RECONSTRUCTION OF TEMPERATURE FOR THE PAST 400 YEARS IN THE SOUTHERN MARGIN OF THE TAKLIMAKAN DESERT BASED ON CARBON ISOTOPE FRACTIONATION OF *TAMARIX* LEAVES

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Abstract. Carbon isotope fractionation is sensitive to the environment factors associated with plant growth; thus, it can be used as a proxy to reconstruct past climate and environmental conditions. We investigated the relationship between carbon isotope signatures ($\delta^{13}C$) and its fractionation ($\Delta\delta^{13}C$) of *Tamarix* leaves and a set of climate and environmental factors in the Southern Margin of the Taklimakan Desert (SMTD). A principal component analysis was used to condense these factors as the temperature-, wind-, precipitation-, and humidity-related index, explaining 51.0%, 18.0%, 5.1%, and 4.7% of the total variance, respectively. Combined with the correlation results, temperature is identified as the key growth-limiting factor for *Tamarix* in the SMTD. Specifically, $\delta^{13}C$ has a statistically significant correlation with the lowest temperature in June (LT_{Jun})(r = 0.717, p = 0.000), and $\Delta\delta^{13}C$ has a statistically significant correlation with the annual mean of the highest temperature (AMHT) (r = 0.700, p = 0.000). Based on these high correlations, we reconstructed the LT_{Jun} and AMHT records in the past 400 years using $\delta^{13}C$ and $\Delta\delta^{13}C$ of *Tamarix* leaves deposited in the *Tamarix* cone. These records revealed a long-term fluctuation in temperature that can be divided into four sub-periods, including the history cold period (1600-1685), history warm period (1686 - 1913), modern cold period (1914-1993), and modern warm period (1994-2010). These records provide useful insight into the paleoclimate and environmental change in this arid region.
Keywords: *climate change, environment, key growth-limiting factor*

Introduction

Climate and environmental change affect plant carbon isotope signatures ($\delta^{13}C$) (Seibt et al., 2008), and the carbon isotope fractionation ($\Delta\delta^{13}C$) is mainly related to the key limiting factors for plant growth (Xu et al., 2015). Temperature and precipitation are the two major growth-limiting factors for the changes in plant carbon isotope signature and fractionation, by affecting its stomata conductance and assimilation rate and altering C:N allocation to carboxylation and leaf structure (Seibt et al., 2008; Liu et al., 2014b). Consequently, $\delta^{13}C$ and $\Delta\delta^{13}C$ can be treated as measures of temperature and precipitation (Saurer et al., 1995; Loader et al., 2007; Dodd et al., 2008; Diefendorf et al., 2010), and used as proxies to reconstruct past climate conditions (Dawson and Siegwolf, 2007; Werner et al., 2012). Studies have indicated that precipitation has a negative influence on plant $\delta^{13}C$ and a positive influence on $\Delta\delta^{13}C$ (Farquhar et al., 1982; Wang et al., 2003, 2008; Kohn, 2010; Ren et al., 2011). However, the influence of temperature on plant $\delta^{13}C$

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is still unclear (Körner et al., 1988, 1991; Morecroft and Woodward, 1996; Wang et al., 2008, 2013; Gebrekirstos et al., 2009; Diefendorf et al., 2010; Kohn, 2010). This uncertainty is caused by difference of the key growth-limiting factors that affect on plant growth in different regions. The key growth-limiting factors of *Tamarix* growth have been statistically identified in the Southern Margin of the Taklimakan Desert (SMTD), and then the paleoclimate condition is reconstructed based on the relationship between the key growth-limiting factors and meteorological factors.

The Taklimakan Desert is the second largest desert in the world surrounded by the Tianshan Mountain in the north, the Aljin Mountain in the southeast, the Kunlun Mountain in the south, and the Pamir Plateau in the west. It is one of the most arid regions in the world because the high mountains and plateau block the water moist from the Atlantic and Indian oceans. The SMTD is one of the most fragile ecological environment areas in China. *Tamarix* is the major vegetation outside of the oasis that can survive the extremely arid climate in this area. *Tamarix* is mainly distributed on riverbanks, abandoned river channels, and the interlaced zone between desert and oasis. The interaction between wind sand and *Tamarix* forms the *Tamarix* cone, a unique bio-geomorphic landform, composing of alternate layers of sand and *Tamarix* twigs and leaves (Xia et al., 2004). Detailed climate records have been derived in this desert area using stable carbon isotope ($\delta^{13}C$) and its fractionation ($\Delta\delta^{13}C$) of *Tamarix* leaves from different layers of the *Tamarix* cones (Zhao et al., 2011a, b, 2015a, b, 2016; Zhao, 2012; Sun, 2013; Sun et al., 2013; Guo et al., 2016; Zhang et al., 2017).

