Identifying critical factors governing the distribution of aboveground biomass in alpine steppe and meadow, Tibetan Plateau

Running title: Relationships between the aboveground biomass and environmental factors

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Abstract

Tibetan Plateau, the world's third pole with extremely harsh and fragile ecological environment, attracts scientists' attention due to its sensibility to global changes. Alpine grassland on Tibetan Plateau plays an important role in global carbon cycling. Many studies have examined the effects of a variety of environmental factors on the biomass distribution but failed to identify critical ones... In this study, relationships between the habitat factors and the aboveground biomass (AGB) abundance on Tibetan Plateau were examined for 110 field sites across the widely distributed alpine steppe and meadow respectively. The obtained data were then analyzed using the classification and regression tree (CART) model and the generalized additive model (GAM)**.** The results showed that (1) the abundance of AGB in alpine steppe was controlled by six critical environmental factors, including soil organic carbon density of top 0-30cm (SOC1), longitude, mean annual precipitation (MAP), latitude, clay and soil moisture. As for the alpine meadow, there were five governing factors, including altitude, soil moisture, nitrogen, MAP and mean annual temperature (MAT). (2) The increased AGB abundance in the alpine steppe was associated with the increases in SOC1, MAP and latitude, while the increase in longitude resulted in decreased AGB abundance. As for the alpine meadow, the altitude and soil moisture showed strong negative effects on the abundance of AGB, while soil nitrogen content is positively related to the AGB distribution across all examined sites. These results suggested that the combinative effects of meteorological, topographic and soil factors were significant on the spatial patterns of AGB on Tibetan Plateau.

Keywords

Environmental factors, Aboveground biomass, Alpine steppe, Alpine meadow, Tibetan Plateau

1 Introduction

Grasslands, covering approximately 25% of the land surface on earth, account for 10% of global C stocks

(Hui and Jackson, 2006). Vegetation biomass and production are of vital importance (Jobbágy and Sala, 2000; Ma et al., 2008) as both aboveground- and belowground biomass are the major contributors to soil organic matter, which may affect the greenhouse gases emission in terrestrial ecosystem and thus play a particular role in the Earth's C cycling (Mokany et al., 2006) (Wang et al., 2011).

Tibetan Plateau is well known for its extremely harsh environment and high sensitivity to climate changes (Chapin et al., 2008). Vegetation there is difficult to recover once disturbed or degraded because of its rather thin soil layer (Zhang et al., 1998). As a matter of fact, the environment and ecology system on Tibetan Plateau have been detrimentally affected in recent years due to excessive human activities in the area such as overgrazing, wood harvesting and collection of specific herbs for producing Chinese medicine (Wang et al., 2000). As a result, the severely affected environment becomes more fragile and sensitive to climate changes and spawns increasing attention in regard to the issue of ecological security in China.

Alpine grasslands are the most extensive vegetation on Tibetan Plateau and cover an area of more than 2.5 million km^2, and play an important role in the global carbon cycling (Shen et al., 2008).Therefore, accurate quantification of alpine grassland biomass and the knowing of its relationship with the environmental factors at the regional scale are essential to the estimation of the global change impact in this area. To better understand the dynamics of alpine grassland C cycles, it is also critical to interpret the spatial pattern of biomass and to identify the controlling factors.

There have been many recent studies on terrestrial biomass in alpine environments with focus on: 1) the relationship between biomass and plant species richness (Bhattarai et al., 2004; Thomas and Bowman, 1998; Namgail et al., 2012; Wang et al., 2008; Han et al., 2007; Grytnes, 2000), 2) the aboveground and belowground biomass allocation from individual plant (Wang et al., 2010) to community level (Yang et al., 2009) leading to the proposals of optimal partitioning and isometric allocation mechanism, and 3) the biomass spatial patterns (Wu et al., 2007; Luo et al., 2002), and the relationship between biomass and meteorological factors (Ma et al., 2010a; Yang et al., 2009; Zhang et al., 2010), soil properties (Yang et al., 2009; Lu et al., 2011; Gerdol et al., 2004), and topographical factors (Bruun et al., 2006; Luo et al., 2004 ; Litaor et al., 2008; Fisk et al., 1998). A number of studies examined the relationship between biomass distribution and environmental factors (e.g., Li et al., 2011; Huang et al., 2011) but no attempt have been seen to screen the most critical factors that govern the biomass distribution.

Generally, the environmental factors that would affect the spatial pattern of biomass can be divided into three categories: meteorological factors (e.g., air temperature, relative humidity, precipitation, etc.), topographic factors (e.g., longitude, latitude, altitude, slope, aspect, etc.), and soil factors (e.g., soil moisture, soil temperature, soil nutrient, soil texture, soil organic matter, etc.).

The objectives of the present study were to investigate the distribution pattern of aboveground biomass (AGB) abundance on Tibetan Plateau and its relationship with the environmental factors in the areas of alpine steppe and meadow respectively, with an aim to screen out the critical factors by the use of CART model. We also predicted the evolutions of aboveground biomass with the major environmental factors by using GAM method.

