

## PHENOLOGICAL BEHAVIOUR OF DESERT PLANTS IN RESPONSE TO TEMPERATURE CHANGE: A CASE STUDY FROM TURPAN EREMOPHYTES BOTANICAL GARDEN, NORTHWEST CHINA

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### Abstract

The phenology of three genera of desert plants (viz., *Calligonum* L., *Haloxylon* L., and *Tamarix* L.) was investigated in response to temperature changes in Turpan. Eremophytes Botanical Garden The temperature was raised gradually from 1977 to 2006, while the phenophases of *Calligonum* L., *Haloxylon* L., and *Tamarix* L. genera were slowly and insignificantly changed in the study area. Their phenophase were similar and did not change significantly over the duration of the study except the beginning of flowering of the average of the three genera from 1977 to 1990 and 1991 to 2006, respectively. The summed temperature of the first four months was the major factor that affected the spring and flowering phenophases of the respective genera. The bud of *Calligonum* species was expanded during 1977 to 1990 and 1991 to 2006, the flower-buds in *Tamarix* species appeared during 1977 to 2006, the fruit setting of *Haloxylon* species started 1990 to 2006 and leaf discoloration of *Tamarix* species appeared during 1977 to 1990.

**Key words:** Phenology, Desert plant; Climate change, Temperature, Turpan in China.

### Introduction

Numerous plant phenological studies have been concentrated worldwide in moist temperate zones, such as Western Europe, eastern North America, and Asia (Ibrahim *et al.*, 2011; Juknys *et al.*, 2012; Ma & Zhou, 2012; McEwan *et al.*, 2011; Ni, 2011; Primack & Miller-Rushing, 2011; Robbirt *et al.*, 2011; Rousi *et al.*, 2011; Sherry *et al.*, 2011). In these locations, temperature was recorded as the main factor in determining the timing of spring flowering and leaf bud break, whereas, precipitation and soil moisture was less limiting factor (Ibanez *et al.*, 2010; Schwartz & Hanes, 2010). However, the findings of these studies are not universal, because large areas of the world are covered by deserts, tropical deciduous forests, tropical and temperate grasslands, and other dryland habitats (Khan *et al.*, 1984; Aziz & Khan, 1993; Naz *et al.*, 2010), where precipitation plays a much more important role in dictating the timing of biological processes (Penuelas *et al.*, 2009). Phenology is relatively understudied in these systems, especially when we consider their contributions to global biodiversity and ecological processes.

Historical records are an important resource for understanding the biological impacts of climatic change. These records include naturalist journals, club and field station records, museum specimens, photographs, and scientific research. Finding these records and overcoming their limitations are serious challenges for climate change research (Primack & Miller-Rushing, 2012). Phenophase records have been kept in the Turpan Eremophytes Botanical Garden since 1977, but they were just recorded in the archive and have not been studied before.

Climate change may exacerbate species' invasions into communities if non-native species can respond better to climate change than native species. The botanical gardens are a good place for obtaining climate and phenology records (Jenouvrier & Visser, 2011; Chang *et al.*, 2011). Desert plants phenology responses to climate

warming in China in Minqin were previously analyzed (Chang *et al.*, 2011) and Xinan (Bai *et al.*, 2010).

The humidity is very low and irrigation water remains changeless during some time but the calculable amount irrigation water is unknowable. The studies of phenological change at low elevations (-76~105m) are rare, despite of significant effects on elevation on plant phenology and the climate in general (Gimenez-Benavides *et al.*, 2007). This paper describes research undertaken at the Turpan Eremophytes Botanical Garden and attempts to identify how desert plants respond to climate change. *Calligonum*, *Haloxylon* and *Tamarix*, species are natives to deserts of Central Asia, which are collectively referred to as "three swordsmen in the desert." They persist in surveying climate change because their longevity is greater than other desert plants. By comparing their phenology and response to temperature we can find the most sensitive desert plants to climate change in the arid areas.

### Materials and Methods

The Turpan Eremophytes botanical garden, built in 1976, is located in the heart of the Turpan basin in Xinjiang, covering an area of 150 h<sup>2</sup> at an altitude of -76 to -105 m, making it the world's lowest altitude botanical garden (89°11' E; 40°51' N; Fig. 1). The average annual rainfall is 16.4 mm, while minimum and maximum temperatures reach both ends of extreme i.e. -28 and 49, respectively. The themes of various galleries include: desert plant garden (e.g., *Tamarix* spp. gallery, *Calligonum* spp. gallery), national medicinal gallery, desert economic plant gallery, desert wild ornamental botanical gallery, rare and endangered botanical gallery, saline desert botanical gallery, biomass energy theme gallery, and native desert plant gallery containing 766 plants. This garden is center of world temperate desert plant species diversity and a special germplasm resource repertory for the most abundant desert plants.