In the work reported here, the relationship between carbon isotope ($\delta^{13}C$) and its fractionation ($\Delta\delta^{13}C$) signatures and various observed climate factors (1960-2010) were investigated to identify the key growth-limiting factor of *Tamarix* growth. Base on the relationship, the lowest temperature in June (LT_{Jun}) and the annual mean of highest temperature (AMHT) of the past 400 years were reconstructed in the SMTD. This study provides useful insight into the relationship between plant $\delta^{13}C$, $\Delta\delta^{13}C$ signatures and climate variables and use $\delta^{13}C$ and $\Delta\delta^{13}C$ as proxies to reconstruct paleo-climate and environmental change in arid regions.

Study area

This study was conducted in Andier Meadow (83.82°E, 37.72°N), far from the Minfeng oasis, which belongs to the Hotian Prefecture in the SMTD of Xinjiang Uygur Autonomous Region, China (*Fig. 1*). The sampling site is located on the edge of the alluvial fan formed by the Andier River, representing a transition zone between the Taklimakan Desert and Kunlun Mountains. This area belongs to the temperate continental and arid desert climate zone. According to the observed data from the Minfeng meteorological station, the mean of annual temperatures is 11.19 °C and relatively constant over the years. The average annual precipitation is 29.4 mm with a relatively large range between 4.0 and 136.9 mm. About 85.4% of the precipitation falls from May to September. The annual average evaporation can reach to 2756 mm.

Data and methods

To minimize the influence of human activity, we investigated a *Tamarix* cone in Andier meadow, more than 100 km away from the Minfeng oasis. We collected the samples layer by layer from top to bottom from June 18th to 20th in 2011. The samples

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were collected based on the average thickness when the sedimentary veins are not clear**.** In total, we collected 106 samples. The freshest leaves of the top layer were dated in 2010.

