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STUDIES ON THE CHARACTERISTICS OF VEGETATION AND SOIL ON MOUNT SEJILA, TIBET

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Abstract

In order to better understand the ecosystems of the Qinghai-Tibet Plateau, we studied the characteristics of the vegetation and soil on Mount Sejila in Tibet, at altitudes ranging from 3700m to 4700m was studied. Eleven sampling areas were examined, and the vegetation composition, species diversity, plant biomass and soil properties were measured in each one. Representatives of 99 different plant species from 26 families were identified, and the plant communities exhibited a clear degree of altitude dependence: some species were found in all samples while others were only present in a single sampling area. Plant aboveground biomass correlated negatively with altitude, but the species diversity (based on the Shannon-Wiener and Simpson diversity indices as well as evenness and species richness measurements) were not altitude dependent. Community similarity decreased as the difference in altitude between sites increased. The measured soil properties had significant effects on plant characteristics, especially the soil nitrogen, soil moisture and temperature. The results presented herein provide a solid foundation for a more comprehensive study of the Qinghai-Tibet Plateau's ecosystems and will be useful in drawing up biodiversity and ecosystem preservation schemes.

Introduction

The Qinghai-Tibet Plateau is a typical high altitude region. It has a cold environment, permafrost and certain unique climatic properties. Climatic fluctuations and other processes have created a wide range of environments and landscape types within the plateau, including deserts, meadows, grasslands and forests. Each of these landscapes has its own distinct vegetation types.

The plateau has been studied extensively due to its unique geological location and the importance of maintaining its ecosystem diversity in due to ongoing climate change. Previous studies on the ecosystems of the Qinghai-Tibet Plateau have focused on: (1) its vegetation, including vegetation types and community diversity, the relationships between vegetation types and altitude, and plant biomass/vegetation productivity (Li *et al*., 2007; Wang *et al*., 2013); (2) its soil properties and their relationship with the local environment (Wang *et al*., 2007; Noor & Khatoon, 2013); and (3) the interactions between its plants and their environment, including the effects of environmental factors (temperature, season shifts, soil moisture and temperature) on plant germination, growth, phenology, community diversity and distribution, and soil conditions (Berdanier & Klein., 2011; Xu *et al*., 2011;Wang *et al*., 2012; Zhang *et al*., 2012; Jin *et al*., 2013; Liu *et al*., 2013). In addition, some new areas of active research have developed due to concerns regarding the potential impact of global warming. These include (1) the effects of climate change on the plateau's ecosystems and vegetation (Xu *et al*., 2008; Yu & Xu, 2009; Li *et al*., 2010; Wang *et al*., 2011), soil properties (Wang *et al*., 2007), and the impact of permafrost melting on vegetation and the soil carbon pool (Wang *et al*., 2008); (2) the impact of climate change on the plateau's vegetation types and community responses to climate change (Song *et al*., 2005; Zhang *et al*., 2011); and (3) changes in the spatial distribution of vegetation phenology due to climate change (Piao *et al*., 2011; You *et al*., 2011). Many of these investigations have relied heavily on satellite data and modeling.

Despite this large body of work, little is known about the effects of altitude on vegetation and soil properties vary across the different regions of the Qinghai-Tibet Plateau or the associated relationships between vegetation types and soil properties. Due to the diversity of ecosystem types within the plateau, there are some inconsistencies between the results that have been reported for its different regions. Moreover, there is a general lack of information concerning the vegetation and ecosystems in certain parts of the plateau. To address these issues, we analyzed data gathered at the Qinghai-Tibet Plateau characteristic resource scientific workstations of Sun Yat-sen University on the Sejila Mountain in Nyingchi district, Tibet. Ecological methods were used to investigate and study the vegetation composition and soil characteristics of the region at altitudes ranging from 3700 to 4700m. The relationships between altitude, vegetation composition, and soil properties were analyzed in order to add to the existing body of data concerning the ecosystems of the Qinghai-Tibet Plateau and facilitate the design of effective schemes for the preservation of ecosystem diversity.

Materials and Methods

Study area: The study was conducted in the Qinghai-Tibet plateau characteristic resources work stations (A stations) of Sun Yat-sen University, which are located on Sejila Mountain (29°35′ ~ 29°57′N, 94°25′ ~ 94°45′E) in Linzhi County of Tibet's Nyingchi district. Sejila Mountain has a long axis that runs from northwest to southeast, extending over about 32km from east to west and about 41km from north to south. It has a sub-alpine cold temperate humid climate and the studied area is home to alpine meadow-type plants.