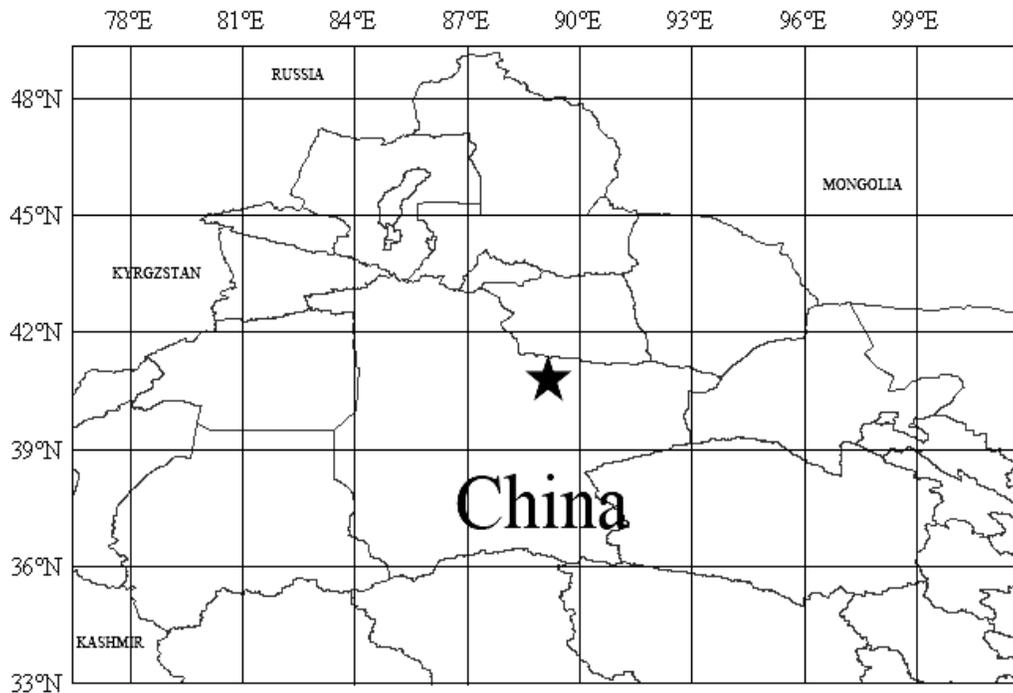


Fig. 1. Location of the study area  
Turpan Eremophytes Botanic Garden

Phenological observations were in 1976 (Zhu & Wan, 1973) in Turpan Eremophytes Botanical Garden started. The 14 species were irrigated every year and amount of irrigation was not the same all the time, and there were 15 phenophases for each. In this study, all the 14 species with incomplete observational data from 1977-2006 were selected for analysis (Table 1).

Phenological observations were made once every two days during their growing period, with 2-3 individuals observed per species, according to the "Chinese Phenological Observation Standard" (Zhu & Wan 1973). The observations covered 15 phenophases (Table 2). Bud expansion marked the beginning of the growing season whereas the completion of defoliation signified the end. Average monthly and annual temperatures were recorded from a weather station installed at the Turpan weather station (9.3 km to the north of the study area). The observations were made using meteorological observation standards formulated by the Chinese State Meteorological Bureau. The first phenophase, coined the "spring phenophase," included four stages: bud expansion, bud opening, beginning of leaf extension, and leaf flourishing. Second was the flower phenophase, which included the following four stages: flower bud appearance, beginning of flowering, flower flourishing, and end of flowering. The final phase, or autumn phenophase, included seven stages: fruit maturity, beginning of fruit drop, end of fruit drop, beginning of leaf discoloration, full leaf discoloration, beginning of leaf fall, and end of leaf fall (Table 2). The "budding period" refers to the process of buds beginning to develop on a part of the plant, the leafing period is the process of forming leaves, the flowering period is the process of flowers blooming, the fruiting period is the process of plants bearing fruits, the leaf coloring period is the process of color changing on

the leaves, and the defoliation period is the process of leaf falling. The starting date of a species' growth period was expressed in the day of year (calculated from 1 January of the current year and thereafter).

Figure 1 was drawn by Arcmap 9.3. Data were analyzed using SPSS 13.0 and figures were drawn using Origin 11.5. Temperature variation, the significance at average monthly and annual level, trends at generic level, and total average level were expressed using linear regression, which resulted in tests performed over the entire period (1977-2006), as well as separate tests for the first and second halves of the record (1977-1990 and 1991-2006). A 95% confidence level was used for regression trends, relevant coefficients, and variance. The significance is expressed in Table 3 and trends are expressed in Fig. 2-5. Correlations between temperature and phenophase are expressed using linear regression with a 95% confidence level (Fig. 6)

## Results

### Temperature changes and plant phenology trends:

From 1977-2006, the average annual temperature in the study area increased (Fig. 2a) at a rate of  $0.71^{\circ}\text{C}/10\text{a}$  ( $p=0.01$ ). In terms of the monthly average temperature, rapid increases occurred in January, February, June, and November, whereas the temperature in March and December showed a distinct increase (Fig. 2b). The starting date of the spring phenophase (marked by bud expansion throughout this paper) showed an unclear advancing trend ( $R^2=0.167$ ,  $p=0.103$ ) (Table 3; Fig. 2c), advanced 0.61 days in 30 years. The completion of the autumn phenophase showed an insignificant delay ( $R^2=0.254$ ,  $p=0.362$ ) (Table 3; Fig. 2d) of 0.25 days over 30 years.

Table 1. The origin area and planting times of 14 plants observed on phenophase in Turpan Eremophytes Botanic Garden.

Family	Genus	Num	Species	Origin area	Planting time
Polygonaceae	<i>Calligonum</i> L.	1	<i>C. calliphysa</i>	Qitai, Xinjiang China	1975
		2	<i>C. pumilum</i>	Shapotou, Gansu China or The former Soviet Union	1975
		3	<i>C. arborescens</i>	Shapotou, Gansu China or The former Soviet Union	1976
		4	<i>C. caput-medusae</i>	Shapotou, Gansu China or The former Soviet Union	1975
		5	<i>C. ebi-nuricum</i>	Jinhe, Xinjiang China	1975
		6	<i>C. leucocladum</i>	Gurbantunggut Desert Xinjiang China	1976
		7	<i>C. rubicundum</i>	Buerjin, Xinjiang China	1975
		8	<i>C. cordatum</i>	Jita, Gansu China	1977
		9	<i>C. densum</i>	Buerjin, Xinjiang China	1975
Chenopodiaceae	<i>Haloxylon</i> L.	10	<i>H. ammodendron</i>	Ganjiahu, Xinjiang China	1973
		11	<i>H. persicum</i>	Ganjiahu, Xinjiang China	1973
		12	<i>T. ramosissima</i>	Shapotou, Gansu China or The former Soviet Union	1978
Tamaricaceae	<i>Tamarix</i> L.	13	<i>T. albiflorum</i>	Xinjiang or Gansu, unknown	1978
		14	<i>T. taklamakanensis</i>	Xinjiang or Gansu, unknown	1978