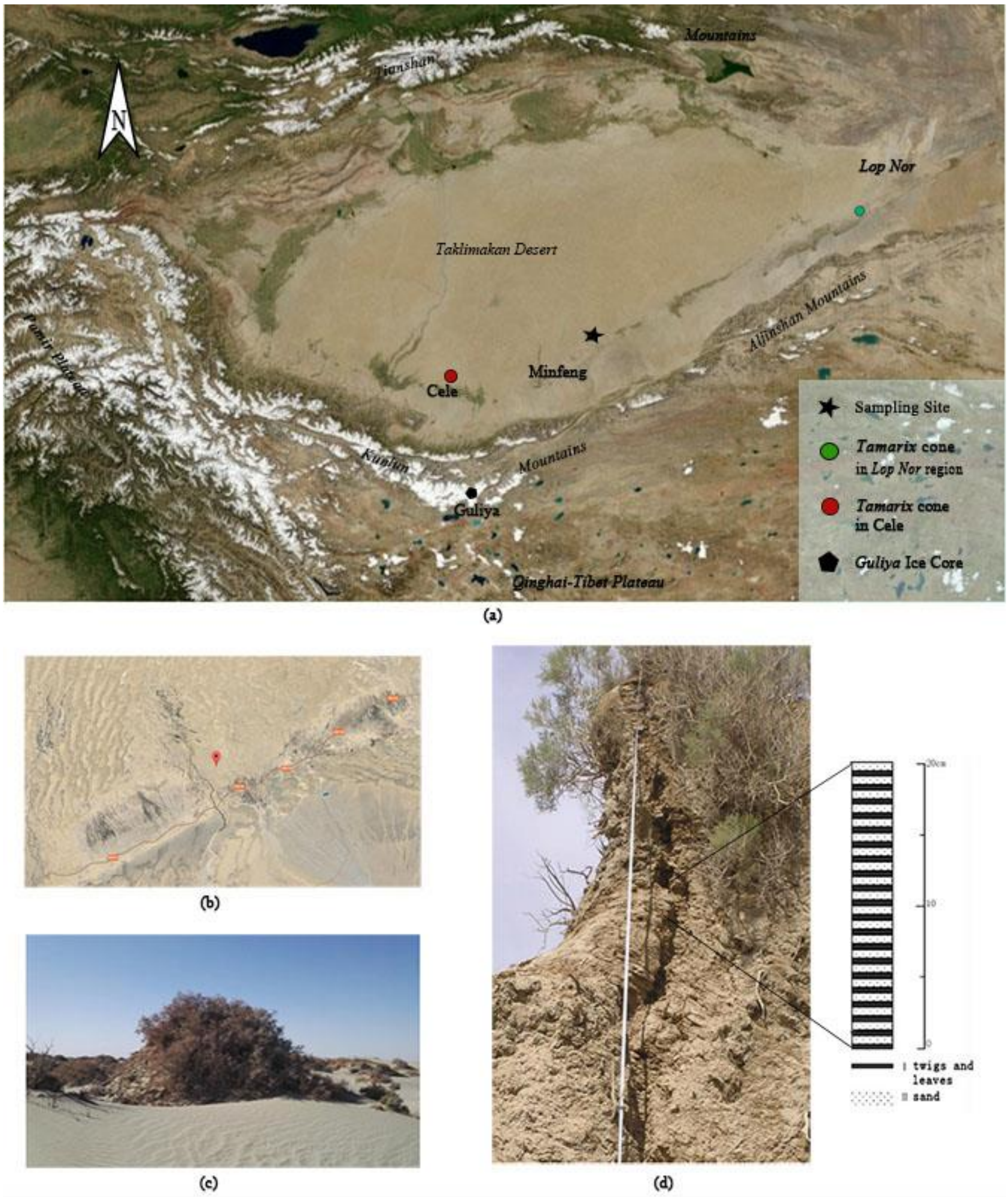

Figure 1. *Location of sampling site in Andier meadow of Minfeng County (a, b); a typical Tamarix cone (c); a sampling profile of Tamarix cone (d)*

All samples were pretreated by washing, stoving, grinding, and packing in penetrative bag in the Key Laboratory of Environmental Change and Ecological Construction, Hebei Normal University. The $\delta^{13}C$ value of each sample was measured in the Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, based on the Vienna Pee Dee Belemnite (VPDB) standard (the standard error of 0.1‰). Both ^{210}Pb and ^{137}Cs were measured to constrain the age sequence, combined with ^{14}C

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dating by the Accelerator Mass Spectrometry Laboratory in Beijing University (Zhao et al., 2015b).

The carbon isotope fractionation ($\Delta\delta^{13}C$) of *Tamarix* leaves is derived by the following formula (*Eq. 1;* Farquhar et al., 1984, 1989):

$$\Delta\delta^{13}C = \frac{\delta^{13}C_a - \delta^{13}C_t}{1+\delta^{13}C_t/1000} \approx \delta^{13}C_a - \delta^{13}C_t \qquad \text{(Eq.1)}$$

Where $\delta^{13}C_a$ represents the carbon isotope ratio in atmosphere measured from ice core bubbles or plant $\delta^{13}C$ value (Friedli et al., 1986; Leavitt and Long, 1989; Mccarroll and Loader, 2004); $\delta^{13}C_t$ represents the carbon isotope ratio of *Tamarix* leaves.

The climate data were obtained from the Mingfeng meteorological station, close to the sampling site. The data include the monthly and yearly lowest, highest and mean temperature, sunshine duration, precipitation, relative humidity, wind speed, windy days, and sand storms during 1960-2010. These data are divided into three categories: temperature-related, water-related, and wind-related variables.

We first explored the descriptive statistics of $\delta^{13}C$ and $\Delta\delta^{13}C$ and then performed bivariate correlation analyses between $\delta^{13}C$, $\Delta\delta^{13}C$ and the temperature-related, water-related, wind-related variables. Due to the large number of the variables and their intercorrelations, we applied the principal component analysis to condense the variables into several major components and determine the contributions of different variables to $\delta^{13}C$ and $\Delta\delta^{13}C$. The key growth-limiting factors for *Tamarix* were then determined based on their correlations and contributions. We applied the least square regression to establish the relationship between $\delta^{13}C$ and $\Delta\delta^{13}C$ and the key growth-limiting factors and use this relationship to reconstruct the variations of these factors in the past. Most of the statistical analyses were performed using IBM SPSS Statistics. The regression was carried out by software, EViews.

Results

$\delta^{13}C$ and $\Delta\delta^{13}C$ variations

Based on the chronology established by Zhao et al. (2015b) using ^{14}C, ^{210}Pb and ^{137}Cs dating, we illustrated $\delta^{13}C$ and $\Delta\delta^{13}C$ variations for the Minfeng sampling site in the past 400 years (*Fig. 2*). The $\delta^{13}C$ values vary from -26.979‰ to -22.149‰, and the $\Delta\delta^{13}C$ values fluctuate between 15.397‰ and 20.265‰ with a mean of 18.009‰.