2 Material and methods

2.1 Study area

Tibetan plateau is a high-altitude arid steppe interspersed with mountain ranges (bordered to the north by the Kunlun Range and to the northeast by the Qilian Range) and large brackish lakes. In the region, grassland mainly consists of alpine meadow and alpine steppe (Wang et al., 2006). From west to east and from north to south of the Tibetan Plateau, annual precipitation increases from 100 to 300 millimeters. Permafrost covers extensive parts of the northern and northwestern plateau. Reaching the remote Changthang region in the northwestern part, the average altitude exceeds 5,000 meters and the winter temperature can drop to −40 ℃. The Changthang-Kekexili region is extremely inhospitable with the least population in Asia and is the third least populated area in the world. (*http://en.wikipedia.org/wiki/Tibetan_Plateau*). The unique climate and vegetation types, together with a relatively low intensity of human disturbance, make the plateau an ideal region to conduct studies on the response of natural ecosystem to climate change (Yang et al., 2009).

The examined alpine grassland area (latitude from 29.41 to 37.61° N and longitude from 81.18 to 101.31° E) and the sampling sites chosen in this study are indicated in Fig. 1. Vegetation types include alpine steppe (dominated by cold-xerophytic, short, dense tussock grasses such as *Stipa purpurea* and *Festuca ovina*) and alpine meadow (dominated by perennial tussock grasses such as *Kobresia pygmaea* and *Kobresia tibetica*, usually mixed with alpine forbs such as species of Gentiana and Pedicularis). (Ma et al., 2010b; Zhang et al., 1988).

2.2 Data collection

Data package required in this study include meteorological factors (MAT, MAP and Idm), topological factors (longitude, latitude, altitude, slope and aspect), soil factors (moisture, clay, silt, nitrogen, organic carbon density at the depth of 30cm (SOC1), 50cm (SOC2) and 100cm (SOC3)), grassland types (alpine steppe and alpine meadow), and one target variable abundance of aboveground biomass (AGB).

Table 1 piles the data we adopted from previous studies (Yang et al., 2009; Yang et al., 2010; Yang et al., 2008), where samples were collected from 110 sites (74 in alpine steppe and 36 in alpine meadow, each site area 10 m*10 m) in July and August of each year between 2001 and 2005.

Moisture, nitrogen, silt, clay, and organic carbon density (at the depths of 30, 50, and 100 cm, respectively) of the soil were determined at each site. Meteorological factors were also examined.

The data of altitude, slope and aspect were extracted from Digital Elevation Model (DEM) using the ARCgis 9.3 software and compared with the results of previous study by Feng et al (2006). Only the factor of altitude showed good fittings (Fig.2 a, R^2=0.9885) between observation (data from Yang' studies) and simulation (data from DEM).

As an important meteorological factor, the index of aridity (Idm) was calculated using the data of mean annual temperature (MAT) and mean annual precipitation (MAP) by the formulae (de Martonne, 1926):

$$Idm = P/(T+10).$$

Where P is the average precipitation (mm) and T is the average temperature (℃).

2.3 Data analysis

Data were processed by the following steps:

Firstly, the apparent effects of each environmental factor on AGB abundance were studied by correlation analysis (CA) using the data collected across various studied sites.

Secondly, the classification and regression tree (CART) analysis, which was developed by Breiman (1984) and allows all possible interactions and adjustments for decision making (Toschke et al., 2005), was performed to identify the critical variables that may have significant influence on the response variables. In the analysis, the R package *repart* was used that contains *repart* function, *repart.control* function, *prune* function, and so forth. The method works by splitting the data into mutually exclusive subgroups (nodes) within which all the objects have similar values for the response variable. Using a repeated binary splitting procedure, the process starts from the split of the root (or parent node) that contains all the objects in the data set into two nodes (or child nodes) and the process continues by treating each obtained child node as a new parent node (Put et al., 2003). *CP* was a parameter indicating the model's complexity (the lower *CP* value, the more complicated model).Details of the CART processing can be found in supplement S1-S4 in the supporting information.

Lastly, the generalized additive models (GAM) analysis was conducted to explore the evolution trend of AGB abundance with respect to the critical environmental factors . The R package *mgcv* was used to fit generalized additive models, specified by giving a symbolic description of the additive predictor and a description of the error distribution. The *gam* used the *backfitting algorithm* to combine different smoothing or fitting methods(R Development Core Team 2011; Qian, 2008). The *mgcv* package contained *gam* function, *gam. fit* function and *family* function etc.

In the study, the statistical analysis and plotting were performed using the R freedom software (version 2.15) (R Development Core Team, 2011).

3 RESULTS

3.1 The impacts of environmental factors on abundance of AGB

The effects of environmental factors (topographic, soil and meteorological) on abundance of AGB were examined by pearson correlation analysis, as shown in Table 2. The results showed that AGB abundance was more sensitive to the topographic factors (i.e., longitude and latitude) and soil factors (i.e., SOC1, SOC2 and SOC3) across all sites in the alpine steppe, with the corresponding values of R^2 being 0.620, 0.645, 0.683, 0.696 and 0.720, respectively. On the other hand, the AGB abundance of alpine meadow was more sensitive to soil nitrogen, SOC1, SOC2, SOC3, moisture, longitude and altitude, with the the corresponding values of R^2 being 0.502, 0.433, 0.432,0.417, 0.303, 0.503 and 0.389, respectively.