Design of the experiment

Sample selection and quadrat placement: Field surveys were conducted from July to September in 2008 and May to August in 2009. In total, 11 sampling areas (A-K, Fig. 1) were established along the sides of the Sichuan-Tibet highway at altitudes ranging from 3700 ~ 4700m. Each sampling area was around $100m^2$. Five random survey quadrats (1m × 1m) were set up in each sampling area and the height, abundance and coverage of each plant species within each quadrat was recorded. An altimeter and GPS unit was used to determine the altitude, latitude and longitude of each sampling area; these data are listed in Table 1.

Field survey methods: (1) Plant specimen collection: Plant specimens were collected from each sampling area. In each case, the sample acquisition time, method of acquisition and specimen selection were performed according to established procedures. At least three plants of each apparently unique species within the quadrats were collected to facilitate reliable plant species identification. (2) Determination of community properties. The main variables used to characterize the studied plant communities were the Height, Coverage, Abundance, and Frequency of their dominant and companion species. (3) Determination of aboveground and belowground biomass. The aboveground biomass (AB) and belowground biomass (BB) were measured within areas of $100cm^2$. Three such measurements were taken in each sampling area. (4) Soil sampling and soil property analysis. The variables measured were: Available Phosphorus (AP); Soluble Nitrogen (SN); Available Potassium (AK) ; Total Phosphorus (TP) ; Total Nitrogen (TN); Total Potassium (TK); Organic Matter (OM); Soil Bulk Density (BD); Other indicators, including soil pH, Soil moisture (SM), Soil temperature (ST), and Soil Water Content (WC). All determinations were performed using standard methods as specified in "Agricultural Soil Analysis" (Bao, 1999) and "Soil Physical and Chemical Analysis" (Anon., 1978).