Correlation analysis

We analyzed the correlations between temperature-related variables, including the monthly highest temperature, monthly lowest temperature, monthly mean temperature, annual mean of highest temperatures, annual mean of lowest temperatures, annual mean temperature, monthly sunshine hours and annual cumulative sunshine hours, and $\delta^{13}C$, $\Delta\delta^{13}C$. At the 95% confidence level, the significantly related variables were selected and listed in *Table 1***.**

The correlations between $\delta^{13}C$, $\Delta\delta^{13}C$ and the water-related variables, such as the monthly precipitation, annual precipitation, monthly mean of air relative humidity, annual mean of air relative humidity, showed that statistically significant correlations ($P < 0.05$) only occur in January ($r = -0.417$, $p = 0.038$) between $\delta^{13}C$ and precipitation,

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and in June (r = 0.401, p = 0.047) and November (r = 0.534, p = 0.006) between $\delta^{13}C$ and air relative humidity. Statistically significant correlations occur in April (r = 0.445, p = 0.026) between $\Delta\delta^{13}C$ and precipitation, and in November (r = -0.579, p = 0.002) between $\Delta\delta^{13}C$ and air relative humidity only.

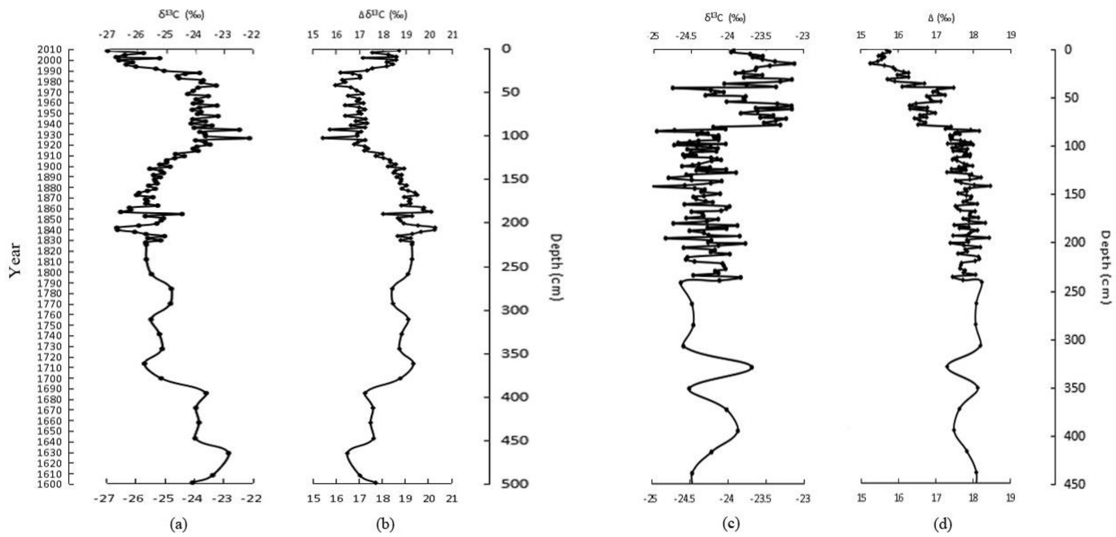

Figure 2. *The age sequence of $\delta^{13}C$ in Minfeng sampling site (a); the age sequence of $\Delta\delta^{13}C$ in Minfeng sampling site (b); the age sequence of $\delta^{13}C$ in Cele (Zhang et al., 2017) (c); the age sequence of $\Delta\delta^{13}C$ in Cele (Zhang et al., 2017) (d)*

Table 1. *Pearson correlations (r) of temperature-related variables with $\delta^{13}C$, $\Delta\delta^{13}C$*

Lowest Temperature	$\delta^{13}C$		$\Delta\delta^{13}C$	
	r	***p***	***r***	***p***
Lowest temperature in Jan	-0.557	0.004	0.564	0.003
Lowest temperature in Feb	-0.546	0.005	0.575	0.003
Lowest temperature in Mar	-0.537	0.006	0.586	0.002
Lowest temperature in Apr	-0.509	0.009	0.530	0.006
Lowest temperature in May	-0.511	0.009	0.452	0.023
Lowest temperature in Jun	-0.717	0.000	0.626	0.001
Lowest temperature in Jul	-0.602	0.001	0.616	0.001
Lowest temperature in Aug	-0.491	0.013	0.497	0.011
Lowest temperature in Sep	-0.553	0.004	0.566	0.003
Lowest temperature in Oct	-0.557	0.004	0.489	0.013
Lowest temperature in Nov	-0.612	0.001	0.526	0.007
Lowest temperature in Dec	-0.586	0.002	0.495	0.012
Annual mean of lowest temperatures	-0.665	0.000	0.639	0.001
Annual mean of highest temperatures	-0.608	0.001	0.700	0.000
Annual mean temperature	-0.694	0.000	0.671	0.000

The correlations between $\delta^{13}C$, $\Delta\delta^{13}C$ and the wind-related variables, such as monthly mean wind speed, annual mean wind speed, monthly windy days, annual

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windy days, monthly sand-blowing days, annual sand-blowing days and sandstorm days, were analyzed, and the significantly related variables ($P < 0.05$) were selected and listed in *Table 2*.