3.2 Identification of critical factors by CART model

The impacts of all kinds of environmental conditions on AGB abundance were apparent. In order to identify the most influencial ones among these factors, CART analysis was carried out in this study. Initially, we set the *CP* value to be 0.005 in the R procedure. Thirteen predictive variables were included in the formula, and the results showed that ten variables were finally adopted in the model. Nevertheless, the model was still very complex. Such trees are often difficult to interpret and their predictive ability for new observations is generally poor since they tend to match noise in the data. The establishment of a smaller tree, derived from the maximal one, was then necessary for predictive purposes. Among other modeling techniques, one is looking for the best compromise between model fit and prediction properties. So we used the *prune* function to prune the tree, througth the R output, we noted that the xerror value decreased with the number of splitting before the No.6, but the xerror value increased in the next splitting. an effective method for developing an appropriate tree is to seek the minimum of xerror value is. We found the minimum of xerror value was associated with a *CP* value of 0.0497 in the output list, this new *CP* value was used to fit the model and the results were shown in Figs. 3 and 4.

As can be seen in Fig. 3, six critical environmental factors (SOC1, longitude, MAP, Latitude, clay and mositure) were tested for alpine steppe, and the tree consists of a root node (SOC1) containing all samples (n=74). The initial parent was splitted based on the value of the soil organic carbon density at the 30 cm soil depth, and the best predictor was obtained. If SOC1 was greater than 9.38 kg m^{-2}, those samples were put in the first terminal node (n=3) , and all other AGB abundance samlpes were placed in node 1 (SOC1 is < 9.38 kg m^{-2}, n=71). The group of samples in node 2 was initially assigned longitude, and it was also splitted into two children nodes. Prediction was improved by further partitions. If longitude was less than 91.88°, the samples were put in the second terminal node (n=35), and all other samples were placed in node 2 (longitude is > 91.88°, n=46). It followed that, the MAP below 299.4 mm were placed in the third terminal node (n=7), and the preciptations above 299.4mm were placed in node 3 (n= 29). The fouth, fifith and sixth subgroups were latitude, clay and moisture, respectively. On the other hand, we also found that the sum of squares of deviations decreased with the parent splitting in boxplots, and the criticlal factors were screened step by step.

In Fig.4, five critical environmental factors (i.e., altitude, moisture, nitrogen, MAP and MAT) were tested for alpine meadow, and the tree consists of a root node (altitude), containing all simples (n=36). The initial parent was splitted based on the value of the altitude, and the best predictor was obtained. If the value of altitude was greater than 4303m, the samples were put in the left children nodes (n=16) and all other samples were placed in the right children nodes (altitude < 4303 m, n=20). The group of AGB abundance in left was initially assigned moisture, it was also splitted into two children nodes. Prediction was improved by further partitions. The right node was assigned the soil nitrogen, where if soil nitrogen content is less than 6.9 mg g^{-1}, the samples were put in the left node (n=16), and all other samples were placed in right node (soil nitrogen content < 6.9 mg g^{-1}). Subsequently, the nodes were assigned to MAP and MAT, respectively. The samples with MAP ≥ 456.2 mm were placed in the left node (n=12), other samples were placed in the right node (n=4). The MAT also was splitted in two subgroups (Both left and right samples of children were n=2). The sum of squares of deviations decreased with the parent splitting in boxplots, and the optimal factors were thus identified.

3.3 Prediction of the changing trend of AGB abundance by GAM

For further exploring the relationships of environmental variables with the response variable (abundance of AGB), the distributed type of samples should be analyzed. Fig.5 shows that the samples were non-normal distribution for both alpine steppe and meadow. The generalized additive models (GAM) were used to better understand such relationship. Abundance of AGB exhibited large variations across all the sites, ranging from 9.80 to 347.50 g m^{-2} for alpine steppe, and from 31.80 to 255.90 g m^{-2} for alpine meadow. The median values were 45.20g m^{-2} and 100.00 g m^{-2} for the alpine steppe and meadow, respectively. Statistical analysis shows that the STDEV values for the alpine steppe and meadow were 58.33 (n=74) and 56.30 (n=36), respectively.

Results of the GAM spline fittings regarding each individual environmental factor to the abundance of AGB varied from simple linear functions to highly complex curves. The response curves of the critical factors for alpine steppe (SOC1, longitude, MAP, MAT and soil moisture) and for the alpine meadow (altitude, soil moisture and nitrogen) were shown in Figs.6 and 7, respectively.

The relationships of AGB abundance with the critical factors showed two dominant patterns in alpine steppe (Fig.6). The first pattern is: The curves of AGB increased with increasing SOC1 and MAP values, with the maxima AGB observed at corresponding values of approximately 10 kg m^{-2} for SOC1 and 500 mm for MAP, respectively. The second pattern is: A linear decline in AGB with increasing longitude, and a linear increase with increasing latitude, with the maxima AGB observed at corresponding values of approximately at the longitude of east 80° and latitude of north 37°, respectively. However, the relationship of AGB with soil moisture was not apparent due to large value of errors. Namely, such relationship cannot be obtained by GAM. Overall, the shapes of these response curves of critical environmental factors were highly variable, indicating their spatial variability.

As for alpine meadow, the relationships between AGB abundance and the critical environmental factors showed a general decline with increasing altitude and soil moisture. Within this trend, the maxima of AGB (Fig.7) were observed at an altitude of approximately 3000 m and soil moisture of 5%. The other trend found is a generally positive relationship between the AGB abundance and the soil nitrogen, with the maxima AGB observed at a soil nitrogen level of approximately 10 mg g^{-1}.

4 Discussion

The abundance of AGB was significantly related to several environmental factors in alpine grassland area on Tibetan Plateau. SOC1, MAP, longitude and latitude were found to be the critical variables in alpine steppe area. The critical variables in alpine meadow area appeared to be altitude, soil moisture and nitrogen. These critical environmental factors can be used to predict the spatial variation of AGB abundance.

