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GEOGRAPHICAL DISTRIBUTION AND ECO-ADAPTABILITY OF *CALLIGONUM* L. IN TARIM BASIN

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Abstract

Global climate fluctuations have profoundly affected the current distribution patterns and created opportunities and challenges for the survival and development of species. Studies on geographical distribution and eco-adaptability are necessary for both biodiversity conservation and sustainable biological resource utilization. In this study, we focus on five species of *Calligonum* in Tarim Basin, i.e. *Calligonum roborovskii*, *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* and *C. taklimakanense* to confirm the distribution range by carrying out field population survey, along with the studies of herbarium specimen and relevant literature and also to find out the associations between the five species, distribution correlated with climate and soil characteristics through the mean variance analysis and principal component analysis. The results of the study were as follows: (1) *C. roborovskii* was widely distributed in Tarim Basin, but *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* and *C. taklimakanense* have narrow distribution. The distribution areas of four latter species were overlapping with that of *C. roborovskii* showing sympatric distribution. (2) All the five species belonged to the warm and arid zone. The adaptability of *C. roborovskii* to moisture was higher, that of *C. juochiangense* and *C. taklimakanense* which grew in more arid areas than that of *C. kurlaense* and *C. yengisaricum*, had stronger drought tolerance. The soil type of the five species main was brown desert soil with high salinity, alkaline, and low content of organic matter in the top soil. (3) Low temperature, moisture factor, salinity and alkalinity were the main reasons leading to the different distribution of the four narrow distributed species. (4) The main factors limiting the distribution range of the five species were high temperature and moisture factor, followed by soil properties. For *C. juochiangense* and *C. taklimakanense*, moisture factor was much stronger than temperature. The results of the research will provide basis for the protection, revegetation and reasonable utilization of *Calligonum*

Key words: Tarim Basin; *Calligonum*; Geographical distribution; Climate; Soil; Eco-adaptability.

Introduction

Calligonum L. belongs to the family Polygonaceae, which are mostly shrubs or subshrubs, mainly distributed in northern Africa, southern Europe and Asia. Its longitude and latitude ranges of distribution area are 1°W~116°E and 14°N~15°N respectively (Mao & Pan, 1986). On the basis of spines on the achene's surface, this genus is divided into four groups, Sect. Calliphysa (Fisch. Et Mey) , Sect. Pterococcus (Pall.)Borszcz., Sect. Calligonum and Sect. Modusa Sosk. et Alexandr.. Sect. Calliphysa and Sect. Pterococcus occupy the central area of the whole distribution area. Sect. Calligonum is distributed in the western area, form continuous distribution area in Africa, Europe and Asia. Sect. Modusa Sosk. et Alexandr. is found in the eastern area, distributed in South Asia and central Asia continuously, apart from a small discontinuous distribution area in north Africa (Mao & Pan, 1986). In total, there are about 35 *Calligonum* species in the world, and includes 11 varieties (Mao & Pan, 1986). And 23 species in China, distributed in Xinjing, central and western of Inner Mongolia, western of Ningxia, western of Gansu and Qinghai province. There are 22 species in Xinjiang, accounted for about 80% of the total species of *Calligonum* in China (Mao 1998).

Sect. Calliphysa, Sect. Pterococcus, Sect. Calligonum and part of Sect. Modusa Sosk. et Alexandr are widely distributed in the Junggar Basin and the eastern of Xinjiang. Whereas, the Sect. Modusa Sosk. et Alexandr, including *Calligonum roborovskii* A. Los., *C. kurlaense* Z. M. Mao, *C. yengisaricum* Z. M. Mao, *C. juochiangense* Liou f. and *C. taklimakanense* B. R. Pan et G. M. Shen, is distributed only in the Tarim Basin. Taklimakan desert located in the Tarim Basin, has most severe ecological conditions in Asian and African desert area, with the characters of strong continental, strong flow-ability of sand, large gobi area and salty loam matrix, which contribute to its some peculiar formations (Zhang & Mao, 1989). Therefore, how the five species of *Calligonum* are distributed in the Tarim Basin? Is there some relationship between their geographic distributions and local ecological environment which determine the current distrbution? In the present study, we focused on five species of *Calligonum* in Tarim Basin, including *C. roborovskii*, *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* and *C. taklimakanense*. (a) We combined with field population survey, and herbarium specimen and relevant literature to confirm the distribution range. (b) we analyzed relationship between their geographic distributions and local ecological environment to explore the eco-adaptability of those five species in Tarim Basin. The current study may provide a basis for the protection, revegetation and reasonable utilization of *Calligonum*.