Table 2. *Pearson correlations (r) of wind-related variables with $\delta^{13}C$, $\Delta\delta^{13}C$*

	$\Delta^{13}c$		$\Delta\delta^{13}C$	
	R	**P**	**R**	**P**
Wind speed in Feb			-0.495	0.012
Wind speed in Mar	0.408	0.043	-0.503	0.010
Wind speed in Apr			-0.494	0.012
Wind speed in May			-0.412	0.041
Wind speed in Jul			-0.415	0.039
Wind speed in Aug	0.433	0.031	-0.415	0.039
Wind speed in Sept	0.656	0.000	-0.629	0.001
Wind speed in Oct	0.528	0.007	-0.593	0.002
Annual wind speed	0.596	0.002	-0.622	0.001

Principal component analysis

Principal component analysis (PCA) carried on the 26 variables related to $\Delta\delta^{13}C$ for data compression. The KMO (Kaiser-Meyer-Olkin) value (0.496) is poor, however Bartlett's test of sphericity ($P < 0.001$) indicates we can proceed. Based on the rule that the minimum eigenvalue should not be less than 1, four components were extracted from the PCA result (*Table 3*). Eliminating the coefficient less than 0.5, the factor loadings are showed in the rotated component matrix (*Table 4*).

Table 3. *Total variance explained*

Component		**1**	**2**	**3**	**4**
Initial eigenvalues	Total	13.258	4.671	1.327	1.223
	% of variance	50.994	17.965	5.103	4.704
	Cumulative %	50.994	68.959	74.062	78.766
Extraction sums of squared loadings	Total	13.258	4.671	1.327	1.223
	% of variance	50.994	17.965	5.103	4.704
	Cumulative %	50.994	68.959	74.062	78.766
Rotation sums of squared loadings	Total	10.639	7.051	1.527	1.261
	% of variance	40.921	27.120	5.875	4.850
	Cumulative %	40.921	68.041	73.916	78.766

Regression analysis

Liner regression analyses were performed to explore the relationship between temperature and $\delta^{13}C$, $\Delta\delta^{13}C$, and then regression models were built to reconstruct the paleotemperature. Firstly, based on the correlation ($r = 0.72$, $P = 0.00$) between $\delta^{13}C$ values and the observed lowest temperature in June (LT_{Jun}), the reconstruction model of LT_{Jun} is (*Eq. 2*):

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$$\begin{array}{lll} LT_{Jun} & = & -9.542 - 1.031 * \delta^{13}C \\ Std.Error & 5.183 & 0.209 \\ P-value & 0.079 & 0.000 \end{array} \qquad \text{(Eq.2)}$$

The R^2 of the model is 0.51. We used this equation to reconstruct the LT_{Jun}. *Figure 3a* illustrates the reconstructed lowest temperature in June, and *Figure 3b* shows the comparison between the reconstructed lowest temperature with the observed data from the Minfeng meteorological station.

Table 4. *Rotated component matrix*[a]

	Component			
	1	**2**	**3**	**4**
Lowest temperature in Jan	0.826			
Lowest temperature in Feb	0.797			
Lowest temperature in Mar	0.720			
Lowest temperature in Apr	0.750			
Lowest temperature in May	0.636			
Lowest temperature in Jun	0.795			
Lowest temperature in Jul	0.682			
Lowest temperature in Aug	0.820			
Lowest temperature in Sep	0.873			
Lowest temperature in Oct	0.882			
Lowest temperature in Nov	0.913			
Lowest temperature in Dec	0.875			
Annual mean of lowest temperature	0.967			
Annual mean of highest temperature	0.519			
Annual mean temperature	0.868			
Mean winds peed		0.880		
Wind speed in Feb		0.899		
Wind speed in Mar		0.904		
Wind speed in Apr		0.866		
Wind speed in May		0.936		
Wind speed in Jul		0.929		
Wind speed in Aug		0.656		
Wind speed in Sept		0.685		
Wind speed in Oct		0.736		
Precipitation in Apr				0.847
Air relative humidity in Nov			-0.726	
Lowest temperature in Jan	0.826			
Lowest temperature in Feb	0.797			
Lowest temperature in Mar	0.720			
Lowest temperature in Apr	0.750			

* *a*. 4 components extracted.