For the alpine steppe, the increase in SOC1 (soil organic carbon density of soil 0-30cm depth), MAP (Mean annual precipitation) and latitude led to increased AGB abundance, but increase in longitude resulted in decreased abundance of AGB. Generally, soil organic matter constrains the supply of soil nutrients, which in turn may limit tundra production (Holzmann and Haselwandter, 1988). In alpine zones, low temperature might have resulted in restricted activity of microbes in the topsoil (0-30 cm depth) and thus reduced microbial decomposition of soil organic matters which led to relatively higher soil organic carbon density

(Wang et al., 2007). Therefore, the environmental factor SOC1 has a positive impact on abundance of AGB in the light of nutrients supply that derived from soil organics for plants growth.

Precipitation was another critical factor controlling primary productivity in most alpine grasslands (Hu et al., 2010; Huxman et al., 2004; O'Connor et al., 2001) that is strongly influenced by water availability (Epstein et al., 1997). Our results are consistent with those in previous studies showing that aboveground net primary production (ANPP) in alpine steppe was positively related to mean annual precipitation (MAP) (Lieth et al., 1978; Xu et al., 2006; Bai et al., 2000).

Geographic position that determines the effect of climatic variation may exert great influence on abundance of AGB in grasslands (Briggs and Knapp, 1995). Fisk et al. (1998) had reported that topography controls snowpack accumulation and hence growing-season length that in turn affects soil water availability, distribution of plant communities and aboveground productivity. Different geographical responses of plants to topographic position had been reported in the literature confirming the significant role of topography in assessing plant species richness. For instance, Bruun et al.(2006) who had studied the species richness of vascular plants, bryophytes and lichens in alpine communities, and suggested that the topography may be an important and better predictor. In our results of the relationship between AGB abundance and topographic factors, negative effect of longitude and positive effect of latitude on the abundance of AGB was observed. This finding is in disagreement with the previously reported inverse relationship between maximum aboveground biomass and latitude (Asaeda et al., 2005). Longitude and latitude are likely to be the most primary topographic factors affecting the abundance of AGB due to the differences in soil conditions and micro-climates in different longitudinal and latitudinal positions. Differences in the resource translocation and belowground organs may also help explain our findings regarding the role of longitude and latitude.

In alpine meadow, on the other hand, a clearly negative linear relationship between abundance of AGB and altitude was observed due to the fact that temperature and soil nutrients decrease with increasing altitude (Rastetter et al. 2004). This result is consistent with previous findings (Roem and Berendse 2000). However, a hump-shaped relationship may also be possible in the case of trampling and overgrazing by domestic livestock at the lower slopes that depletes plant resources (Namgail et al., 2012).

The strongly negative relationship between abundance of AGB and soil moisture across the sites in alpine meadow was an interesting finding. We argue that soil moisture is a limiting factor for the growth and production of alpine plants and thus can influence the abundance of AGB. Same conclusion was made by Oberbauer and Billings (1981) and Yang (2009) that local distribution of plant species was largely determined by moisture within the alpine zone of a mountain range. Also, such relationship could reflect the result of long-term plant adaptation to local habitants in these studied areas.

As for the factor of soil nitrogen, it has been well established that nitrogen is the mineral nutrient that plants require in the greatest quantity (Chapin et al., 1987), and reportedly often limits the plant growth in natural ecosystems due to its central role in the photosynthetic apparatus and high mobility in soil system (Bowman et al., 1993). Therefore, nitrogen content was a major soil factor affecting the abundance of AGB in the alpine meadow as the abundance of above-ground biomass strongly depends on soil fertility (Han et al., 2007). It is very likely that the relatively low soil mineralization rates and low nutrient availability resulted in the relatively low aboveground production in such cold, dry environment of alpine grassland on Tibetan Plateau. This is in agreement with the reported observations that nitrogen was the major limiting element in the alpine meadow and nitrogen addition caused the change of functional groups especially of the predominant grass (Han et al., 2007; Niklaus et al., 1998).

So far, most researches had mainly focused on response and adaptation of plants to individual features of the environment, but in real circumstances plants usually encounter comprehensive effects of a variety of environmental factors (Chapin et al., 1987). Therefore, abundance of AGB in the alpine grassland is influenced by soil fertility, spatial pattern and meteorological conditions of the alpine grassland. In this study, however, there are great differences between the results of alpine steppe and of alpine meadow: The prior limiting factors in alpine steppe were SOC1and MAP, but in alpine meadow they are soil moisture and nitrogen content. This could be easily explained by the fact that soil water content and organic matter in the area of alpine meadow are already higher than that in alpine steppe. Soil organic matter and rainfall appear to be the prior important factors in alpine steppe because they are the preconditions for soil nitrogen content and moisture. However, due to the cold temperature and immaturity of the soil, conversion of soil organic matter into nitrogen nutrient was limited. Therefore, soil nitrogen was found to be a critical factor affecting abundance of AGB in alpine meadow although relatively high soil organic contents present in soil.

From the geographic point of view, meadow is not zonal distribution, and the adequate water and lowlands maybe spring up the meadow, thus the altitude becomes a limiting factor, and the higher the altitude, the lower the atmospheric temperature that is more likely to limit meadow growth. On the other hand, steppe exhibits a zonal distribution under sub-humid and semi-arid climatic conditions; elevation becomes a directly decisive parameter for alpine steppe, with abundance of AGB determined mainly by latitude and longitude.

