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Modeling grassland above-ground biomass based on artificial neural network and remote sensing in the Three-River Headwaters Region

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ABSTRACT

Effective and accurate monitoring of grassland above-ground biomass (AGB) is important for pastoral agriculture planning and management. In this study, we combined 1433 AGB field measurements and remotely sensed data with the goal of establishing a suitable model for estimating grassland AGB in the Three-River Headwaters Region (TRHR) of China, which is one of the most sensitive regions to the warming climate. A back-propagation artificial neural network (BP ANN) was used to select the variables that contribute the most to the model's estimation of AGB, and then we built the model. Out of 13 variables, 5 variables were selected to build the BP ANN model, and we used cross validation for the accuracy assessment. The results show that: (1) the modeled mean AGB (2001–2016) provides a reasonable spatial distribution that is similar to the field measurements but reveals more details and has better spatial coverage than the limited field measurements are able to provide; (2) the overall trend of AGB in the TRHR is increasing more than decreasing (44.4% vs 29.2%, respectively) and has a stable area of 26.4%; and (3) the BP ANN model achieves better results than do the traditional multi-factor regression models (R^2: 0.75–0.85 vs 0.40–0.64, RMSE: 355–462 vs 537–689 kg DW/ha). This study presents an effective and operational BP ANN model that estimates grassland AGB for the study area with high accuracy at 500 m spatial resolution, providing a scientific basis for the determination of reasonable stocking capacity and possible future development.

1. Introduction

Grassland is an important component of terrestrial ecosystem that plays a vital role in protecting the ecological environment and preventing erosion (Wang et al., 2009; Liu et al., 2011). Grassland is the material foundation for the development of the national economy in pastoral areas, and it functions as a natural barrier that provides land eco-environmental protection. The Three-River headwaters region (TRHR) is important for its large area of grassland and wetland ecosystem (Zhang et al., 2012; Li et al., 2013b; Tong et al., 2014). As China's most extensive wetland, the TRHR has abundant river, lake, mountain snow, and glacier resources and is known as one of the world's largest alpine wetland ecosystem. Due to its special geographical location, rich natural resources, and distinguished ecological function, the TRHR is an important nature reserve in the Qinghai-Tibet Plateau, China (Liu et al., 2008b; Liu et al., 2014; Zhang et al., 2012; Tong et al., 2014). However, the region's high altitude and harsh natural conditions make its ecosystem extremely fragile. In recent years, the ecosystem has undergone large changes from climate warming and increasing human activities (Jiang and Zhang, 2016). Estimating the grassland biomass timely and accurately and establishing suitable forecasting model can provide a scientific basis for determining a reasonable stocking capacity (Yang et al., 2012). Grassland above-ground biomass (AGB) monitoring methods are categorized into two groups: ground-based and remote sensing methods. The ground-based methods traditionally involve cutting the grass in the field, drying it, and weighing it in the laboratory. However, this approach is time consuming and costly; consequently, it is applicable only for small-scale monitoring (Xu et al., 2008). With the advances in space-borne sensor technology and increase in spatial and temporal resolutions, satellite remote sensing is now regarded as the best choice for large-scale monitoring (Claverie et al., 2012). The remote sensing-based methods

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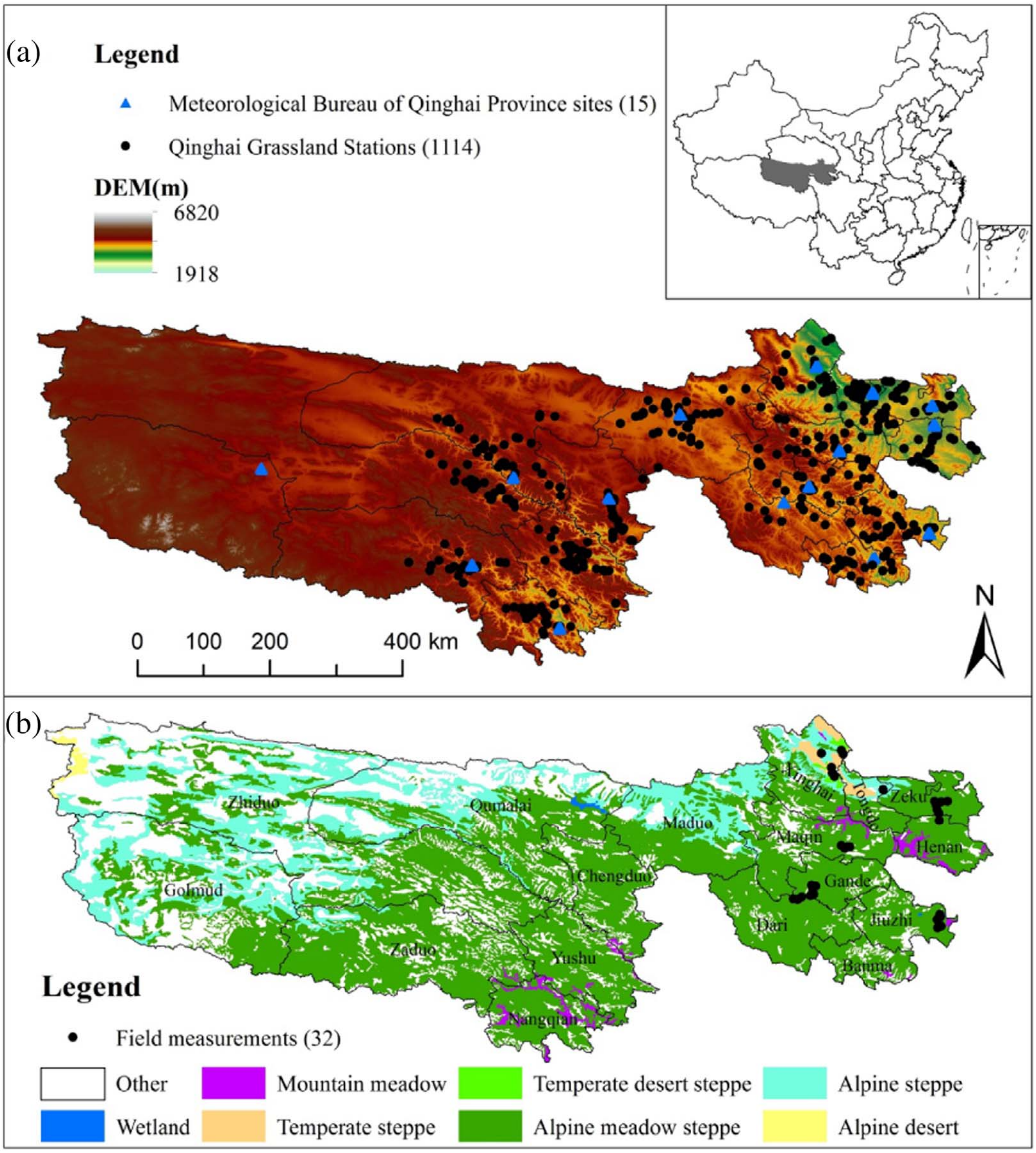