Materials and Methods

Natural conditions: Tarim Basin is located in the south of Xinjiang, which is an enclosed inland basin, surrounded by mountains on three sides. It is near the Pamir in its southwestern, borders the Qinghai-Tibet Plateau in its south, borders on Tian Mountain in its northwest and north, adjoins to the Lop-Nur depression in the east. The Basin has a higher ground in its south and southeast, and a relatively lower ground in its east and northeast. So the whole basin inclines from southwest to northeast. The Tarim Basin has a length of 1100km from east to west, and a width of 600km from south to north, with a total area of 10634km^2. The three types of landform, mountains, plains and deserts, respectively accounts for 47.3%, 21.6% and 31.1% of the Basin's total area (Shi *et al.*, 2001). Because the Basin is located in the inland, and surrounded by mountains, forming a unique climate type i.e. warm temperate zone continental typical arid desert climate, which is dry and hot, with less rain, high air transparency, long sunshine time, rich light and heat resources. The main climatic factors are listed in Table 1 (Ji, 2001).

Table 1. Mainly climate factors of the Tarim Basin.

Climate factors	Value range
≥10℃ annual accumulated temperature	3900 ~ 4300℃
Annual sunshine hours	2800 ~ 3200 h
Frost-free days	180 ~ 270 d
Annual average temperature	10 ~ 12℃
Average temperature in January	-5 ~ 10℃
Average temperature in July	25 ~ 27℃
Annual average relative humidity	35% ~ 55%
Annual precipitation	70 mm, and it has great difference in different regions, about 10 mm to 80 mm in plains, 250 ~ 500 mm on mountains, 50 ~ 70 mm in the northern of basin, 40 ~ 80 mm in its western, generally 15 ~ 30 mm in the southern desert
Annual average wind speed	1.5 ~ 2.8 m/s, it is stronger in spring and summer, about 2 ~ 3.5 m/s, the days with strong wind can reach 15 ~ 30 d in its east and southeast

Wild survey: During July 2014, the field studies were conducted. To make sure the sample plots more representative, comprehensive and integrity, the sample plots of five species of *Calligonum*. in the way of Braun–Blanquet's typical sample recording were choosen (Song, 2001). Each plot set one or two small plots on two scales of 10 m×10 m and 20 m×20 m, respectively (Tian *et al.*, 2016, Zhang, 2011, Wang *et al.*, 2015). The habitat, species composition, quantity of shrubs and GPS data were recorded in the quadrats. Plant specimens were collected at the same time. Soil samples were collected along the diagonal of the 10 m×10 m sample plot. Three point at both ends and the middle of the diagonal were collected with 0 ~ 40 cm deep soil.

The geographic distributions of the five species: The database of detailed geographic distribution and taxonomic data of the five species was prepared based on the Floras of country and region, and the specimens preserved in herbaria, The geographic distribution map of the five species, *C. roborovskii*, *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* and *C. taklimakanense*, were drawn by ArcGis10.0.

Collection and calculation of the climate data: The single climate data come from the software LocClim1.0, developed by the United Nations food and agriculture organization (FAO). The climate parameters in the software are calculated by the continuous climate data in 50 years to 200 years, and it can estimate the climate data of the places without meteorological stations (Rene *et al.*, 2004). We got the climate data of distribution areas of the wild fruit forest by LocClim 1.0, they were average temperature of month, annual average temperature, extreme high temperature, extreme low temperature, annual average precipitation, annual average wind speed.

On the basis of checking several related literatures, fourteen kinds of climate index were confirmed, including the heat indexes, they were Kira's warmth index (WI, ℃, month), Holdridge's annual biology temperature (ABT, ℃), Kira's coldness index (CI, ℃), the extreme high temperature, (T_{max}, ℃), the extreme low temperature (T_{min}, ℃), the annual average temperature (T, ℃), July mean temperature (T_7, ℃), January mean temperature (T_1, ℃), annual range of temperature (ART, ℃). And the moisture indexes, they were Xu wenduo's humidity index (HI, mm (℃) - 1), the annual average precipitation (AP, mm). The hydro-thermal synthetical index, they were potential evapotranspiration rate of Holdridge (PER), hydro-thermal synthetical factor index (S). Wind index was Annual average wind speed (AW，$m \cdot s^{-1}$). Following are the computation formulas of the comprehensive indexes (in the computation formulas, "t" is the average temperature of month, "P" is annual precipitation, "P_i" is monthly precipitation).