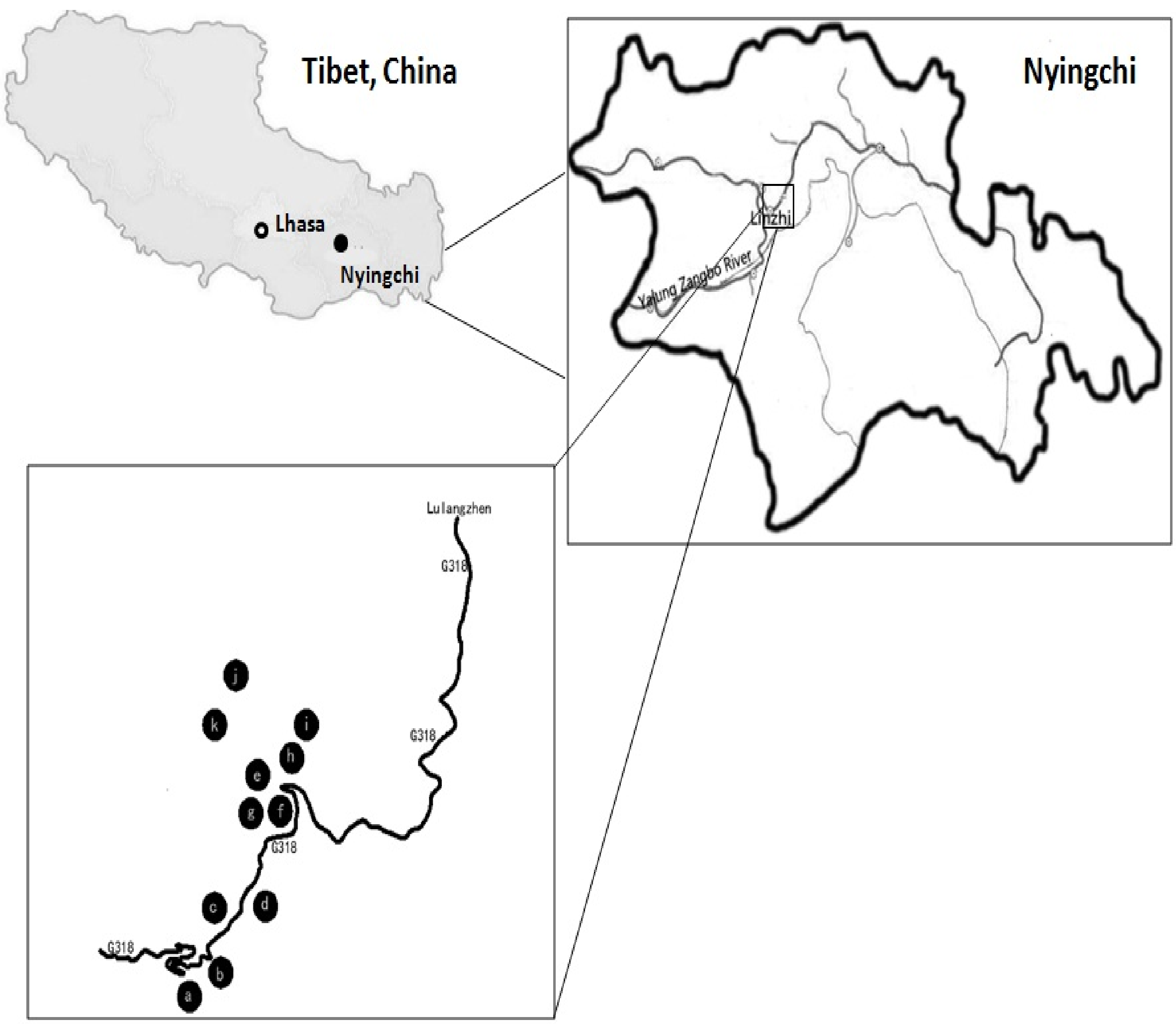

Fig. 1. Location of the study area and sampling sites. A-K: the selected 11 samples along the State Road 318(China) in Nyingchi district.

Table 1. Situation of the sampling sites.

Sample	Long. Lat.	Altitude (m)	Altitude gradient
A	29°33′N 94°33′E	3700	<4000m (Lower altitude)
B	29°33′N 94°34′E	3803	
C	29°35′N 94°35′E	4144	4000 4200m (Medium altitude)
D	29°35′N 94°36′E	4157	
E	29°36′N 94°36′E	4179	
F	29°36′N 94°36′E	4165	
G	29°36′N 94°36′E	4170	
H	29°37′N 94°37′E	4356	4200 4700m (Higher altitude)
I	29°38′N 94°37′E	4362	
J	29°36′N 94°39′E	4558	
K	29°38′N 94°35′E	4620	

Calculation of the evaluation index:

(1) Calculation of the importance value:
Importance value = (relative frequency + relative density + relative coverage + relative height) / 400

(2) Community species diversity calculation

Shannon-Wiener Index (H): $H=-\sum P_i \ln P_i$
Simpson Index (D): $D=1-\sum P_i^2$

Plant evenness index (E): $Jsw = \frac{H'}{H'_{max}} = -\frac{\sum_{i=1}^{S} P_i \ln P_i}{\ln S}$

In each of the above expressions, P_i refers to the ratio of the number of individuals belonging to species i within the quadrats of the sampling area relative to the total number of individual plants within the same area. S denotes the number of distinct species within the quadrats of a sampling area.

The diversity index for each sampling area is the mean value of the species diversity index for its five quadrats.

Species richness index (S)

The species richness for each sampling area was equal to the total number of individual species identified within its quadrats per unit area.

(3) Community similarity analysis

This was done using the Jaccard index: $C_J = j/(a+b-j)$

Here, a and b are the species numbers for two different samples, and j is the number of common species present in both communities or samples.

Data processing: The value of each ecological variable for a given sampling area was calculated as the mean of five repeat measurements (i.e. one for each quadrat). Preliminary data analysis and processing were done using Excel. SPSS 10.0 was used for variance analysis (ANOVA), mean significant difference analysis (LSD test, $p<0.05$) and correlation analysis (Pearson Correlation, Sig.2-tailed). Tables and figures were prepared using Excel.

Results

Plant composition of the sampling areas: The study area had an alpine meadow plant community and was found to contain 99 distinct plant species from 26 different families. The plant species present in each sampling area are listed in Table 2. The greatest number of plant species was found in the low altitude sampling area C, followed by the intermediate altitude sampling area F. These two areas had 23 plant species in common, belonging to 13 families. The distribution of each plant family identified in this work is shown in Table 3. Six of the 26 families observed in the study region were only present in one of the 11 sampling areas: the Iridaceae in sampling area A, the Liliaceae and Boraginaceae in sampling area B, the Leguminosae in sampling area C, the Brassicaceae in sampling area F, and the Crassulaceae in sampling area J. In addition, there were three families that were only observed in lower altitude sampling areas (Onagraceae, Caprifoliaceae and Caryophyllaceae), another four that were only present in intermediate altitude areas (Apiaceae, Gentianaceae, Geraniaceae and Scrophulariaceae), and four that were found in all 11 sampling areas (Asteraceae, Polygonaceae, Ranunculaceae and Cyperaceae). The highest altitude sampling area (K) contained only 7 distinct plant species belonging to 6 families. Of these families, 4 were present in all 11 sampling areas as noted above and the other two also had altitude-independent distributions (Table 3).

Table 2. Plant species identified in the sampling areas.