Fig. 1. Observation sites from three different sources: (a) Meteorological Bureau of Qinghai Province sites (15 sites with 287 effective AGB data) and Qinghai Grassland Stations (1114 effective AGB data) overlaid on an elevation map; and (b) the 32 effective AGB field measurement sites of this study in the Three-River Headwaters Region, China. The background elevation data used in (a) are from the Shuttle Radar Topography Mission.

for grassland biomass estimation can be grouped into regression (statistical) and machine learning algorithm models (Ali et al., 2016).

The remotely sensed normalized difference vegetation index (NDVI) has been used to study the health and biomass of natural grasslands since the 1970s (Ullah et al., 2012; Li et al., 2014; Zhao et al., 2014). In addition to the NDVI, other vegetation indexes (VIs) have been used, including but not limited to the soil-adjusted vegetation index (SAVI) (Huete et al., 1985; Huete, 1988), the modified soil-adjusted vegetation index (MSAVI) (Qi et al., 1994), the enhanced vegetation index (EVI) (Garroutte et al., 2016), and the narrow-band vegetation index (Jacques et al., 2014). Studies have indicated that the MSAVI can reduce the influence of soil background, and it is particularly useful for estimating the AGB of sparsely vegetated grassland areas (Gilabert et al., 2002). The EVI can enhance the sensitivity to high vegetation areas, where NDVI saturation occurs at a leaf area index over 2.0–2.5 (Baret and Guyot, 1991; Huete et al., 2002). However, most of the previous studies involved statistical models based on a single VI, and each has its own limitations and uncertainties (Zhao et al., 2014).

The Artificial Neural Network (ANN) model belongs to a powerful class of empirical modeling algorithms that are capable of computing, predicting and classifying data and are more versatile than regression models (Ali et al., 2016). The Back Propagation (BP) ANN has been used to estimate forest biomass (Wang and Guan, 2007; Liu et al., 2008a; Wang and Xing, 2008; Wang et al., 2017) and crop yields, e.g., corn and rice (Panda et al., 2010). However, only limited studies have focused on grassland biomass estimation. Xie et al. (2009) compared the performances of ANN and regression models for AGB estimation in the Xilingol River Basin, Inner Mongolia, by using topographic, vegetation index and spectral information from Landsat ETM + as inputs. The ANN accuracy was $R^2 = 0.82$ and its RMSEr was 40.61%, which were better than those of the regression model ($R^2 = 0.60$ and RMSEr = 50.08%). Yang et al. (2012) used the ANN algorithm for grassland biomass estimation based on five vegetation indices derived from MODIS and found that the ANN models were more accurate ($R^2 = 0.56$–0.71) than the statistical models ($R^2 = 0.54$–0.68). Vahedi (2016) developed both site-specific allometric equations and ANN models for predicting tree biomass and found that the best ANN model, using the Tan-sig function, resulted in lower error ($R^2 = 0.91$, RMSE% = 7.37), compared with the allometric equations ($R^2 = 0.88$, RMSE% = 8.83). Li et al. (2013a) used single and multi-temporal remotely sensed data to estimate grassland biomass with both statistical and ANN models and found that the use of multi-temporal remotely sensed data has advantages for AGB estimation and that the ANN achieved higher accuracy for AGB estimation. Although studies have shown that it is difficult to determine