WI (Xu 1985) = Σ (t - 5) (t > 5) .... (1)
ABT (Tian 2007, Holdridge 1947) = Σ (t)/12 (0 < t < 30) ....(2)
CI (Xu 1985) = Σ (5 - t) (t <5) .... (3)
HI (Xu 1985, Xu 1983) =AP/WI .... (4)
PER (Zhang 1989) = (ABT*58.93)/P .... (5)
S (Zhang 1989) = Σ ($0.18P_i/1.045t$) .... (6)

On the premise of enough reliable data, when the frequency distribution of the heat index is similar to normal, the optimum range of heat index half of tree species could be confirmed with the method of peak width at half height (PWH) (Hong & Li, 1981), and moisture index could also be calculated by this method (Ni, 1997).

PWH=2.354×S .... (7)
Optimum range X-0.5PWH～X+0.5PWH

In the computation formulas, "S" is the standard deviation of climate index, "x" is the average of climate index.

Experimental analysis of soil samples: Physical and chemical indexes of soil included particle size, organic matter, pH, and salt content were investigated. Organic matter of soil was determined using the method of potassium dichromate volumetric. pH was determined by using pH meter, total salt of soil was tested by the method of weight.

Statistical analysis of climate and soil indices: The mean variance analysis was used to compare the climate and soil indices of all the species to confirm why *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* and *C. taklimakanense* were distributed in some areas independently.

The principal component analysis (PCA) is a statistical analysis method to control the main contradiction. It can reveal the main aspects of life phenomenon from multiple incidents, and find out the key indicators influencing the state of events, so as to achieve to refine and simplify the purpose of the complex data. The key ecological factors influencing the geographic distribution of the five species were tested by the PCA.

Results

The geographic distributions of the five species in Tarim Basin: Survey of those five species' wild populations are shown in Fig. 1 and Table 2.

Comparative analysis of climate and soil characteristics of the four species having narrow distribution: The results of comparative analysis of climate and soil characteristics of the four narrowly distributed species viz. *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* and *C. taklimakanense*, in relation to their mutual independent distributions and overlapping distribution with *C. roborovskii* are shown in Tables 5-7.

The heat indices showed that the differences of T_7, T_{max}, WI, ART and ABT were not significant between each of the four species. Difference of T between *C. yengisaricum* and *C. juochiangense* was significant. Differences of T_1 between *C. kurlaense* and *C. juochiangense* was also significant, *C. yengisaricum* with *C. kurlaense*, *C. juochiangense* and *C. taklimakanense* were highly significant. Differences of T_m between *C. kurlaense* and *C. juochiangense*, *C. taklimakanense* were significant, *C. yengisaricum* with *C. kurlaense*, *C. juochiangense* and *C. taklimakanense* were highly significant. Differences of CI between *C. yengisaricum* and *C. kurlaense* were significant and between *C. yengisaricum* and *C. juochiangense* were highly significant.

Comparative analysis of the moisture indices showed that differences of AP between *C. taklimakanense* and *C. kurlaense*, *C. yengisaricum*, between *C. juochiangense* and *C. kurlaense*, *C. yengisaricum* were highly significant. Differences of HI between *C. taklimakanense* and *C. kurlaense*, *C. yengisaricum* were also highly significant.

Comparative analysis of PER, S and AW of the four narrowly distributed species had the same difference law, which was similar to their moisture indices and also showed that differences of PER, S and AW between *C. taklimakanense* and *C. kurlaense*, *C. yengisaricum*, between *C. juochiangense* and *C. kurlaense*, *C. yengisaricum* were highly significant.

Comparative analysis of the soil properties showed that differences of pH between *C. taklimakanense* and *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* were highly significant. Differences of total salt content between *C. taklimakanense* and *C. kurlaense*, *C. yengisaricum*, between *C. yengisaricum* and *C. kurlaense*, *C. juochiangense*, between *C. yengisaricum* and *C. taklimakanense* were highly significant. Organic matter of the four species was similar.