Sample	Plant species number	Family number	Genus number	Dominant species (Latin Name)
A	24	15	22	*Anemone rivularis*
B	24	17	24	*Artemisia mattfeldu*
C	40	18	34	*Deschampsiacaespitosa*; *Polygonumviviparum*
D	31	16	28	*Aster tongolensis*; *Polygonumviviparum*
E	32	17	29	*Polygonum viviparum*
F	39	19	34	*Fragaria nubicola*
G	21	16	20	*Polygonumviviparum.*
H	23	12	17	*Polygonumviviparum*;*Potentillaconferta*
I	23	14	18	*Polygonum viviparum*; *Kobresia macrantha*
J	22	14	18	*Polygonummacrophyllum*; *Potentillaanserina*
K	7	6	6	*Androsace mollis*; *Potentilla gracillima*

Table 3. Distribution of plants within the sampling areas

Family/sample	A	B	C	D	E	F	G	H	I	J	K
Apiaceae			√■	√■	√■	√■	√■	√■	√■	√■	
Asteraceae	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲
Boraginaceae		√□									
Brassicaceae						√□					
Campanulaceae			√	√	√	√		√	√	√	
Caprifoliaceae	√●	√●									
Caryophyllaceae	√●	√●	√●	√●	√●	√●					
Crassulaceae										√□	
Cyperaceae	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲
Gentianaceae		√■	√■	√■	√■	√■	√■	√■	√■	√■	
Geraniaceae			√■	√■	√■	√■	√■	√■	√■		
Iridaceae	√□										
Juncaceae	√	√			√	√	√		√		
Lamiaceae	√	√	√	√	√	√	√	√		√	
Leguminosae			√□								
Liliaceae		√□									
Onagraceae	√●	√●	√●	√●	√●	√●	√●				
Plantaginaceae		√	√				√				
Poaceae	√	√			√	√	√	√	√	√	
Polygonaceae	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲
Primulaceae	√		√	√	√	√	√		√	√	√
Ranunculaceae	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲	√▲
Rosaceae		√	√	√	√	√	√	√	√	√	√
Rubiaceae	√	√				√					
Saxifragaceae			√	√	√	√			√	√	
Scrophulariaceae		√■	√■	√■	√■	√■	√■	√■	√■	√■	

"√": this family was present in the indicated sampling area; "√□": this family was only present in a single sampling area; "√●": this family was only present in low altitude sampling areas; "√▲": this family was present in every sampling area; "√■": this family was only present in sampling areas at intermediate altitudes

Table 4. Species diversity index values and plant biomass measurements for the sampling areas.

	H	D	E	S	AB(g/m^2)	BB(g/m^2)
A	2.43 ± 0.05bc	0.877 ± 0.004abc	0.87 ± 0.01ab	16.2 ± 0.5c	3459.4 ± 896.5a	--
B	1.77 ± 0.58fg	0.682 ± 0.067e	0.75 ± 0.13d	10.8 ± 1.9e	3256.4 ± 1925.8ab	--
C	2.11 ± 0.26de	0.823 ± 0.028cd	0.78 ± 0.06cd	14.8 ± 1.2c	1955.6 ± 145.2bc	3323.2 ± 325.0a
D	2.28 ± 0.11cde	0.868 ± 0.007bc	0.83 ± 0.02bc	15.6 ± 1.2c	1733.3 ± 451.3cd	2102.4 ± 277.5ab
E	2.14 ± 0.31cde	0.815 ± 0.035cd	0.76 ± 0.10cd	17.0 ± 2.4bc	1575.2 ± 921.2cd	3231.4 ± 1925.8a
F	3.19 ± 0.02a	0.944 ± 0.001a	0.90 ± 0.01ab	35.0 ± 0.8a	545.9 ± 234.2d	714.3 ± 389.4c
G	2.03 ± 0.13ef	0.835 ±0.019cd	0.84 ± 0.07bc	11.4 ± 0.6de	1299.9 ± 264.5cd	2633.6 ± 503.4ab
H	2.37 ± 0.20bcd	0.874 ± 0.016bc	0.87 ± 0.03ab	15.4 ± 1.3c	1233.1 ± 378.5cd	1500.7 ± 400.3bc
I	2.63 ± 0.11b	0.910 ± 0.005ab	0.89 ± 0.02ab	19.4 ± 0.8b	1100.1 ± 199.9cd	3267.3 ± 404.4a
J	2.17 ± 0.14cde	0.842 ± 0.016cd	0.83 ± 0.06bcd	14.0 ± 1.0cd	1733.3 ± 451.3cd	1867.1 ± 551.0bc
K	1.71 ± 0.09g	0.796 ± 0.014d	0.92 ± 0.05a	6.4 ± 0.3f	--	--

H: Shannon-Wiener diversity index; D: Simpsons diversity index; E: Pielou evenness index; S: Species richness; AB: Above-ground biomass; BB: Below-ground biomass

Data are means ± SE of five replicates (n=5), and data followed by the same small letter in each column indicate no significant (p>0.05) differences between different samples; --: plant samples were not collected

Table 5. Jaccard Similarity Index values for the communities in the sampling areas.