Besides, there are two changing trends in our findings that require attentions: one is the declining of AGB abundance with increasing latitude in alpine steppe; the other is the declining of AGB abundance with increasing soil moisture in alpine meadow. Even though the generalized additive model was used in this study provided us useful information, further study is needed to explain the above observations.

5 Conclusions

The abundance of AGB across 110 sites was analyzed with the generalized additive model (GAM) to identify its governing environmental factors in alpine steppe and meadow on Tibetan Plateau. By using the classification and regression tree (CART) model, it was found that soil organic carbon density of top 30cm (SOC1), longitude, mean annual precipitation (MAP) and latitude were the critical environmental factors for alpine steppe, while for alpine meadow the governing environmental factors apparently include altitude, moisture and nitrogen. These identified factors can be used to predict the spatial variation trend of AGB abundance in this studied region. The combinative effects of meteorological, topographic and soil factors on the spatial patterns of AGB abundance were found significant. A better in-depth understanding of critical factors that determine temporal and spatial variation in AGB abundance on Tibetan Plateau is of high relevancy regarding the ecological security issue in China.

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Table1 List of the selected environmental factors in the study

Index	**Unit**	**Abbreviation**	**Source**	**Sample size**	**Category**
Longitude	°	●	Yang *et al.* (2008,2009)	110	Topographic factors
Latitude	°	●	★	110	
Altitude	m	●	★	110	
Slope	°	●	Extracted from DEM	110	
Aspect	°	●	★	110	
Moisture	%	●	Yang *et al.* (2008,2009)	110	Soil factors
Clay	%	●	★	110	
Silt	%	●	★	110	
Nitrogen	mg g^{-1}	●	★	110	
Soil organic carbon density in the depth 30cm	kg m^{-2}	SOC1	★	110	
Soil organic carbon density in the depth 50cm	kg m^{-2}	SOC2	★	110	
Soil organic carbon density in the depth 100cm	kg m^{-2}	SOC3	★	110	
Mean annual temperature	°	MAT	Yang *et al.* (2008,2009)	110	Meteorological factor
Mean annual precipitation	mm	MAP	★	110	
Index of aridity	●	Idm	▲	110	
Aboveground biomass	g m^{-2}	AGB	Yang *et al.* (2008,2009)	110	Target variable

Note: ▲Idm = $P/(T+10)$, P is the average precipitation(mm), T is the average temperature(°).

★Same as above

●Missing value or unit

Table2 The correlations of abundance of AGB with environmental factors

Abundance of AGB	Items	Longitude	Latitude	Altitude	MAT	MAP	Moisture	Clay	Silt	Nitrogen	SOC1	SOC2	SOC3	Iam
Alpine steppe	Pearson Correlation	.620**	.645**	-.616**	-0.177	.504**	.555**	0.121	.519**	.583**	.683**	.696**	.720**	.465**
	Sig. (2-tailed)	0	0	0	0.131	0	0	0.302	0	0	0	0	0	0
	N	74	74	74	74	74	74	74	74	74	74	74	74	74
Alpine meadow	Pearson Correlation	.503**	.389*	-.418*	0.071	0.092	0.303	0.132	.342*	.502**	.433**	.432**	.417*	0.022
	Sig. (2-tailed)	0.002	0.019	0.011	0.679	0.594	0.072	0.443	0.041	0.002	0.008	0.009	0.011	0.9
	N	36	36	36	36	36	36	36	36	36	36	36	36	36

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

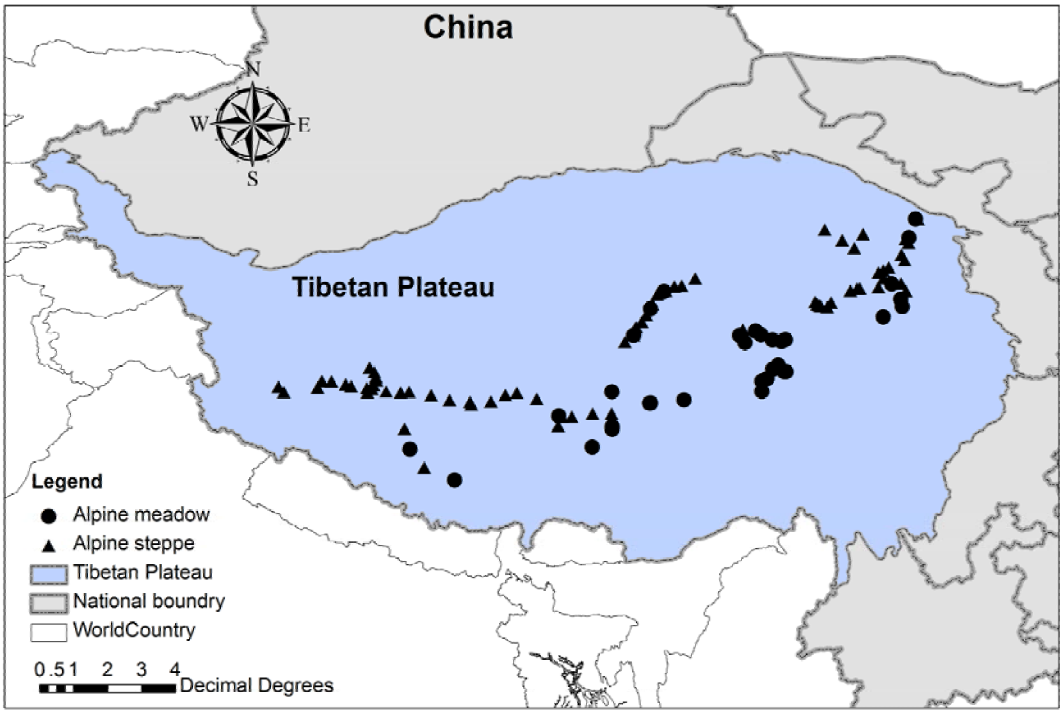

Figure 1 Spatial distribution of sampling sites in alpine grasslands on the Tibetan Plateau, China. The black solid triangles represent the samples collected in alpine steppe, and the black solid circles represent the samples collected in alpine meadow. The locations of sampling sites surveyed during 2001–2005.