Climate and soil characteristics of *Calligonum* species distribution areas: The climate and soil characteristics of the five species' distribution areas are shown in tables 3 and 4.

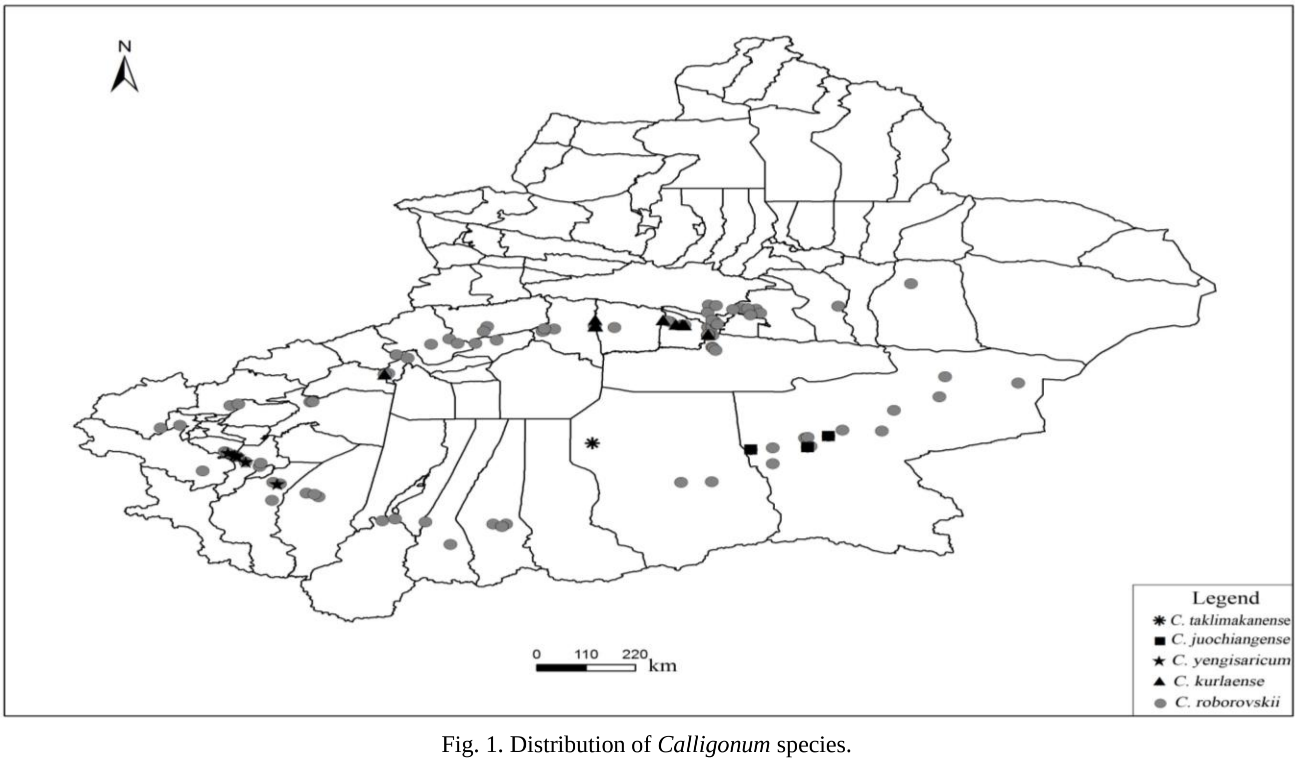

Fig. 1. Distribution of *Calligonum* species.

Table 2. Distribution ranges of the five species.

Species	Longitude and latitude	Altitude / m
C. roborovskii	The north distribution boundary was Kumishi town of Tuokexun county (88.81°E, 42.34°N), the south distribution boundary was Nuer village of Cele county (81.01°E, 36.30°N), the west distribution boundary was Wupaer village of Shufu county (75.19°E, 39.25°N), the east distribution boundary was Kuruketag Mountain in the east of Lop Nur (92.42°E, 40.40°N). The biggest latitude range of *C. roborovskii* was 6.04°. The biggest longitude range of *C. roborovskii* was 17.23°	450 ~ 3 300
C. kurlaense	Mainly distributed in Kuerle city, Luntai county, Yuli county, etc. Its distribution range was from 40.62°N to 42.00°N and from 76.69°E to 86.19°E	900 ~ 1 200
C. yengisaricum	Mainly distributed in Yingjisha, Yecheng, and Shache county, etc. Its distribution range was from 37.83°N to 38.62°N and from 76.54°E to 77.53°E	1 296 ~ 1 450
C. juochiangense	Mainly distributed in Ruoqiang county. Its distribution range was from 38.70°N to 39.05°N and from 87.04°E to 88.61°E	987 ~ 1 340
C. taklimakanense	Middle Taklimakan (83.87°E, 38.87°N)	1107.3