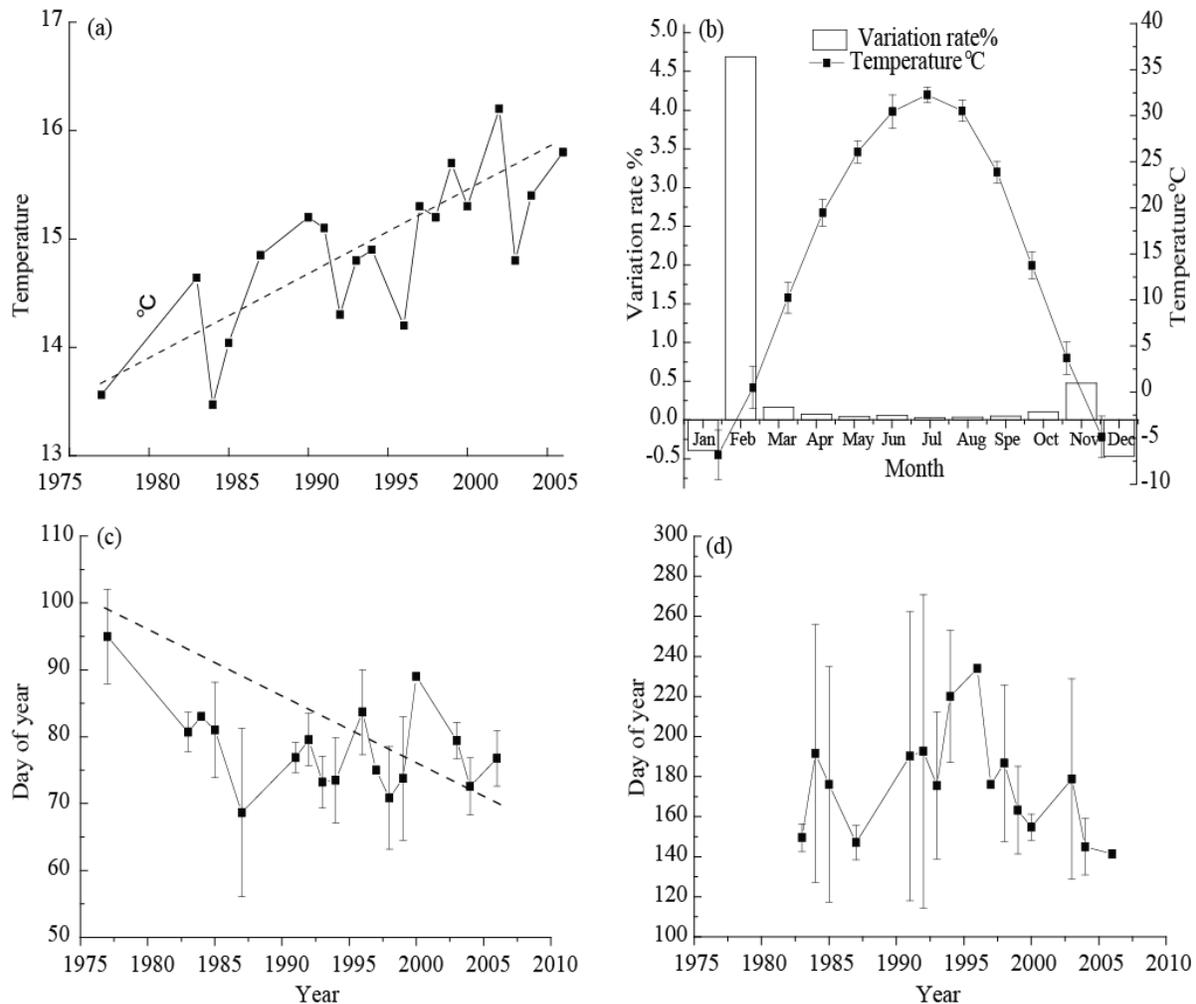


Fig. 2. Variations of temperature and phenophase during 1977–2006. (a) Annual mean temperature; (b) Monthly average temperature and the standard error; (c) Starting date of spring phenophase; (d) Ending date of autumn phenophase.

Table 2. The average phenophase of *Calligonum L.*, *Haloxylon L.* and *Tamarix L.* from 1977 to 2006.

Genus	Phenophase														
	Spring phenophase					Flower phenophase					Autumn phenophase				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>Calligonum L.</i>	Mean ± SE	80.42 ± 6.18	86.00 ± 3.25	92.46 ± 3.90	101.26 ± 8.26	113.23 ± 4.19	119.61 ± 4.08	104.51 ± 5.16	125.45 ± 3.34	136.91 ± 6.44	145.32 ± 5.91	158.72 ± 12.89	275.07 ± 20.76	309.42 ± 7.93	
<i>Haloxylon L.</i>	Mean ± SE L.	73.00 ± 8.32	71.20 ± 5.17	66.56 ± 5.13	80.32 ± 10.72	158.99 ± 28.91	175.39 ± 35.54	147.85 ± 29.45	188.60 ± 39.68	166.50 ± 37.04	201.57 ± 34.02	210.38 ± 45.63	277.06 ± 14.11	317.40 ± 6.83	
<i>Tamarix L.</i>	Mean ± SE L.	71.13 ± 6.01	79.68 ± 7.43	89.85 ± 6.39	99.33 ± 14.35	141.35 ± 71.41	151.59 ± 81.17	122.33 ± 60.27	134.19 ± 61.89	213.14 ± 55.01	296.83 ± 13.79	210.07 ± 51.00	289.61 ± 8.98	311.00 ± 4.24	