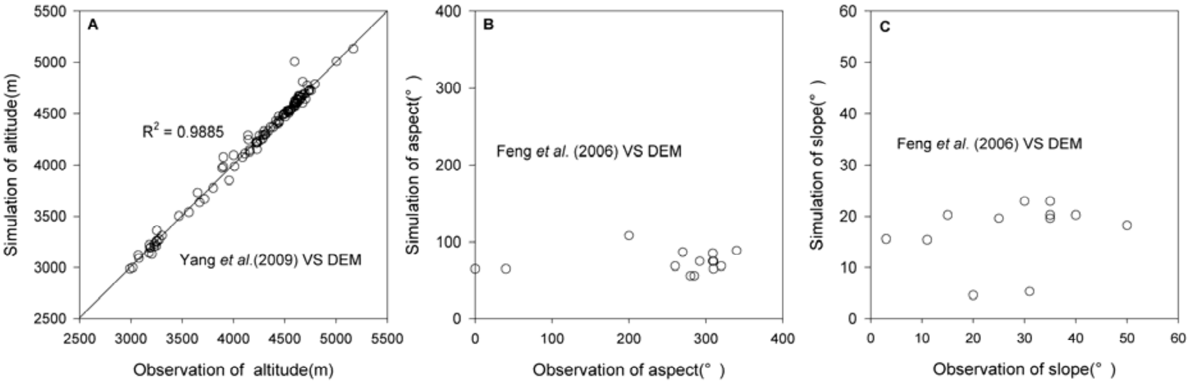

Figure 2 The simulated results of altitude (A), aspect (B) and slope (C) of the terrain parameters compared to observed values. In (A), the fitting effect was very accurate ($R^2 = 0.9885$), so the datum of altitude was used in the paper. And we did not consider using the bad fitting effect of the aspect and slope for analyzing the relationship between AGB abundance and the topographic factors.

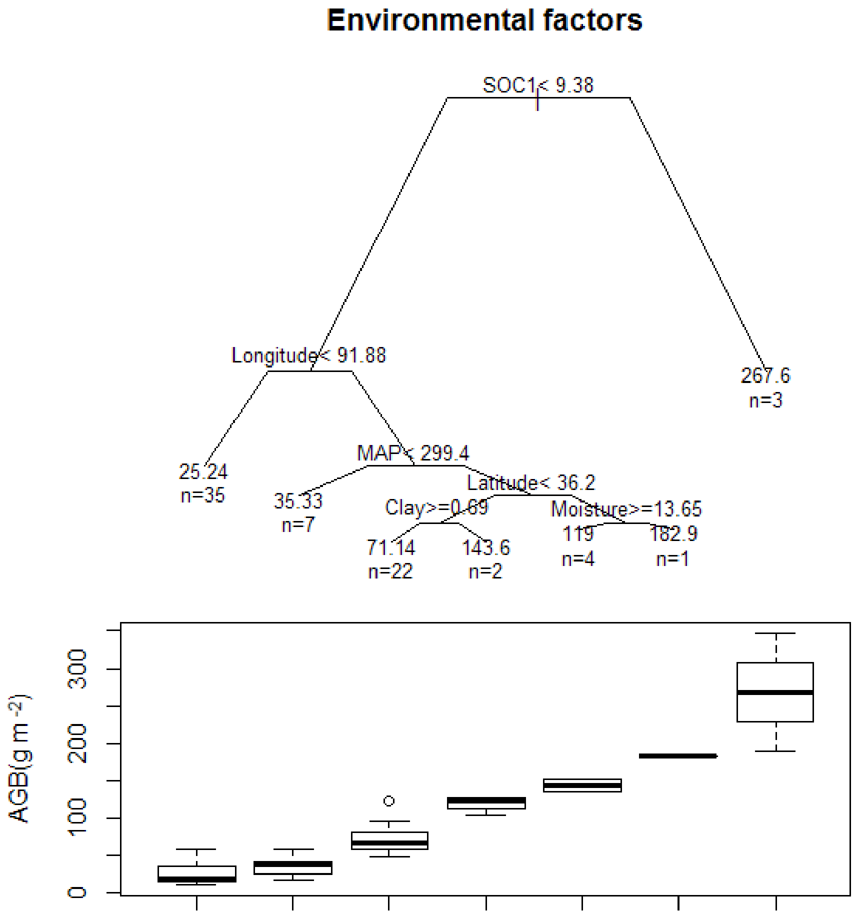

Figure 3 The relationships between AGB (aboveground biomass) abundance and environmental factors were analyzed via the CART (the classification and regression tree) analysis in the alpine steppe, and the critical factors were showed in the graph by screening. The y-axis represented the aboveground biomass, and the abbreviations of SOC1 and MAP were the soil organic carbon density in the depth 30 cm and the mean annual precipitation respectively. In lower panel, the box-plots represent deviation of the aboveground biomass under the corresponding environmental factors in children nodes