Table 3. Climate and soil characteristics of *C. roborovskii* and *C. Kuerlese*.

Indexes	*C. roborovskii*				*C. kuerlese*			
	Minimum	Maximum	Mean	Optimum range	Minimum	Maximum	Mean	Optimum range
WI/℃·mon	51.4	111.8	98.7	86.1~111.3	85.9	105.9	97.5	88.7~106.2
AP/mm	7.1	88.7	49.7	25.3~74.2	54.1	72.0	60.4	53.5~67.2
HI/mm·(℃·mon)$^{-1}$	0.1	1.3	0.5	0.2~0.8	0.5	0.7	0.6	0.5~0.7
pH	7.2	9.1	8.0	7.5~8.6	7.4	8.0	7.6	7.3~8.0
Total salt/g·kg^{-1}	1.2	10.0	5.8	2.2~9.5	6.9	10.0	8.6	6.7~10.5
Organic matter/g·kg^{-1}	1.2	8.0	3.8	1.3~6.2	2.2	3.6	3.0	2.2~3.9

Table 4. Climate and soil characteristics of *C. yingisaricum* and *C. Ruoqiangense*.

Indexes	*C. yingisaricum*				*C. ruoqiangense*			
	Minimum	Maximum	Mean	Optimum range	Minimum	Maximum	Mean	Optimum range
WI/℃·mon	108.9	109.3	109.1	108.8~109.3	57.3	109.6	93.8	64.7~122.9
AP/mm	56.6	66.5	62.2	56.2~68.2	17.4	40.6	23.8	10.6~37.0
HI/mm·(℃·mon)$^{-1}$	0.5	0.6	0.6	0.5~0.6	0.2	0.7	0.3	0.01~0.6
pH	7.7	8.1	8.0	7.7~8.2	7.7	8.2	8.0	7.7~8.3
Total salt/g·kg^{-1}	2.6	6.9	5.0	2.4~7.6	6.2	9.9	8.3	6.1~10.5
Organic matter/g·kg^{-1}	1.2	7.8	3.9	-0.2~8.0	2.5	3.2	2.9	2.4~3.3

Table 5. Comparative analysis to heat indices of four species of *Calligonum*.

Species	Heat indexes			
	T/℃	T_1/℃	T_{min}/℃	CI/℃·mon
C. kuerlese	10.29 ± 0.21ab	-7.47 ± 0.25b(A)	-13.46 ± 0.27b(A)	-36.91 ± 2.94a(AB)
C. yingisaricum	12.10 ± 0.02b	-4.91 ± 0.02c(B)	-10.72 ± 0.20c(B)	-23.83 ± 0.11 b(B)
C. ruoqiangense	9.46 ± 1.36a	-8.73 ± 0.54a(A)	-14.78 ± 0.53a(A)	-40.30 ± 4.01a(A)
C. taklimakanense	10.50ab	-7.96ab(A)	-14.68a(A)	-35.21a(AB)

Species	Heat indices				
	T_7/℃	T_{max}/℃	WI/℃·mon	ART/℃	ABT/℃
C. kuerlese	23.90 ± 0.56a	31.01 ± 0.53a	97.48 ± 2.82a	31.36 ± 0.78a	11.60 ± 0.24a
C. yingisaricum	25.64 ± 0.08a	32.70 ± 0.01a	109.06 ± 0.10a	30.55 ± 0.10a	12.78 ± 0.01a
C. ruoqiangense	24.26 ± 1.84a	32.76 ± 1.96a	93.78 ± 12.35a	32.99 ± 1.31a	11.15 ± 1.14a
C. taklimakanense	25.64a	33.83a	106.56a	33.60a	12.35a

*Mark the letters in the table as the results of the multiple comparison, each index between two of the four species, if one letter between them is the same, suggest that the difference of them is not significant. The difference is significant. Significance level of Capital letters is 0.01 and lowercase letters is 0.05

Table 6. Comparative analysis to humidity, hydrothermal synthesis and wind indices of *Calligonum* species.

