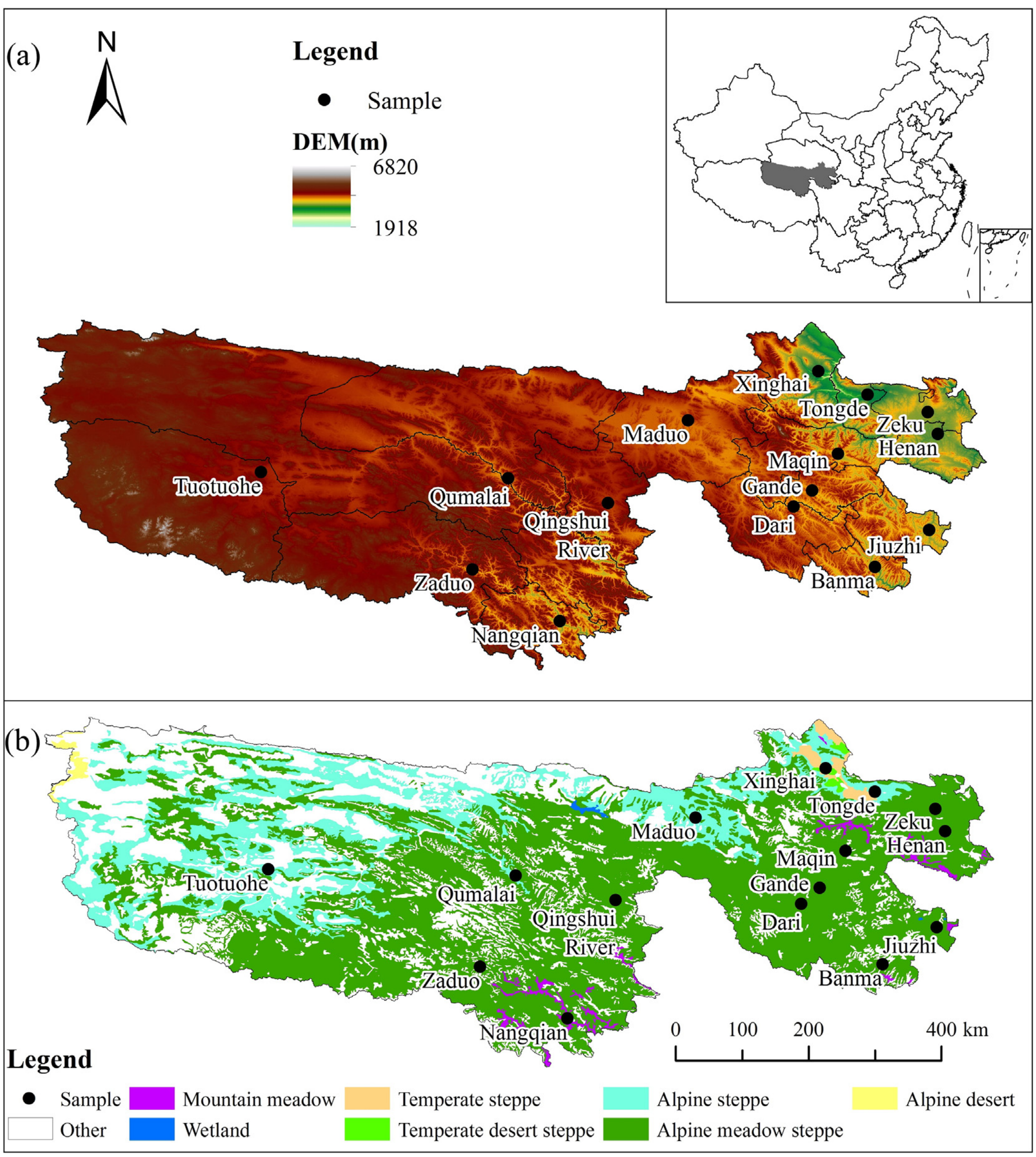

Fig. 1. Digital elevation model (DEM) and locations of the long-term grassland and climate observation stations (a) & spatial distribution pattern of grassland type (b) in the pastoral area in southern Qinghai Province, China.