Secondly, based on the highest correlation coefficient (r = 0.70, P = 0.00) between $\Delta\delta^{13}C$ and the Annual Mean of Highest Temperature (AMHT), which is the highest one

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among all temperature-related variables, the relationship between $\Delta\delta^{13}C$ and AMHT is (*Eq. 3*):

$$\begin{array}{llll} AMHT & = 10.274 & + & 0.556*\Delta\delta^{13}C \\ Std.error & 2.041 & & 0.118 \\ P-value & 0.000 & & 0.000 \end{array} \qquad \text{(Eq.3)}$$

The R-squared of the model is 0.49. Therefore, we selected AMHT as the representative temperature indicators for the past climate reconstruction. The reconstructed AMHT shows in *Figure 3c*, the reconstructed data compared with the observed data at Minfeng meteorological station is shown in *Figure 3d*.

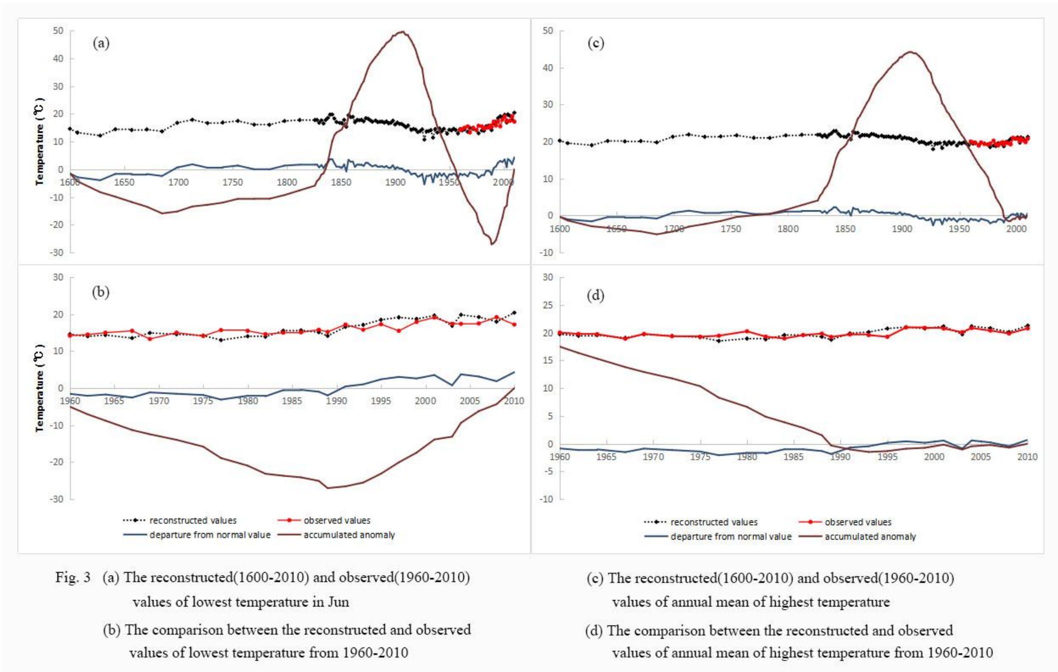

Figure 3. *The reconstructed (1600-2010) and observed (1960-2010) values of lowest temperature in Jun (a); the comparison between the reconstructed and observed values of lowest temperature from 1960-2010 (b); the reconstructed (1600-2010) and observed (1960-2010) values of annual mean of highest temperature (c); the comparison between the reconstructed and observed values of annual mean of highest temperature from 1960-2010 (d)*

Discussion

Features of the $\delta^{13}C$

The values of *Tamarix* leaf $\delta^{13}C$ in the Minfeng sampling site are consistent with the results from Lop Nor (ranging from -24.75‰ to -22.38‰, with a mean of -23.56‰, Xia et al., 2004) and Cele (ranging from -25.008‰ to -23.138‰, with a mean of -24.137‰, Zhang et al., 2017) regions. The $\delta^{13}C$ signature is heavier than that of arid areas in northern China (Liu et al., 2014a) and broadly in accordance with the $\delta^{13}C$ composition of C_3 plants in arid environments. The slight difference between the range and average values of $\delta^{13}C$ in the Minfeng site and values from the Lop Nor and Cele areas is likely due to the difference in climate conditions. Compared with the extremely arid Lop Nor

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area (the annual mean precipitation from 1960 to 2010 is 26.83 mm), the climate of Minfeng sites (the annual mean precipitation from 1960 to 2010 is 29.45 mm) is more humid relatively, leading to slightly lower $\delta^{13}C$ values due to improved water conditions. This finding is similar to other studies (Liu et al., 1997; Sun et al., 2003; Yun, 2010; Zhao, 2012).