Species	Humidity indexes		Hydrothermal synthesis indexes		Wind index
	AP/mm	HI/mm·(℃·mon)$^{-1}$	PER	S	AW/m·s^{-1}
C. kuerlese	60.36 ± 2.20B	0.62 ± 0.03b(B)	11.42 ± 0.48A	10.40 ± 0.38B	2.06 ± 0.09A
C. yingisaricum	62.23 ± 2.93B	0.57 ± 0.03b(B)	12.16 ± 0.59A	10.72 ± 0.51B	1.87 ± 0.18A
C. ruoqiangense	23.77 ± 5.61A	0.31 ± 0.13a(AB)	32.69 ± 7.14B	4.09 ± 0.97A	2.74 ± 0.13B
C. taklimakanense	18.24A	0.17a(A)	39.89B	3.14A	2.70B

Table 7. Comparative analysis to soil property indices of *Calligonum* species.

Species	Soil property indexes		
	pH	Total salt/g·kg^{-1}	Organic matter/g·kg^{-1}
C. kuerlese	7.64 ± 0.16A	8.61 ± 0.92c(C)	3.04 ± 0.42a
C. yingisaricum	7.96 ± 0.13A	4.97 ± 1.27b(AB)	3.90 ± 2.00a
C. ruoqiangense	8.01 ± 0.14A	8.29 ± 1.09c(C)	2.88 ± 0.21a
C. taklimakanense	9.10B	1.69a(A)	1.21a

Table 8. Principal component analysis of climate and soil factors of *C. Roborovskii*.

Indexes	Component				
	1	2	3	4	5
AW/m·s^{-1}	0.414	-0.266	0.351	-0.458	0.002
AP/mm	-0.729	-0.31	0.495	0.342	-0.061
T_1/℃	0.054	0.951	0.16	0.104	0.118
T_7/℃	0.928	-0.062	0.008	0.346	0.011
T/℃	0.891	0.105	0.319	0.275	-0.07
T_{max}/℃	0.736	-0.219	0.363	-0.043	0.179
T_{min}/℃	-0.192	0.879	0.185	0.042	0.251
ART/℃	0.799	-0.528	-0.072	0.257	-0.049
WI/℃·mon	0.928	-0.161	0.245	0.2	-0.077
CI/℃·mon	0.23	0.821	0.335	0.33	-0.007
ABT/℃	0.917	-0.1	0.266	0.256	-0.086
PER	0.906	0.195	-0.267	-0.206	0.096
S	-0.729	-0.31	0.495	0.342	-0.061
HI/mm·(℃·mon)$^{-1}$	-0.875	-0.214	0.364	0.22	-0.016
pH	-0.027	0.222	0.726	-0.268	-0.452
Total salt/g·kg^{-1}	-0.244	0.048	-0.663	0.683	-0.099
Organic matter/g·kg^{-1}	-0.088	-0.336	0.342	0.078	0.837
Eigen value	7.521	3.238	2.442	1.569	1.062
Information content/%	44.242	19.047	14.362	9.227	6.249
Cumulative information content/%	44.242	63.289	77.651	86.878	93.128

*AW is annual average wind speed. AP is annual average precipitation. T is annual average temperature. T_1 is January average temperature. T_7 is July average temperature. T_{max} is the extreme high temperature. T_{min} is the extreme low temperature. ART is annual range of temperature. WI is Kira's warmth index. CI is Kira's coldness index. ABT is Holdridge's annual biology temperature. PER is potential evapotranspiration rate of Holdridge. S is hydro-thermal synthetical factor index. HI is Xu wenduo's humidity index

The main factors limiting expansion of the five species: The result of the main ecological factors limiting the distribution range of the five species by principal component analysis of their climate and soil indexes are shown in tables 8, 9.