Note: 1, Bud-expansion; 2, Bud-opening; 3, Beginning of leaf extension; 4, Leaf flourishing; 5, Flower-bud appearance; 6, Beginning of flowering; 7, Flower flourishing; 8, End of flowering; 9, Fruit maturity; 10, Beginning of fruit drop; 11, End of fruit drop; 12, Beginning of leaf discoloration; 13, Full leaf-discoloration (data is not available); 14, Beginning of leaf fall (data is not available); 15, End of leaf fall; SD = standard deviation

Table 3. The significance analysis (p value) of trends of the 15 phenophase in *Calligonum L.*, *Haloxylon L.* and *Tamarix L.* at generic level and total average level.

Year	Genus	Phenophase														
		Spring phenophase					Flower phenophase					Autumn phenophase				
		1	2	3	4	5	6	7	8	9	10	11	12	13		
1977-2006	<i>Calligonum L.</i>	0.099	0.607	0.715	0.904	0.999	0.405	0.963	0.275	0.201	0.538	0.106	0.479	0.737		
	<i>Haloxylon L.</i>	0.890	0.883	0.300	0.754	0.339	0.244	0.612	0.673	0.841	0.319	0.726	0.567	0.593		
	<i>Tamarix L.</i>	0.432	0.372	0.471	0.896	0.009	0.174	0.143	0.475	0.939	0.303	0.825	0.342	0.681		
1991-2006	<i>Calligonum L.</i>	0.008	0.075	0.302	0.756	0.307	0.689	0.832	0.150	0.507	0.901	0.246	0.187	0.740		
	<i>Haloxylon L.</i>	0.924	0.902	0.068	0.554	0.898	0.950	0.968	0.984	0.712	0.010	0.144	0.636	0.681		
	<i>Tamarix L.</i>	0.872	0.219	0.101	0.929	0.202	0.943	0.344	0.779	0.482	0.303	0.692	0.995	-		
1977-1990	<i>Calligonum L.</i>	0.025	0.220	0.551	0.991	0.283	0.692	0.553	0.060	0.258	0.285	0.051	0.173	-		
	<i>Haloxylon L.</i>	0.892	0.446	0.688	0.700	0.285	0.151	0.266	0.325	0.118	0.012	0.097	0.932	-		
	<i>Tamarix L.</i>	0.879	0.222	0.026	0.505	0.542	0.810	0.885	0.745	0.659	0.548	0.412	0.006	-		
1977-1990	Ave. of 3 genus	0.046	0.534	0.745	0.493	0.521	0.761	0.817	0.169	0.164	0.725	0.094	0.237	-		
1991-2006	Ave. of 3 genus	0.879	0.937	0.868	0.042	0.960	0.762	0.739	0.473	0.278	0.020	0.156	0.184	0.812		
1977-2006	Ave. of 3 genus	0.103	0.470	0.518	0.556	0.125	0.018	0.088	0.199	0.481	0.538	0.464	0.362	0.362		

Note: 1, Bud-expansion; 2, Bud-opening; 3, Beginning of leaf extension; 4, Leaf flourishing; 5, Flower-bud appearance; 6, Beginning of flowering; 7, Flower flourishing; 8, End of flowering; 9, Fruit maturity; 10, Beginning of fruit drop; 11, End of fruit drop; 12, Beginning of leaf discoloration; 13, Full leaf-discoloration (data is not available in this analysis); 14, Beginning of leaf fall (data is not available in this analysis); 15, End of leaf fall (some data is not available in this analysis)