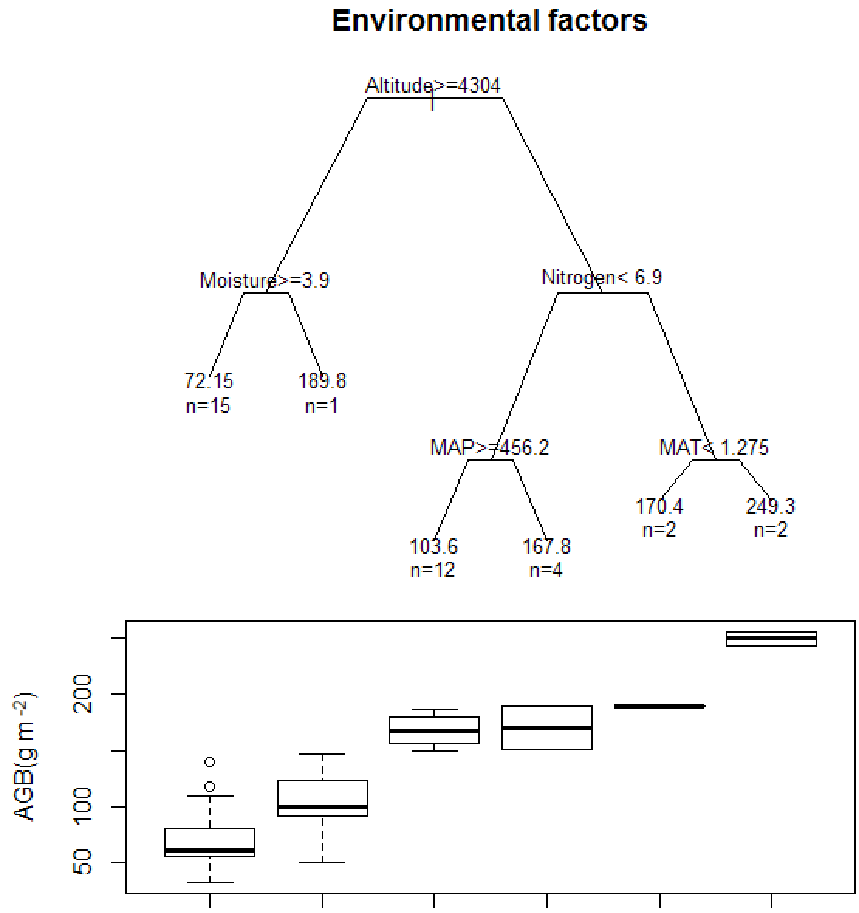

Figure 4 The relationships between AGB (aboveground biomass) abundance and environmental factors were analyzed via the CART (the classification and regression tree) analysis in the alpine meadow, and the critical factors were showed in the graph by screening. The y-axis represented the aboveground biomass, and the abbreviations of SOC1 and MAP were soil organic carbon density in the depth 30 cm and mean annual precipitation respectively. In lower panel, the box-plots represent deviation of the aboveground biomass under the corresponding environmental factors in children nodes

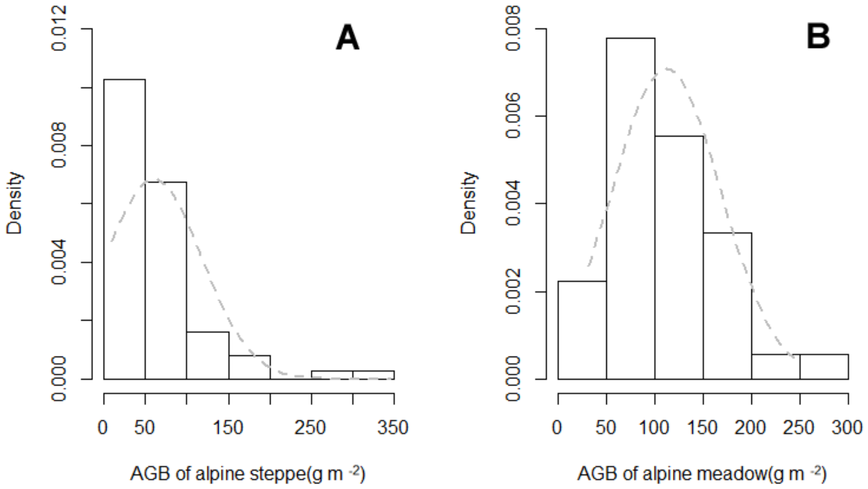

Figure 5 The graphs show the density distribution curves of AGB (aboveground biomass) abundance of samples collected in the alpine steppe (A) and alpine meadow (B) of Tibetan Plateau during 2001–2005.