Based on the result of the PCA to the climate and soil indices of *C. roborovskii*, five representative principal components showed that cumulative contribution rate of information reached 93.13%. The order of the main indices information load in the first principal component (accounting for 44.242% of the total amount of information) was, T_7 > WI > ABT > PER > T > HI, pertaining to high temperature and the moisture factor. The order of the main indices information load in the second principal component (accounting for 19.047% of the total amount of information) was, T_1 > T_{min} > CI, pertaining to low temperature factor. The third, fourth and fifth principal component accounted for 14.362%, 9.227% and 6.249% of the total amount of information.

Based on the PCA to the climate and soil indices of *C. kurlaense*, two representative principal components showed that cumulative contribution rate of information reached about 100%. The order of the main indices' information load in the first principal component (accounting for 74.234% of the total amount of information) was, T_{max} > ART > T_7 > WI = T_1 > ABT > AW > T > content of organic matter > HI > PER > S = AP, pertaining to the high temperature and the moisture factor. The order of the main indices' information load in the second principal component (accounting for 25.766% of the total amount of information) was, T_{min} > pH > CI, on behalf of the low temperature factor.

Based on the PCA to the climate and soil indices of *C. yengisaricum*, two representative principal components indicated that the cumulative contribution rate of information reached about 100%. The order of the main indices information load in the first principal component (accounting for 78.431% of the total amount of information) was, T_{max} > ART = pH > T_{min} > T_7 > content of organic matter > content of total salt > AW > CI > T > T_1 > ABT, pertaining to the high temperature factor and the low temperature factor. The order of the main indices information load in the second principal component (accounting for 21.569% of the total amount of information) was, PER > S, on behalf of the hydro-thermal synthetical factor.

Table 9. Principal component analysises of climate and soil factors of *C. kuerlese*, *C. yingisaricum*, and *C. ruoqiangense*.

Indexes	Component					
	C. kuerlese		*C. yingisaricum*		*C. ruoqiangense*	
	1	2	1	2	1	2
AW/m·s^{-1}	-0.982	0.189	-0.952	-0.306	-0.472	0.881
AP/mm	-0.821	0.571	-0.710	0.705	0.989	0.147
T_1/℃	-0.985	0.171	-0.855	0.519	0.732	0.681
T_7/℃	0.989	0.150	0.996	0.088	0.990	-0.142
T/℃	0.979	0.204	0.877	0.481	0.981	0.196
T_{max}/℃	0.990	0.138	-1.000	0.022	0.978	-0.210
T_{min}/℃	0.125	0.992	-0.998	0.066	-0.036	0.999
ART/℃	0.995	0.098	0.999	-0.051	0.871	-0.492
WI/℃·mon	0.985	0.175	0.736	0.677	0.995	0.101
CI/℃·mon	0.290	0.957	0.898	0.439	0.835	0.550
ABT/℃	0.984	0.178	0.838	0.546	0.992	0.123
PER	0.930	-0.369	0.699	-0.715	-0.691	-0.723
S	-0.821	0.571	-0.710	0.705	0.989	0.147
HI/mm·(℃·mon)$^{-1}$	-0.966	0.260	-0.724	0.690	-0.998	0.059
pH	-0.137	0.991	0.999	-0.044	-0.818	0.575
Total salt/g·kg^{-1}	0.788	0.616	0.957	0.291	-0.024	-1.000
Organic matter/g·kg^{-1}	0.978	0.209	-0.980	-0.200	-0.867	0.498
Eigen value	12.62	4.38	13.333	3.667	11.94	5.06
Information content/%	74.234	25.766	78.431	21.569	70.237	29.763
Cumulative information content/%	74.234	100	78.431	100	70.237	100

Based on the PCA to the climate and soil indices of *C. juochiangense*, two representative principal components showed that the cumulative contribution rate of information reached about 100%. The order of the main indexes' information load in the first principal component (accounting for 70.237% of the total amount of information) was, HI > WI > ABT > T_7 > AP > S > T > T_{max} > ART > content of organic matter > CI > pH, pertaining the moisture factor, the high temperature factor and the low temperature factor. The order of the main indices' information load in the second principal component (accounting for 29.763% of the total amount of information) was, content of total salt > T_{min}, on behalf of the soil saline and alkaline.

Discussion

Distribution characteristic of the five species: The study revealed that *C. roborovskii* was widely distributed in Tarim Basin, but *C. kurlaense*, *C. yengisaricum*, *C. juochiangense* and *C. taklimakanense* had narrow distribution. The four latters' distribution areas of the four narrowly distributed species were overlapping with that of *C. roborovskii*, which was sympatric alternative phenomenon. The four species of narrow distributions may be evolutionary species due to the special climate, matrix, hydrology conditions of their distribution areas.