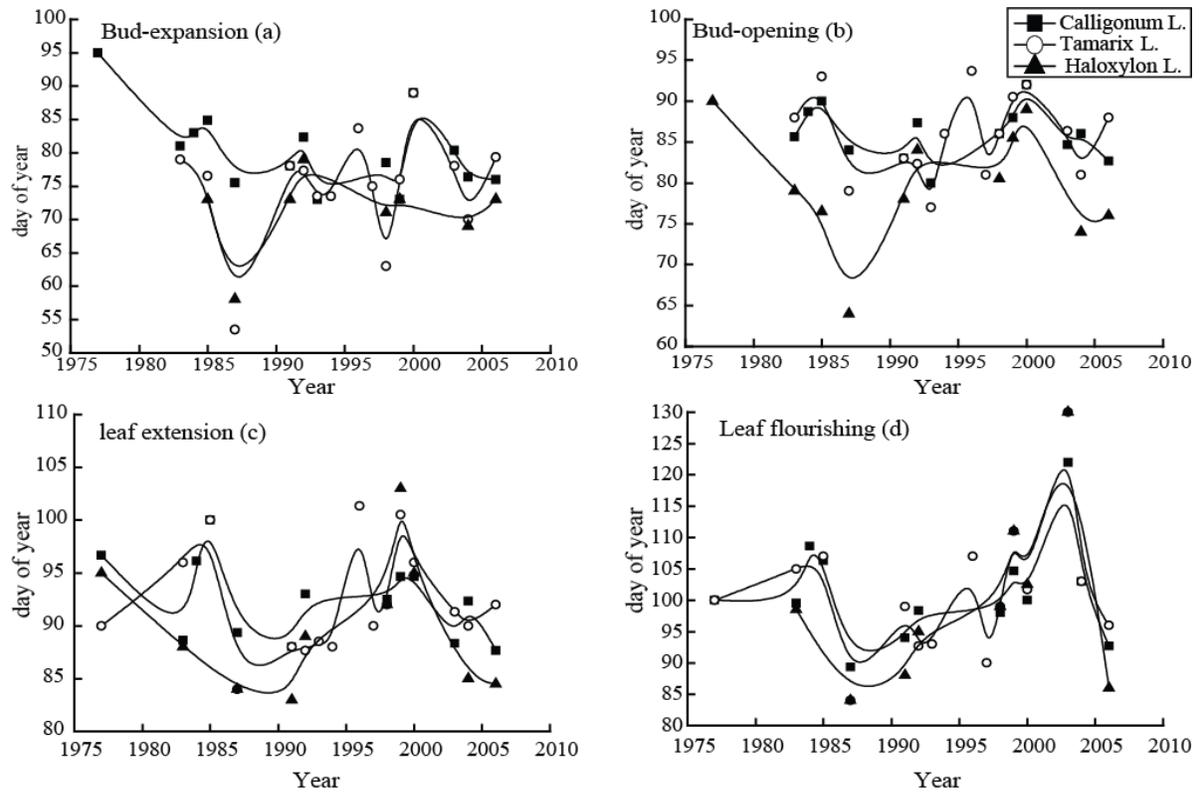


Fig. 3. Differences among the spring phenophase of three genera in *Calligonum L.*, *Haloxylon L.* and *Tamarix L.* (a) Bud-expansion; (b) Bud-opening; (c) Beginning of leaf extension; (d) Leaf flourishing (Julian days).

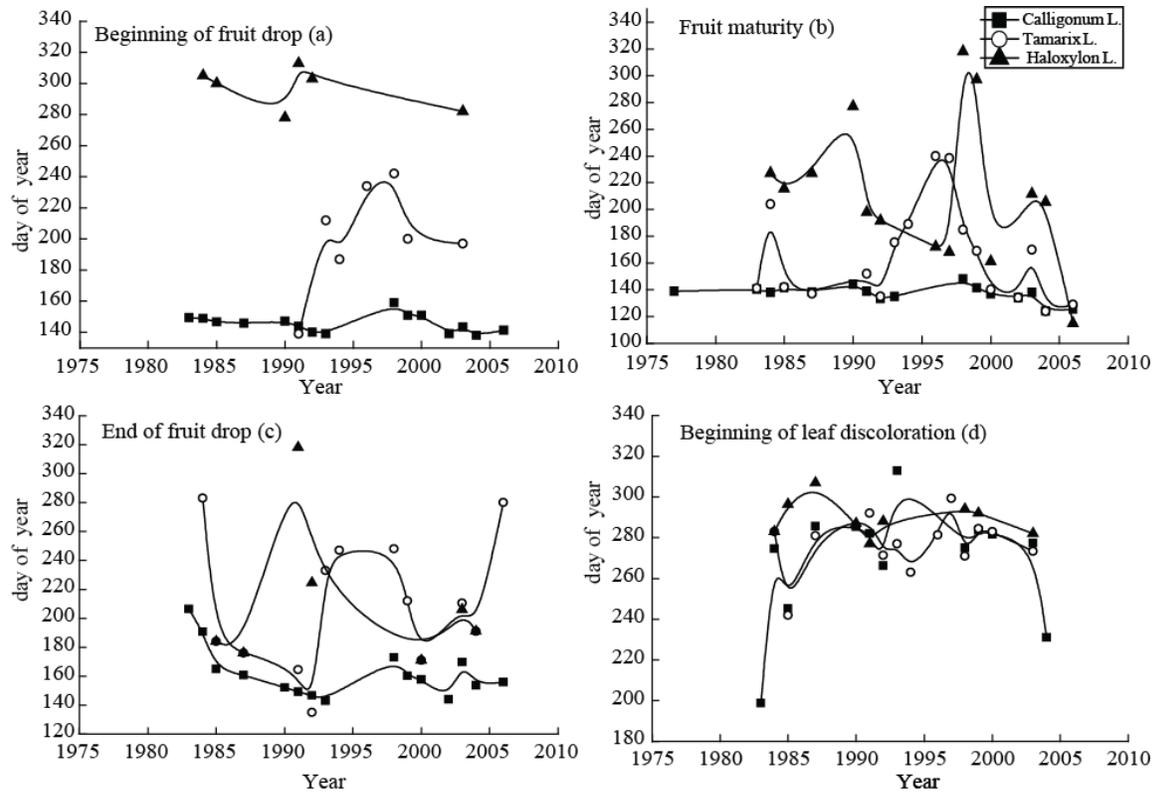


Fig. 4. Differences among the flower phenophase of three genera in *Calligonum L.*, *Haloxylon L.* and *Tamarix L.* (a) Flower-bud appearance; (b) Beginning of flowering; (c) Flower flourishing; (d) End of flowering.