	A	B	C	D	E	F	G	H	I	J	K
A	--	0.30	0.14	0.12	0.12	0.16	0.18	0.04	0.04	0	0
B	--	--	0.19	0.17	0.12	0.21	0.22	0.02	0.02	0	0
C	--	--	--	0.73	0.60	0.40	0.42	0.31	0.13	0.13	0
D	--	--	--	--	0.62	0.39	0.44	0.32	0.29	0.13	0
E	--	--	--	--	--	0.38	0.43	0.28	0.28	0.06	0
F	--	--	--	--	--	--	0.36	0.15	0.15	0.00	0
G	--	--	--	--	--	--	--	0.19	0.22	0.02	0
H	--	--	--	--	--	--	--	--	0.48	0.32	0.03
I	--	--	--	--	--	--	--	--	--	0.29	0.03
J	--	--	--	--	--	--	--	--	--	--	0.04

Species diversity of the sampling areas: (1) Diversity index: The highest altitude sampling area K had the lowest Shannon-Wiener diversity index, but did not differ significantly (p>0.05) from the lower altitude sampling area B in this respect. The intermediate altitude sampling area F (4165m) had the highest Shannon-Wiener diversity index, and differed significantly from the other sampling areas (p<0.05). F also had the highest Simpson diversity index but did not differ significantly from sampling areas I and A in this respect (p>0.05). Sampling area B had the lowest Simpson diversity index and differed significantly (p<0.05) from the other sampling areas (Table 4). It was clear that plant diversity was not affected by altitude in the investigated samples. (2) Evenness: The highest altitude sampling area (K) had the highest Pielou evenness index value but did not differ significantly from that for the lowest area (A) (p>0.05). The second lowest sampling area, B, had the lowest plant evenness index value but did not differ significantly (p>0.05) from areas C, E, or J. There was no strong relationship between plant evenness and altitude. (3) Species richness: The highest altitude area K had the lowest species richness, and differed significantly (p<0.05) in this respect from all the other samples. However, the intermediate altitude sampling area F had the highest plant species richness and differed significantly (p<0.05) from all the other samples. This indicates that there was no significant relationship between plant species richness and altitude. (4) Aboveground and belowground biomass: Sampling area F had the lowest belowground and aboveground biomass but did not differ significantly (p>0.05) in this respect from the other sampling areas (Table 4). (5)Community similarity analysis: The Jaccard similarity coefficients for the sampling areas ranged from 0 to 0.73. Communities at similar altitudes had higher similarity coefficients, and the value of the similarity coefficient for pairs of sampling sites decreased significantly as the difference in altitude between the sites increased, to the point that the similarity index values for either of the two highest sampling areas (J and K) with either of the two lowest sampling areas (A and B) were all 0. Similarity index values of 0 were also observed when comparing the highest altitude sampling area, K, to sampling areas C, D, E, F and G, whose altitudes ranged from 4000 - 4200m (Table 5).

Correlation of soil and community characteristics: Of the studied sampling areas, the intermediate altitude area F had the highest soil soluble nitrogen (SN), soil total phosphorus (TP), and total nitrogen (TN) contents as well as the greatest soil bulk density (BD) and the lowest soil temperature (ST). The lowest altitude sampling area, A, had the lowest soil available potassium (AK), soil total phosphorus (TP), and soil pH. None of the studied soil properties correlated significantly with altitude. However, according to the correlation analysis results listed in Table 6, the soil temperature (ST) had significant negative correlations ($p<0.05$) with the species richness index (S) and Shannon-Wiener diversity index (H), and an extremely significant negative correlation ($p<0.01$) with the Simpson diversity index (D). This indicates that increases in soil temperature reduce plant species richness and plant diversity. However, there was an extremely significant positive correlation ($p<0.01$) between soil temperature and plant aboveground biomass, indicating that higher soil temperatures may promote the growth of aboveground plant parts. There was also an extremely significant negative correlation ($p<0.01$) between the soil's soluble nitrogen (SN) content and plant biomass (including both aboveground and belowground biomass), and a significant negative correlation ($p<0.05$) between the soil's total nitrogen (TN) content and plant biomass (including both aboveground and belowground biomass). The correlation analysis also revealed a significant negative correlation ($p<0.05$) between altitude and plant aboveground biomass (Table 6), indicating that high altitude was not beneficial to the growth of aboveground plant parts.

Table 6. Pearson's correlation coefficients for ecological factors within the sampling areas.