Influence of temperature on Tamarix

Temperature is one of the main factors affecting plant growth. The change in temperature may change the plant physiological responses. A declining temperature may result in a reduction in enzyme activity and photosynthetic rate, leading to decreased CO_2 assimilation and a lower growth rate (Beerling, 1994). Several studies have observed an increase in $\Delta\delta^{13}C$ with decreasing temperature (Mccarroll and Loader, 2004; Treydte et al., 2007; Wang et al., 2013). However, our results show a statistically significant negative correlation between temperature-related variables and $\delta^{13}C$, and a significantly positive correlation between temperature and $\Delta\delta^{13}C$. The $\delta^{13}C$ and $\Delta\delta^{13}C$ values are correlated with the annual mean of highest temperatures and the lowest temperature in each month. It appears that the higher temperature led to lower $\delta^{13}C$ values and increased the carbon isotope fractionation. An opposite trend was observed in the Cele site (Zhang et al., 2017), showing some disagreement with our results (Wang et al., 2003; Liu et al., 2007; Shen and Chen, 2000; Zhao et al., 2011b).

Influence of wind speed on Tamarix

Few studies have investigated the effect of wind-related factors on plant growth. In this study, we found that the wind speed is positively related to $\delta^{13}C$ values and negatively related to $\Delta\delta^{13}C$ values in *Tamarix* growing seasons, and the correlations between the annual wind speed and $\Delta\delta^{13}C$ values are more significant than those of $\delta^{13}C$. The highest correlations are mostly in September, and the correlation between annual mean wind speed and $\Delta\delta^{13}C$ is -0.622(P = 0.001). These results suggest that the wind speed affects the *Tamarix* growth. The $\delta^{13}C$ values are much heavier on higher wind speed conditions, and the effect of carbon isotope fractionation is weaker. This may due to the wind from desert is usually hot and dry, which may increase the transpiration and water consumption of *Tamarix*. Therefore, *Tamarix* may reduce stomatal opening status to mitigate water loss. Consequently, the photosynthesis is restrained and the $\delta^{13}C$ value increases.

Influence of precipitation and relative humidity on Tamarix

Studies have reported the influence of water availability on plant carbon isotope fractionation, and a positive correlation between $\Delta\delta^{13}C$ and water availability has been observed in most studies (e.g., Wang et al., 2005, 2008; Diefendorf et al., 2010; Kohn, 2010). In our study, a statistically poor negative relationship between the $\delta^{13}C$ values and the precipitation occurs in January only, and a positive relationship between the $\Delta\delta^{13}C$ values and the precipitation occurs in April only. We found the relative humidity has a significantly positive correlation with $\delta^{13}C$ values and negative correlation with $\Delta\delta^{13}C$ values in November. Different from our study, the $\delta^{13}C$ values are correlated with precipitation only in February (r = -0.522, p = 0.012) in the Cele site (Zhang et al., 2017).

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These results suggest that the effect of local precipitation and relative humidity is relatively weak on the growth of *Tamarix*. This illustrates that the *Tamarix* growth has been adapted to the arid environment, mainly relies on the groundwater, the annual precipitation of 29.4 mm has little effect on *Tamarix* growth. Our preliminary analysis suggests that more precipitation in January and April, likely correlated with more snow, ice and rainfall on the mountains, may supply more available water for the growth of *Tamarix*, and consequently promote the photosynthetic rate and *Tamarix* growth.

Temperature as the key growth-limiting factor

The results of correlation analysis show that the effect of temperature-related variables on $\delta^{13}C$, $\Delta\delta^{13}C$ of *Tamarix* leaves is more significant than those of wind-related and precipitation-related variables. The $\delta^{13}C$ and $\Delta\delta^{13}C$ values are highly correlated with temperature-related variables: monthly lowest temperatures, the annual mean of lowest temperatures, the annual mean of highest temperatures and annual mean temperature. The number of wind-related variables is small and that of precipitation- and humidity-related variables is few.

The PCA results show the temperature-related index is the major influence factor on the $\Delta\delta^{13}C$. The first principal component explained about 51% of the standardized variance, whereas the second principal component accounted for 18%. The first two components explained about 69% of the variance (*Table 3*). The first component showed strong positive loadings on 15 variables: annual mean temperature, annual mean of lowest temperature, annual mean of highest temperature and all monthly lowest temperatures. The second component shows the positive loadings the 9 wind-related variables only.

The influence of temperature on $\Delta\delta^{13}C$ has been studied extensively (e.g., Körner et al., 1988, 1991; Morecroft and Woodward, 1996; Wang et al., 2008, 2013; Gebrekirstos et al., 2009; Diefendorf et al., 2010; Kohn, 2010). Our results indicate that the influence of temperature on the *Tamarix* growth is mainly on the carbon isotope fractionation. Thus, the temperature is identified as the key growth-limiting factor for the *Tamarix* growth. Similar results have also been observed by Liu et al. (2014a) and Xu et al. (2015).