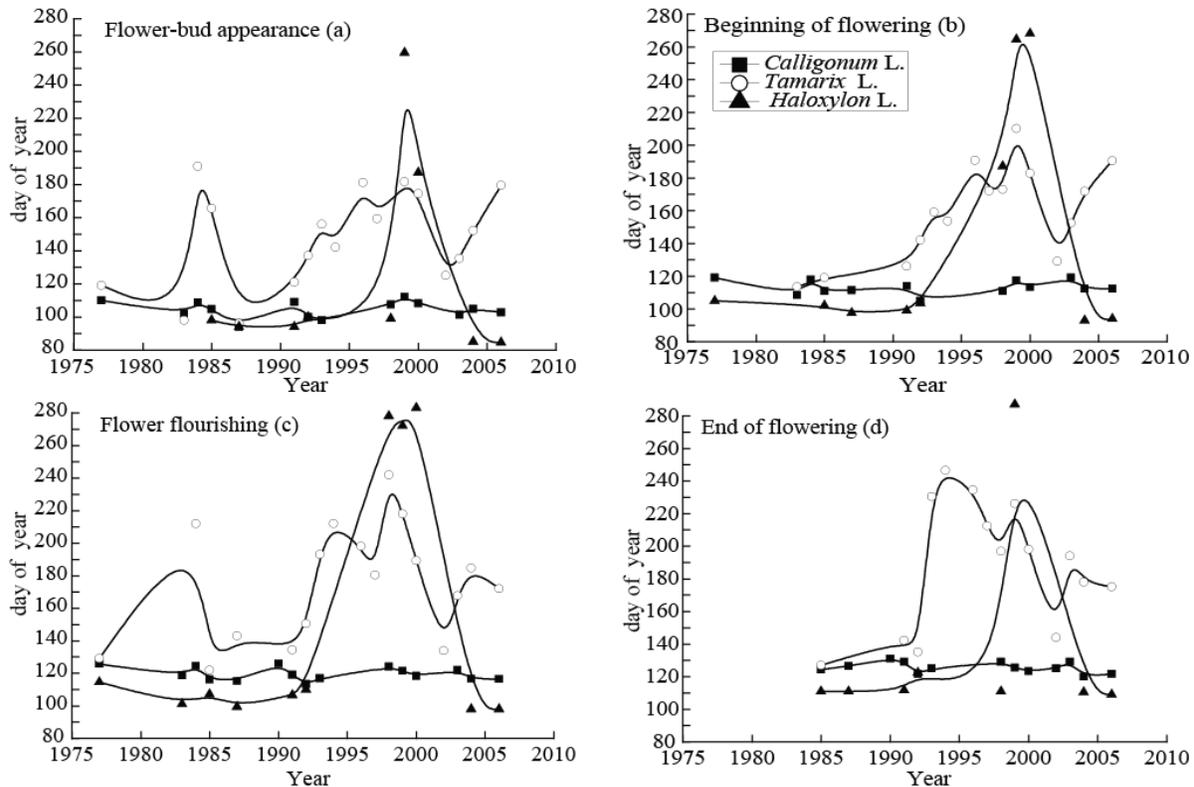


Fig. 5. Differences among the autumn phenophase of three genera in *Calligonum L.*, *Haloxylon L.* and *Tamarix L.* (a) Beginning of fruit drop; (b) Fruit maturity; (c) End of fruit drop; (d) beginning of leaf discoloration.

### Phenological differences among plants from different genera

**Spring phenophase:** The total spring phenophases of *Calligonum* spp., *Haloxylon* spp., and *Tamarix* spp., each decreased insignificantly throughout the study period, but from 1977 to 2006, the start date notably fell backwards nearly one month ( $R^2=0.254$ ;  $p=0.046$ ). (Table 3; Fig. 3)

Over the term of the study as a whole, the spring phenophase start date for all species showed either an insignificant shift forward or remained essentially unchanged (*Calligonum L.* had a  $-0.64$  d/a and 19 day advance; *Tamarix L.* had a  $0.01$  d/a and 0.33 day advance; and *Haloxylon L.* had a  $0.00$ d/a and  $0.00$ d/30a) (Table 3; Fig. 3). The bud opening times of *Haloxylon L.* and *Tamarix L.* were similar from 1977 to 1990, whereas that of *Calligonum L.* decreased quickly ( $p=0.025$ ). These results were mirrored from 1991 to 2006, and *Calligonum L.* was again different and decreased quickly ( $p=0.008$ ). Changes in the leaf flourishing of the three genera were the same from 1977 to 1990, after which they increased slowly before decreasing; whereas from 1991 to 2006, they increased fairly rapidly ( $p=0.042$ ) (Table 3; Fig. 3).

**Flower phenophase:** The flower phenophase of the three genera did not change much over the term of the study period (Table 2; Fig. 4). *Calligonum* species were consistent, whereas, *Haloxylon* and *Tamarix* species changed over time. The flower bud appearance of *Tamarix L.*, had two peaks, one in 1984-1985 and another point in 1990-2000. *Haloxylon L.* had only one peak in 2000 (Fig. 4a). The starting date of *Tamarix* and

*Haloxylon* species flowering also changed with time and both peaked in 2000 (Fig. 4b). The changes in the flowering period of the three genera were similar to the change in start date, although *Tamarix* species had peaks in 2000 and 1984 (Fig. 4c). Due to incomplete data, records analyzing the end of the flowering period were not integrated. The peak for *Tamarix L.* was in 1995, and *Haloxylon L.* was in 2000, whereas *Calligonum L.* did not change much (Table 3; Fig. 4d).

The total flower phenophase periods for *Calligonum L.*, *Haloxylon L.* and *Tamarix L.* were all reduced insignificantly. The average of the three species' flowering initiation date however, showed a slightly significant change ( $p=0.018$ ), as well as the bud appearance specifically for *Tamarix L.*, which advanced by  $1.50$  d/a ( $p=0.009$ ) (Table 3; Fig. 4).

**Autumn phenophase:** The autumn phenologies of the three genera did not change much (Table 2, Fig. 5), with exception to the significant reduction in the start date of the fruit drop average from 1991 to 2006 ( $p=0.020$ ) and the actual start date of the fruit drop for *Haloxylon* species, the earliest of the three genera, also showed a significant reduction from 1977 to 1990 ( $p=0.012$ ) and 1991 to 2006 ( $p=0.010$ ). The fruit maturity of *Calligonum* species hardly changed over 30 years (Table 3). *Haloxylon* species shared similar results, but with three peaks in 1995, 1998, and 2000. *Tamarix* species had only one peak in 1995 (Fig. 5b). There were insufficient recordings for the starting date for leaf discoloration and the beginning of leaf fall, although it was the same for all three genera from 1995 to 2006.