	S	D	H	E	AB	BB
AP	-0.215	-0.493	-0.402	-0.483	-0.03	0.287
SN	0.502	0.646*	0.517	0.435	-0.849**	-0.894**
AK	0.047	-0.378	-0.192	-0.417	-0.359	-0.306
TP	0.794**	0.385	0.613	0.249	-0.591	-0.653*
TN	0.462	0.487	0.396	0.193	-0.734*	-0.711*
TK	-0.033	0.171	0.109	0.356	-0.238	-0.141
OM	0.293	0.473	0.324	0.272	-0.597	-0.574
pH	-0.093	-0.097	-0.251	-0.195	0.476	-0.122
SM	-0.120	-0.155	-0.082	-0.380	0.762*	0.484
ST	-0.620*	-0.759**	-0.664*	-0.282	0.896**	0.305
WC	-0.468	-0.139	-0.375	0.065	0.141	0.656*
Altitude	-0.139	0.21	-0.081	0.414	-0.754*	-0.161
BD	0.416	0.620*	0.451	0.385	-0.316	0

E: Pielou evenness index; S: Species richness; D: Simpsons diversity index; H: Shannon-Wiener diversity index; PD: Population density; AP: Available Phosphorus; SN: Soluble Nitrogen; AK: Available Potassium; TP: Total Phosphorus; TN: Total Nitrogen; TK: Total Potassium; OM: Organic matter; pH: Soil pH; SM: Soil moisture; ST: Soil temperature; WC: Soil water content; BB: Below-ground biomass; AB: Above-ground biomass; BD: Soil bulk density

*= Correlation is significant at the 0.05 level, **= Correlation is significant at the 0.01 level

Discussion

Vegetation composition: Previous studies have shown that altitude affects vegetation types (Liu *et al*., 2004). Our results extend this finding, demonstrating that there are altitudinal differences in plant distribution even within a single vegetation type (alpine meadow) in the Mount Sejila region. However, the composition of the studied plant communities was not wholly determined by altitude; the additional variation that was observed may be related to the plants' preferred habitats and niches, and the environmental conditions within each sampling area. The community similarity index decreased as the difference in altitude between sampling sites increased, which may also shed some light on the distribution of plant communities within the region.

Community characteristics: No clear relationship between the species diversity within a sampling area and its altitude could be identified, in contrast to previous findings (Wang *et al*., 2006). Shimono *et al*., (2010) compared their own field data to those obtained in previous studies and found that while altitude played a significant role in regulating species composition in the Qinghai-Tibet Plateau, there was no clear relationship between altitude and species richness. Another study (Qiong *et al*., 2010) showed that there can be different trends in species richness along altitude gradients in different areas of the plateau. Qiong's study also showed that species richness patterns differed between transects and varied according to the grain size used. The results of Hegazy *et al.,* (2011) and Noor & Khatoon (2013) indicate that different types of vegetation are dominant at different altitudes, and that local conditions, habitat types and environmental diversity are the main drivers of variation in vegetation types rather than altitude, soil properties, and aspect. Ahmad's results (2012) also showed that plant species responded differently to environmental variables even within a single same region. All of these findings indicate that multiple factors should be considered when analyzing vegetation diversity in the Qinghai-Tibet Plateau, including altitude, transect selection, location, aspect, vegetation type, and other environmental factors.

Biomass and soil correlations: In contrast to the findings of Wang *et al*., (2007), we did not observe any direct decrease in plant aboveground biomass as the altitude increased. However, a negative correlation between aboveground biomass and altitude was identified (Table 6). Our results also revealed that the aboveground biomass correlates negatively with the soil nitrogen content and positively with soil moisture and soil temperature. These findings are consistent with previous results (Wang *et al*., 2008). Due to the area's permafrost and seasonal freeze-thaw cycles, soil moisture and temperature have very important effects on vegetation patterns (Wang *et al*., 2012; Zhang *et al*., 2012; Jin *et al*., 2013), and the vegetation cover in the region has previously been shown to respond to variations in soil temperature, soil moisture and temperature, with subsequent effects on plant growth and productivity (Yang *et al*., 2006; Yang *et al*., 2009; Wang *et al*., 2013). It has also been argued that the distribution of vegetation biomass reflects differences in community composition and competition, and is influenced by the plant species that are present and the vegetation type (Wang *et al*., 2008).

Soil properties also have important effects on species diversity. We found negative correlations between soil temperature (ST) and the Shannon-Wiener (H) and Simpson (D) diversity indices, indicating that higher soil temperatures may decrease plant diversity. This is probably because higher soil temperatures give rise to a larger difference in temperature between the aboveground and belowground parts of the plant, such that only plants with a high tolerance for such differences can survive. It has also been observed that spatial heterogeneity in the distribution of soil moisture, nutrients, and vegetation types can have profound effects on soil properties (Liu *et al*., 2004). This may also have affected the level of species diversity observed at the sampling sites in this work.

Although we observed distinct changes in the vegetation composition at the sampling sites as the altitude changed, altitude did not appear to be the main determinant of community characteristics or the soil's physicochemical properties. There was also a close relationship between soil properties and vegetation indices, indicating that the two cannot be treated as completely separate entities. It should be noted that only vegetation and soil properties were considered in this study, and that no attention was paid to geological factors (e.g. site location, the properties of the mountain range, slope aspects, transects and so on) despite their potential importance. Moreover, our research was conducted in the summers of 2008 and 2009 but community characteristics change with the seasons. It will therefore be necessary to conduct similar investigations in other seasons in order to properly understand the long-term direction of community succession.