Climate and soil characteristics of the five species: According to the Kira' standard of climate zone (Xu 1986), *C. roborovskii* (WI = 98.7 ℃·mon), *C. kurlaense* (WI = 97.5 ℃·mon), *C. yengisaricum* (WI = 109.1 ℃·mon), *C. juochiangense* (WI = 93.8 ℃·mon) and *C. taklimakanense* (WI = 106.6 ℃·mon), their warmth index were all among 85 ~ 180 ℃·mon, suggested that the five species belonged to warm temperate zone.

Wen-duo xu marked off four regional types of arid zone (HI ≤ 3.5), semi-arid zone (3.5 < H I≤5.5), semi-humid zone (5.5 < HI ≤ 7.5) and humid zone (HI > 7.5) by using the humidity index (Xu 1983). According to Xu's classification standard (Xu 1983), *C. roborovskii* (0.5 mm·(℃·mon)$^{-1}$), *C. kurlaense* (0.6 mm·(℃·mon)$^{-1}$), *C. yengisaricum* (0.6 mm·(℃·mon)$^{-1}$), *C. juochiangense* (0.3 mm·(℃·mon)$^{-1}$) and *C. taklimakanense* (0.2 mm·(℃·mon)$^{-1}$), all the five species belonged to arid zone. Annual average precipitation of *C. kurlaense* and *C. yengisaricum* were 54.1 ~ 72.0 mm and 56.6 ~ 66.5 mm, their optimum ranges respectively were 53.5 ~ 53.5 mm and 56.2 ~ 68.2 mm, which suggested that *C. kurlaense* and *C. yengisaricum* grow in similar moisture condition. Annual average precipitation of *C. juochiangense* was 17.4 ~ 40.6 mm, the optimum range was 10.6 ~ 10.6 mm, but the annual average precipitation of *C. taklimakanense* was only 18.2 mm. Thus, the distribution of *C. juochiangense* and *C. taklimakanense* were more drought area than that of *C. kurlaense* and *C. yengisaricum*, had maximum drought tolerance.

Field investigation result indicated that *Calligonum* tended to distribute along the main road, and concentrate in the gritty soil nearby the inside of roads. The five species of *Calligonum* mostly distributed in brown desert soil, of which pH was around 8.0, soil organic matter content was 1.2 ~ 8.0 $g \cdot kg^{-1}$ and salt content was 1.2 ~ 10 $g \cdot kg^{-1}$, with high salinity, alkaline, and lower content of organic matter in the top soil.

Reasons for the four narrow distributed species: According to the analysis of climate and soil characteristics of the four narrowly distributed species, the Low temperature factor was the main difference of the four narrowly distributed species in heat indices which reflected that the differences of *C. yengisaricum* with *C. kurlaense*, *C. juochiangense* and *C. taklimakanense* were highly significant, differences of *C. kurlaense* with *C. juochiangense* and *C. taklimakanense* were also significant. Moreover, moisture factor, saline and alkaline were also the main reasons leading to the independent distribution of the four narrowly distributed species.

Local ecological environment which determine the current distrbution: The main ecological factors affecting the distribution of *C. roborovskii* were, high temperature factor > moisture factor > low temperature factor > soil properties. The main ecological factors affecting the distribution of *C. kurlaense* were, high temperature factor > moisture factor > low temperature factor. The main ecological factors affecting the distribution of *C. yengisaricum* were, high and low temperature factor > moisture factor. The main ecological factors affecting the distribution of *C. juochiangense* were moisture factor high and low temperature factor > soil properties. So the main limiting factors for the distribution ranges of the five species were high temperature factor and moisture factor, followed by soil properties. For *C. juochiangense* and *C. taklimakanense*, the limited function of moisture factor was stronger than temperature.

It is highly recommended that the biodiversity particularly the rare should be protected. Therefore, for the five endemic species' distribution of *Calligonum* in China, we should protect *C. juochiangense* and *C. taklimakanense* with narrow distribution areas first, the next are *C. kurlaense* and *C. yengisaricum*. But, harsh wild conditions of their distribution areas are against in situ protection, so we should be strengthening the protection of long-distance work based on their respective environment adaptability.

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