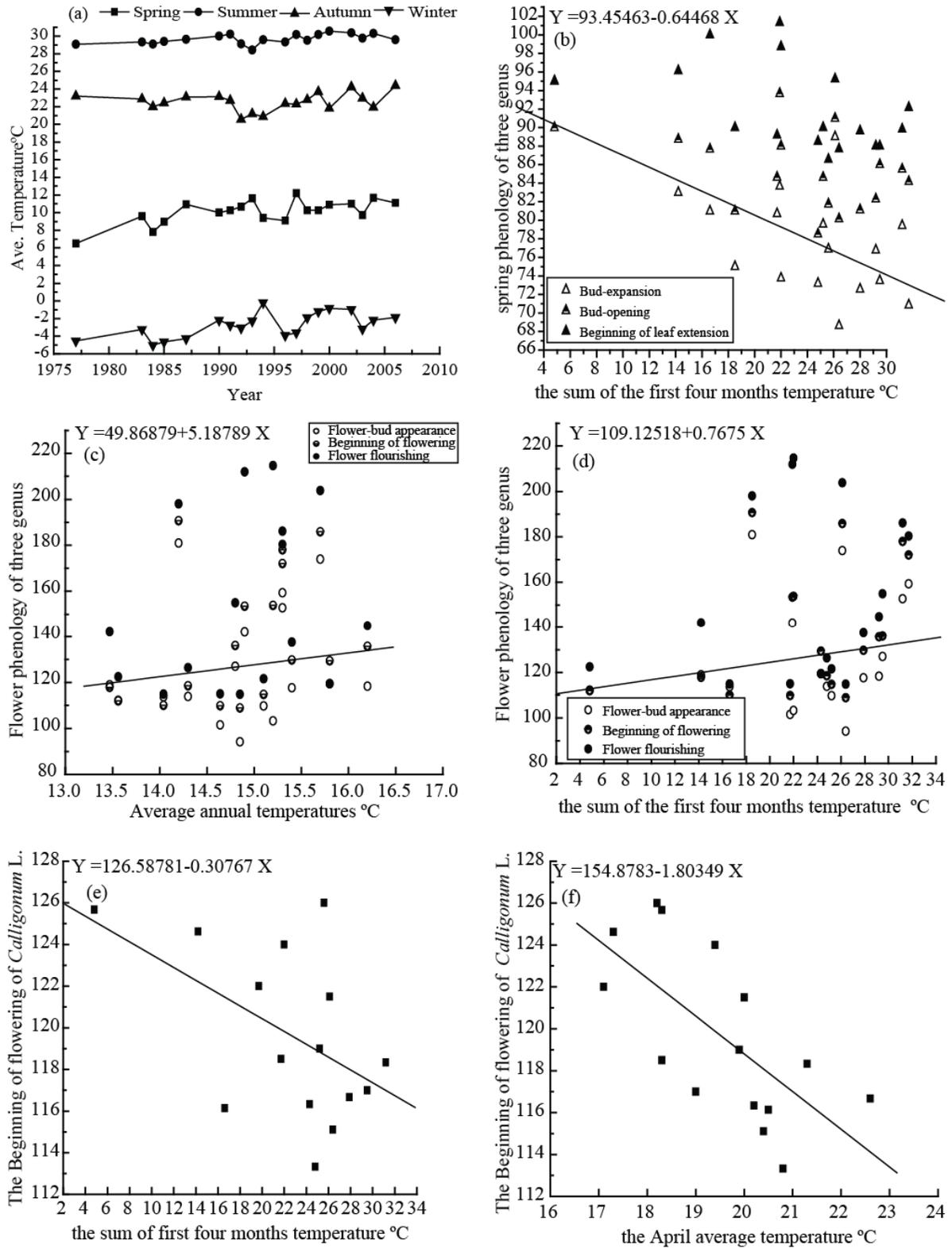


Fig. 6. Correlation between plants' phenophase and temperature variation. (a) The four season temperature in 1975 to 2006; (b) Correlation between the sum of first four months temperature and the spring phenophase; (c) Correlation between annual average temperatures and the flower phenophase; (d) Correlation between the sum of first four months temperature and the flower phenophase; (e) Correlation between the sum of first four months temperature and the Beginning of flowering of *Calligonum* species; (f) Correlation between the April average temperature and the Beginning of flowering of *Calligonum* L.

**Correlation between temperature and phenological changes in different genera of desert plants:** The average temperature of the four seasons changed between 1977 and 2006. Autumn was consistent, while spring increased ( $p=0.002$ ) at a rate of  $0.39^{\circ}\text{C}$ , summer ( $p=0.020$ ) at an even higher rate of  $0.76^{\circ}\text{C}$ , and winter ( $p=0.003$ ) at a significant but lower rate of  $0.36^{\circ}\text{C}$  (Fig. 6a).

The first two phenophases of the three genera correlated directly to temperature. The results showed that the spring phenophase was significant ( $p<0.05$ ). Flower phenologies (beginning of flowering, flower flourishing, and end of flowering) for all three genera correlated to annual temperatures ( $p<0.05$ ) and the summed temperature of the first four months ( $p<0.05$ ), although there was no correlation with temperature in April. There were no significant correlations between the autumn phenophase and temperature (the annual average temperature, the summed temperature of the first four months, the April average temperature, and the monthly average temperature when the specific phenophase occurred).