Conclusions

We studied the vegetation present at sampling sites with different altitudes on Mount Sejila in Tibet. In total, 99 different plant species from 26 families were identified at altitudes of 3700 - 4700m. There were clear altitudinal trends in plant species composition, but species diversity (based on diversity indices, evenness, and species richness) within the study area was not particularly sensitive to altitude. However, there was a significant negative correlation ($p<0.05$) between plant aboveground biomass and altitude. There was a negative correlation between the gap in the altitudes of two sampling sites and their community similarity values: sites at similar altitudes had comparable similarity values but sites at very different altitudes had small or zero values. There were significant positive correlations ($p<0.05$) between the soil water content and plant belowground biomass, soil moisture and plant aboveground biomass, while significant or extremely significant negative correlations were identified between the soil nitrogen content (including soluble nitrogen and total nitrogen) and plant biomass (including aboveground and belowground biomass). In addition, the Simpson and Shannon-Wiener plant diversity index correlated negatively with the soil temperature. Further research will be required to better understand the ecosystems of Mount Sejila and the broader Qinghai-Tibet Plateau, particularly in order to evaluate seasonal changes and the succession characteristics of their vegetation.

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References

Ahmad, S.S. 2012. Species response to environmental variables in Ayubia national park, Pakistan using multivariate analysis. *Pak. J. Bot*., 44(4): 1225-1228.

Anonymous. 1978. *Soil Physical and Chemical Analysis*. Institute of Soil Science, Chinese Academy of Sciences. Science and Technology Press, Shanghai, China.

Bao, S.D. 1999. *Agricultural Soil Analysis*.(3rd Ed) China Agricultural Press, Beijing.

Berdanier, A.B. and J.A. Klein. 2011. Growing season length and soil moisture interactively constrain high elevation aboveground net primary production. *Ecosystems*., 6(14): 963-974.

Hegazy, A.K., L. Boilos and H.F. Kabiel. 2011. Vegetation and species altitudinal distribution in Al-Jabal Al-Akhdar landscape, Libya. *Pak. J. Bot*., 43(4): 1885-1898.

Jin, Z.N., Q.L. Zhuang, J.S. He, T.X. Luo and Y. Shi. 2013. Phenology shift from 1989 to 2008 on the Tibetan Plateau: an analysis with a process-based soil physical model and remote sensing data. *Climatic Change*, 119(2): 435-449.

Li, K.H., Y.K. Hu, X. Wang, Y.G. Fan and W.S. Wu-maier. 2007. Relationships between aboveground biomass and environmental factors along an altitude gradient of alpine grassland. *Yingyong Shengtai Xuebao*, 18(9): 2019-2024.

Li, L., S. Yang, Z.Y. Wang, X.D. Zhu and H.Y. Tang. 2010. Evidence of warming and wetting climate over the Qinghai-Tibet Plateau . *Arct. Antarct Alp. Res*., 42(4): 449-457.

Liu, K., J.M. Baskin, C.C. Baskin, H.Y. Bu and G.Z. Du. 2013. Effect of Diurnal Fluctuating versus Constant Temperatures on Germination of 445 Species from the Eastern Tibet Plateau. *Plos One*., 8(7): (e69364)1-10.

Liu, S.L., B.J. Fu, K.N. Ma and G.H. Liu. 2004. Effects of vegetation types and landscape features on soil properties at the plateau in the upper reaches of Minjiang River. *Yingyong Shengtai Xuebao,* 15(1): 26-30.

Noor, A. and S. Khatoon. 2013. Analysis of Vegetation pattern and soil characteristics of Astore valley Gilgit-Baltistan. *Pak. J. Bot*., 45(5): 1663-1667.

Piao, S.L., M.D. Cui, A.P. Chen, X.H. Wang, P. Ciais, J. Liu and Y.H. Tang. 2011. Altitude and temperature dependence of change in the spring vegetation green-up date from 1982 to 2006 in the Qinghai-Xizang Plateau. *Agr. Forest Meteorol*., 151(12): 1599-1608.

Qiong, L., J.A. Grytnes and H. B. Birks. 2010. Alpine vegetation and species-richness patterns along two altitudinal gradients in the Gyama Valley, south-central Tibet, China. *Plant Ecol. Divers*., 3(3): 235-247.

Shimono, A., H.K. Zhou, H.H. Shen, M. Hirota, T. Ohtsuka and Y.H. Tang. 2010. Patterns of plant diversity at high altitudes on the Qinghai-Tibetan Plateau. *J. Plant Ecol. UK*., 3(1) (Sp.lss): 1-7.