Analysis of reconstructed temperature

The lowest temperature in June is significantly associated with the mean value of lowest temperatures in summer ($r = 0.882$, $p = 0.000$), annual mean of lowest temperatures ($r = 0.810$, $p = 0.000$) and the annual mean temperature ($r = 0.746$, $p = 0.000$). So, the reconstructed records of the lowest temperature in June and annual mean of highest temperature represent a long-term temperature fluctuation in the past 410 years (*Fig. 3*). The mean of LT_{Jun} is 16.08 °C and that of AMHT is 20.58 °C for the full records. According to the departure from the average and the accumulated anomaly, the records can be further divided into the following four sub-periods:

The first period (1600-1685): The departure from normal value of the reconstructed LT_{Jun} and AMHT decreased year after year. The reconstructed LT_{Jun} (the average value is 13.81 °C) and AMHT (the average value is 19.85 °C) below averages. This period is defined as a history cold period.

The second period (1686-1910): The departure from normal value of the reconstructed LT_{Jun} and AMHT rebounded from its lows (1685), and rose fast after

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1830. The mean of reconstructed LT_{Jun} is 17.11 °C before 1830, and that rose to 17.37 °C in late 80 years. The mean of AMHT is 21.52 °C. The reconstructed temperatures are warmer than averages. It is defined as the history warm period.

The third period (1911-1993): The departure from normal value of the reconstructed LT_{Jun} and AMHT decreased rapidly till 1993. The mean of reconstructed LT_{Jun} is 14.18 °C and that of AMHT is 19.44 °C, those are cooler than averages until 1993. It is defined as modern cold period.

The fourth period (1994-2010): From 1994, the reconstructed temperatures turned warmer. The mean of reconstructed LT_{Jun} is 18.91 °C and that of AMHT is 20.75 °C. The LT_{Jun} rose more rapidly than AMHT. It is defined as modern warm period.

The mean of observed LT_{Jun} is 15.14 °C and that of AMHT is 19.76 °C from 1960 to 1993, and those from 1994 to 2010 are 19.76 °C and 20.42°C, respectively. The trend of the constructed temperature is accord with those of the observed.

Our reconstructed records are broadly consistent with Zhao et al. (2016) that concluded that the past climate had experienced 4 stages based on TOC, TN and C/N analysis on the same sampling site. In particular, the two of our four periods, 1600-1690 (cool) and 1991-2010 (warm), are consistent with their study, but the other two, 1691-1900 (cool) and 1901-1990 (warm), have the opposite trends. The result shows that it had been warmer before 1912, and then turned cool. This is partly consistent with Zhao et al. (2015a) that reconstructed the climate record of the past 200 years using fossil pollen from the Andier ancient city; the history warm period (1685-1912) is roughly consistent with Guo et al. (2016) that reconstructed the past climate in Cele site based on fossil pollen data, and the history cold period (1600-1685) is consistent with Yao et al.'s (2001) study of the Guliya ice core. The discrepancies between these results may be caused by different materials, precision, or time scale.

Sensitivity of the reconstructed records

The $\delta^{13}C$ and $\Delta\delta^{13}C$ signature of *Tamarix* leaf are sensitive to the climate in the SMTD. The effects of climate on $\delta^{13}C$ and $\Delta\delta^{13}C$ in Minfeng sites are reversed with those in the Cele site and Lop Nor region except for the precipitation. The higher monthly lowest temperature and annual mean of highest temperature promote the *Tamarix* growth in the Minfeng site, whereas limit the *Tamarix* growth in the Cele site (Zhang et al., 2017). The opposite results suggest that the *Tamarix* growth is sensitive to the ecological environment. It may be caused by the difference in their geographical environment. With less population and no reservoir was constructed to adjust the runoff of the Andier river, the Minfeng oasis is smaller than the Cele oasis. Thus, the human interference is relatively lower in the Mingfeng site.

Conclusions

In this paper, we investigated the effects of the climate factors on $\delta^{13}C$ and $\Delta\delta^{13}C$ signatures in the Minfeng site. We found that the effect of temperature is most significant, can contribute to 50% of the carbon isotope fractionation, and is the key growth-limiting factor for the *Tamarix* growth. The wind speed is the second factor affecting on the *Tamarix* growth and it might significantly affect on plant growth in the growing seasons.

The reconstructed records in the lowest temperature in June and annual mean of highest temperature showed that the temperature fluctuated during the past 400 years.

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The lowest temperature in June rose more rapidly than the annual mean of highest temperatures in recent decades. Future studies are recommended to investigate the mechanism of the climate factors on the *Tamarix* growth and using multiple proxies to improve the understanding of the past climate change and predict how plants respond to climate change in the future.

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