The spring phenophase was generally positively correlated with the summed temperature of the first four months ( $R = 0.844$ ,  $p<0.01$ , Fig. 6b) and started earlier with the increasing average temperature from 1977 to 2006. The flower phenophase (flower bud appearance, beginning of flowering, and flower flourishing) was positively correlated with the annual average temperature ( $R = 0.745$ ,  $p<0.01$ , Fig. 6c) and the summed temperature of the first four months ( $R = 0.668$ ,  $p<0.01$ , Fig. 6d), although it started later depending on the temperature increase throughout the year. The beginning of flowering of *Calligonum* species correlated with the summed temperature of the first four months ( $R = 0.878$ ,  $p<0.01$ , Fig. 6e) and the April average temperature ( $R = 0.787$ ,  $p<0.01$ , Fig. 6f), while it began earlier depending on the increasing average temperature from 1977 to 2006. The autumn phenophase (fruit maturity, beginning of fruit drop, end of fruit drop, beginning of leaf discoloration, full leaf-discoloration, beginning of leaf fall, and end of leaf fall) did not correlate with any temperature characteristics.

## Discussion

Since 1977, the temperature in the study area increased significantly, whereas the phenophase did not begin earlier in conjunction with the rising temperature. The phenological response to climate change has rarely been investigated (Chang *et al.*, 2011; Ghazanfar, 1997) but our results were inconsistent with the Minqin study ( $103^{\circ}48'\text{E}$ ;  $38^{\circ}37'\text{N}$ ), which reported that the plants were sensitive to temperature. The three plants in this study were not sensitive to the changing temperature. The beginning of vegetation (18 March) was earlier than other arid areas, for example 1<sup>st</sup> April in Minqin desert (Chang *et al.*, 2011). The temperature increased by an average of  $0.075^{\circ}\text{C}$  each year, which was not higher than the average temperature increase in the northern hemisphere ( $0.4\text{--}0.8^{\circ}\text{C}$ ) (Dillon *et al.*, 2010) and not higher than the  $0.040\text{--}0.050^{\circ}\text{C}$  increase in China overall. Meanwhile, the phenophase starting date did not advance significantly, with only a  $0.02\text{ d}$  average annual increase, which was

similar to that in the Minqin area (Chang *et al.*, 2011). This advance, however, was slower than the rest of the world (Dillon *et al.*, 2010), particularly the northern hemisphere and the rest of China.

The phenology of the three genera (*Calligonum*, *Haloxylon*, and *Tamarix*) changed in different ways. In the spring phenophase, there was no obvious ordering among the three genera with respect to which began first. Thus, the bud expansion and bud opening of *Calligonum* species were different, while *Haloxylon* and *Tamarix* species were similar. The leaf extension of *Calligonum* and *Tamarix* species were similar, whereas the leaf flourishing among the three genera was similar. The flower phenophase of the three genera were similar in that all were delayed from 1995 to 2006, but they quickly restored themselves to the levels found from 1975 to 1995, which reflected climate change. The beginning of the autumn phenophase of *Haloxylon* species was the earliest among all the three genera, whereas *Calligonum* species remained the same throughout the years.

Phenology records for arid plants are rare. There are no previous reports for *Calligonum* and *Tamarix* species (Chang *et al.*, 2011; Du *et al.*, 2010; Ghazanfar, 1997), so this study compares them for the first time.

These plants can be used as windbreakers and sand fixers in landscaping, according to their phenology; specifically the leaf extension and branches can change the construction of windbreak forests. For example, in winter, dense windbreak forests will change into a sparse structure, reducing the wind-preventing effects due to losses of leaves or branches (Kang *et al.*, 2012). Oscillation of the delay, then advanced, then delayed pattern is the main change rule of the phenology in the three genera in Turpan Eremophytes Botanic Garden.

Our phenological observations of the low-altitude plant garden did not detect any unique characteristics. This downhill shift is counter to what would be expected given 20th-century warming, but is readily explained by the species' niche tracking of regional changes in climatic water balance rather than temperature (Crimmins *et al.*, 2011). The onset of spring flowering for species in the lowest elevations was most commonly driven by temperature and precipitation conditions of the previous autumn (Crimmins *et al.*, 2010). The precipitation in arid areas is the key factor, which affects plants phenology, because of negligible rainfall. Thus, the climate is important to the phenology, and inconsistent irrigation water cannot be ignored. The summed temperature of the first four months was a key characteristic affecting the phenology of the three genera, which correlated with the spring and flower phenophases, but the phenophase was not affected by the local temperature in April as the results in Harbin (Li *et al.*, 2011) nor the temperature in the same month as the results in Shandong (Zang *et al.*, 2011) in this area of China. These results indicate that the water deficit in drought years could threaten lowland populations of these mountainous species, whereas high altitude environments would likely stabilize over time (Gimenez-Benavides *et al.*, 2007). Unfortunately, we lacked detailed irrigation records at the study site, but inadequate irrigation from 1990 to 2006 (Fig. 6c & 6d) was known, which significantly affected the flower phenophase in these years rather than the temperature.

## Conclusion

The temperature in Turpan Eremophytes Botanical Garden was raised gradually from 1977 to 2006, while the phenophases of *Calligonum* L., *Haloxylon* L., and *Tamarix* L. genera were insignificantly progressively changed. Their phenophase were similar over the duration of the study, except 1977 to 1990 and 1991 to 2006, respectively. The summed temperature of the first four months was the major factor that affected the spring and flowering phenophases of the respective genera.

## Acknowledgments

This work was supported by the National Natural Science Foundation of China (Grant No 31100150) and the West Light Talents Cultivation Program of Chinese Academy of Sciences (XBBS 201003).

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(Received for publication 8 June 2013)