Song, M.H., C.P. Zhou and H. Ouyang. 2005. Simulated distribution of vegetation types in response to climate change on the Tibetan Plateau. *J. Veg. Sci*., 16(3): 341-350.

Wang, C.T., R.J. Long, Q.J. Wang, M. Lu and M.P. Wang. 2007. Effects of altitude on plant-species diversity and productivity in an alpine meadow, Qinghai-Tibetan plateau. *Aust. J. Bot*., 55(2): 110-117 .

Wang, C.T., R.J. Long, Q.L. Wang, Z.C. Jing, Y.G. Du and G.M. Cao. 2008. Effects of soil responses on species composition, plant diversity, and plant biomass in an alpine meadow, Qinghai-Tibetan Plateau. *Isr. J. Ecol. Evol*., 54(2): 205-222.

Wang, G.X., W. Bai and N. Li. 2011. Climate changes and its impact on tundra ecosystem in Qinghai- Tibet Plateaau, China. *Climate Change*., 106(3): 463-482.

Wang, G.X., Y.B. Wang, Y.S. Li and H.Y. Cheng. 2007. Influences of alpine ecosystem responses to climatic change on soil properties on the Qinghai-Tibet Plateau, China. *Catena.*, 70(3): 506-514.

Wang, G.X., Y.S. Li, Y.B. Wang and Q.B. Wu. 2008. Effects of permafrost thawing on vegetation and soil carbon pool losses on the Qinghai-Tibet Plateau, China. *Geoderma*, 143(1-2): 143-152.

Wang, H.B., M.G. Ma, X.F. Wang, W.P. Yuan, Y. Song, J.L. Tan and G.H. Huang. 2013. Seasonal variation of vegetation productivity over an alpine meadow in the Qinghai-Tibet Plateau in China: modeling the interactions of vegetation productivity, phenology, and the soil freeze-thaw process. *Ecol. Res.,* 28(2): 271-882.

Wang, W.Y., Q.J. Wang, S.X. Li and G. Wang. 2006. Distribution and species diversity of plant communities along transect on the Northeastern Tibetan plateau. *Biodivers. Conserv*., 15(4): 1811-1828.

Wang, Z.R., G.J. Yang, S.H. Yi, S.Y. Chen, Z. Wu, J.Y. Guan, C.C. Zhao, Q.D. Zhao and B.S. Ye. 2012. Effects of environmental factors on the distribution of plant communities in a semi-arid region of the Qinghai-Tibet Plateau. *Ecol. Res.,* 27(4): 667-675.

Xu, W.X., S. Gu, X.Q. Zhang, J.S. Xiao, Y.H. Tang, J.Y. Fang, J. Zhang and S. Jiang. 2011. High positive correlation between soil temperature and NDVI from 1982 to 2006 in alpine meadow of the Three-River Source Region on the Qinghai-Tibetan Plateau. *Int. J. Appl. Earth Obs*., 4(13): 528-535.

Xu, X.K., H. Chen and J.K. Levy. 2008. Spatiotemporal vegetation cover variations in the Qinghai-Tibet Plateau under global climate change . *Chinese Sci. Bull*., 53(6): 915-922.

Yang, J.P., Y.J. Ding and R.S. Chen. 2006. Spatial and temporal of variations of alpine vegetation cover in the source regions of the Yangtze and Yellow Rivers of the Tibetan Plateau from 1982 to 2001. *Environ. Geol*., 50(3): 313-322.

Yang, Y.H., J.Y. Fang, Y.D. Pan and C.J. Ji. 2009. Aboveground biomass in Tibetan grasslands. *J. Arid Environ*., 73(1): 91-95.

You, S.C., C.Q. Song, L.H. Ke, G.H. Liu and X.K. Zhong, 2011.Spatial distribution characteristics of vegetation phenology in northern Tibetan Plateau based on MODIS enhanced vegetation index. *Shengtaixue Zazhi*., 30(7): 1513-1520.

Yu H.Y. and J.C. Xu. 2009. Effects of climate change on vegetations on Qinghai- Tibet Plateau: A review. *Shengtaixue Zazhi*., 28(4): 747-754.

Zhang, F.W., Y.N. Li, G.M. Gao, S.P. Wang, X.Q. Zhao, M.Y. Du and Q.X. Wang. 2011. Response of alpine plant community to simulated climate change: Two-year results of reciprocal translocation experiment (Tibetan Plateau). *Pol. J. Ecol*., 59(4): 741-751.

Zhang, X.M., Y. Sheng, J. Li, J.C. Wu, J. Chen and Y.B. Cao. 2012. Changes of alpine ecosystem along the ground temperature of permafrost in the source region of Datong River in the Northeastern Qinghai-Tibet Plateau. *J. Food Agric. Environ*., 10(1, part2): 970-976.

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