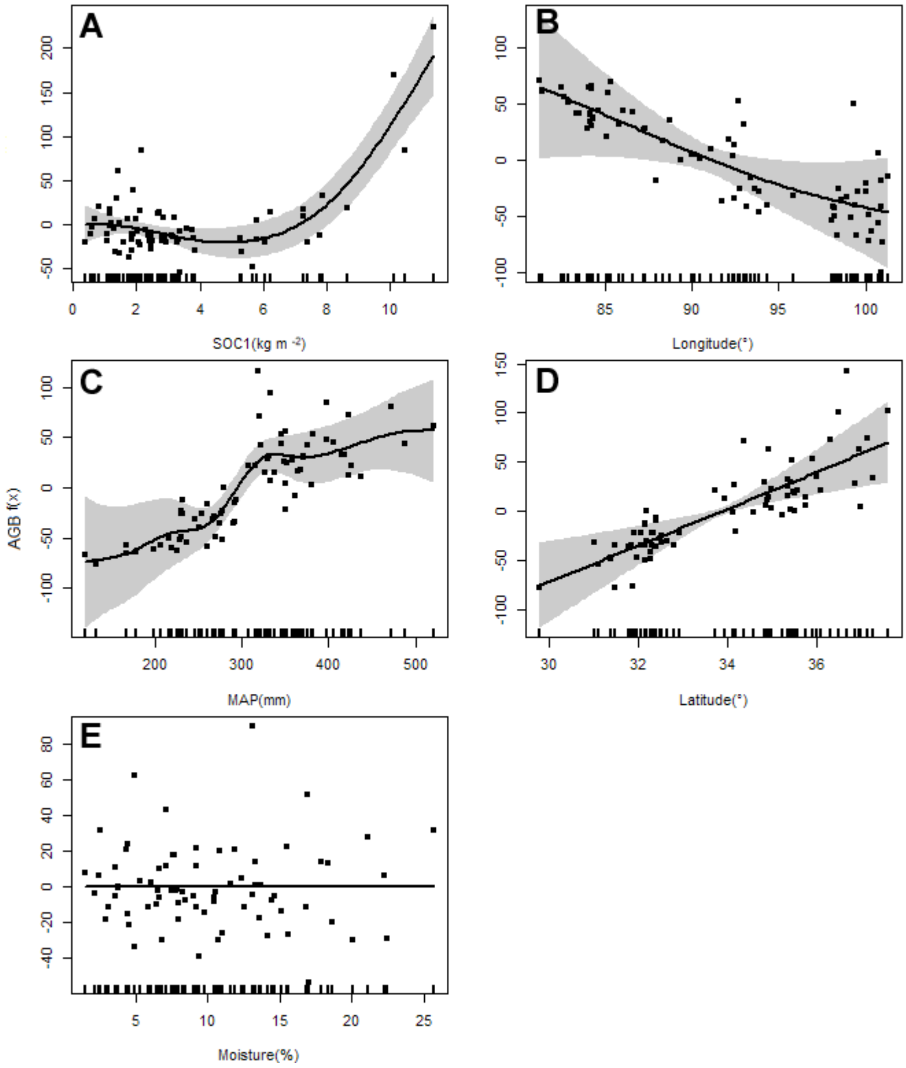

Figure 6 Exploring and predicting the AGB (aboveground biomass) abundance changed with the major environmental factors using GAM (the generalized additive models) analysis in the alpine steppe. Rugplot on the x-axis represents the number of observations, and the gray belts are the credible intervals. The y-axis label stands for the abundance of the aboveground biomass (g m^{-2}) and the x-axis label of the panels (A), (B), (C), (D) and (E) are SOC1 (soil organic carbon density in the depth 30 cm), longitude, MAP (mean annual precipitation), latitude, and moisture respectively.

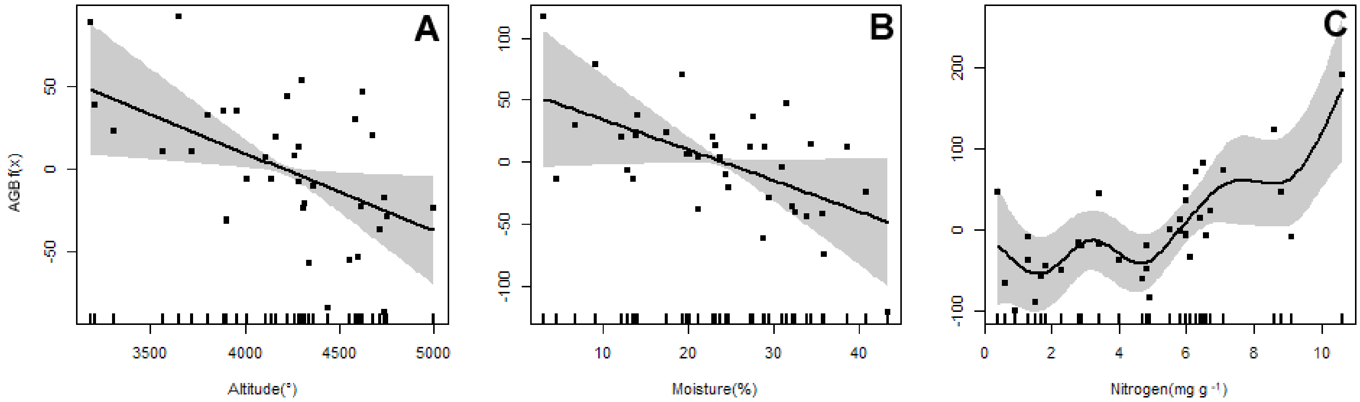

Figure 7 Exploring and predicting the AGB (aboveground biomass) abundance changed with the major environmental factors using GAM (the generalized additive models) analysis in the alpine meadow. Rugplot on the x-axis represents the number of observations, and the gray belts stand for the credible intervals. The y-axis label is the abundance of the aboveground biomass (g m^{-2}) and the x-axis label of the panels (A), (B) and (C) represent altitude, moisture and nitrogen respectively.