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Distribution of ephemeral plants and their significance in dune stabilization in Gurbantunggut Desert

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Abstract: Based on systematically monitoring plants on dune ridges in the southern part of the Gurbantunggut Desert in 2002, this paper, from the angle of dune stabilization by vegetation, describes the temporal and spatial distribution patterns of ephemeral plants on isolated sand dunes, analyses the natural invasion processes of ephemeral plants on human-disturbed sand surface and expounds the importance of ephemeral plants in stabilizing sand dune surface. A total of 45 plant species were identified in the study area, 29 of which are ephemeral plants. Ephemeral plants sprouted in early April and completed their life-circle within about two months. Just as aeolian sand activities came to the strongest stage from April to June in desert regions of northern Xinjiang, the total coverage of trees, shrubs and herbs of long vegetational period on most dune ridges was less than 10%, while the mean coverage of ephemeral plants reached 13.9% in April, 40.2% in May and 14.1% in June. Therefore ephemeral plants acted as the major contributor to dune surface stabilization in the Gurbantunggut Desert. Investigations of vegetation restoration on engineering-disturbed dune surface show that ephemeral plants first recolonized the disturbed dune surface.

Key words: ephemeral plant; temporal and spatial distribution; dune surface stabilization; Gurbantunggut Desert
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1 Introduction

Ephemeral flora is a particular component of desert flora that can take the advantage of water resources and temperature conditions in spring to rapidly complete their life-cycle in about two months. They mainly occur in Central Asia, Junggar Basin, Mediterranean Coast, West Asia and North Africa. In China they are only distributed in north Xinjiang, with the east edge of Junggar Basin as its easternmost limit (Mao *et al.*, 1994). As an important and unique constituent component of China's desert flora, ephemeral plants have attracted attentions of some botanists but whose work mostly focused on the plant flora (Liu, 1982), plant geography (Mao *et al.*, 1994), phonology (Wang *et al.*, 1993) and eco-biology (Zhang, 1985; Liu *et al.*, 1992; Li, 2000). Ephemeral plants form significant synusia from late March to mid June, a season witnessing the strongest wind force in the desert regions of north Xinjiang. Accordingly, this phenomenon has attracted the concern of desert scientists who believe that the presence of ephemeral plants are one of the important factors responsible for the fixed and semi-fixed character of the Gurbantunggut Desert (Hu *et al.*, 1962; Chen, 1963; Wu, 1997; Ji *et al.*, 2000). However, little information is available on the study of the temporal and spatial distribution of ephemeral plants from the angle of dune stabilization by vegetation, especially their effects on the intensity of the aeolian sand activity is rarely reported. The work is only

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limited to the de scription or prediction of the roles of ephemeral plants in dune surface stabilization.

Controlling wind erosion and weakening dune surface mobility by vegetation are realized by the study of the interactions between vegetation and air flow. They can be reflected by surface roughness, mainly depending on plant density, followed by plant height and width (Catherine Bressolier *et al.*, 1979). Since these parameters are easily grasped in theory and practice, the study of vegetation weakening aeolian sand activity generally concentrates on the relations between sand mobility and vegetation cover. The present study, using some key parameters of ephemeral plant coverage that could control wind erosion effectively and analyzing the meteorological data, elucidates the dune surface stabilization by ephemeral plants.

2 Environment condition and study method

2.1 Environment condition

Gurbantunggut Desert, located in the hinterland of the Junggar Basin at the north-westernmost part of the desert zone of northern China, lies between 44°11'-46°20'N and 84°31'-90°00'E. It covers an area of 48,800 km^2 and is the largest fixed and semi-fixed desert in China. Main morphological dune types in the desert are balk-hollow dune ridge and dentritic dune ridge (Figure 1), which are generally a few hundred meters to more than 10 km in length, 10-50 m in height and orientate from north to south. Interridge and middle to lower parts of a dune are stabilized but the crests of dune often have 10-40 m wide mobile zone. Under the action of bi-directional winds, sand materials move leftward and rightward and extend along the crest line of dune (Wang *et al.*, 1998). Annual accumulated temperature varies between 3000 and 3, 500°C, annual precipitation 70-150 mm and annual evaporation exceeds 2,000 mm. It belongs climatically to the typical inland arid zone (Figure 2). There is a stable accumulated snow with a thickness of 20 cm in winter. Precipitation distribution is better in spring and summer than in

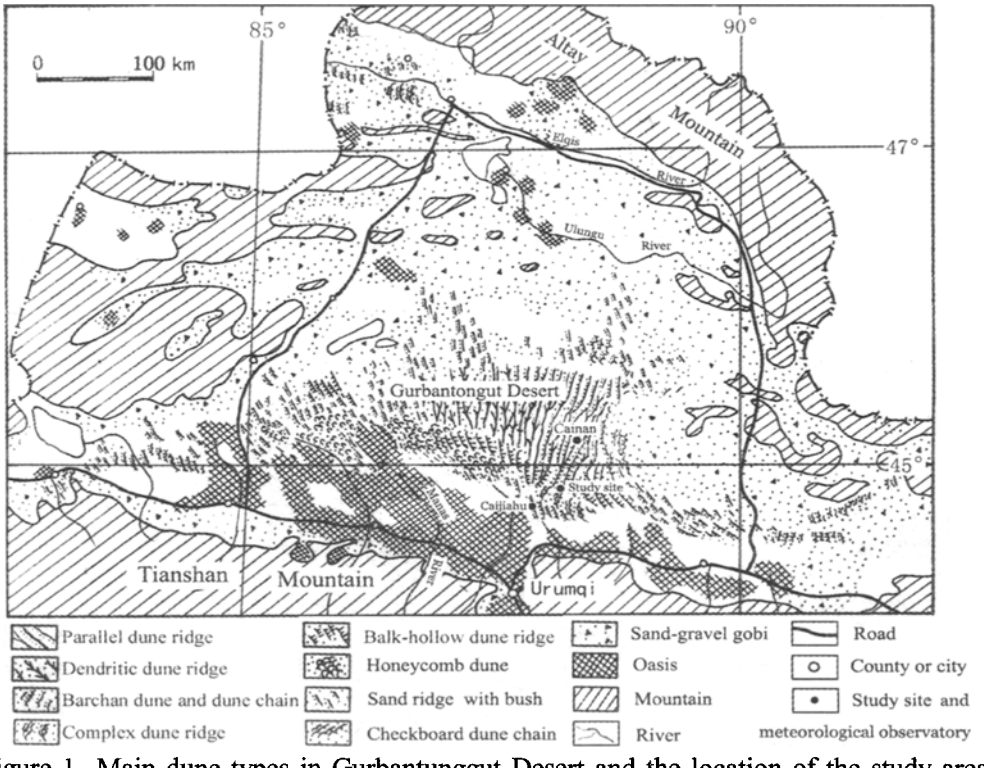

Figure 1 Main dune types in Gurbantunggut Desert and the location of the study area

autumn and winter, such a water and heat allocation pattern creates a favorable condition for the growth and development of ephemeral plants. *Haloxylon persicum* is a widespread species in the Gurbantunggut Desert and it generally occupies the middle to upper parts of dunes. Interdune depression and middle to lower parts of sand dunes are occupied by *Ephedra distachya*, and their under-stories are widely distributed by ephemeral plants and black cryptobiotic crusts. Crest of dune mainly consists of well-sorted medium and fine sand. Soil profile differentiation is invisible and surface layer is poor in organic matter. Interridge consists mixed sand that concludes coarse, medium, fine and silt sand and there is little organic matter on soil surface. Dominant winds over the region are NW and NE winds caused by westerly circulation and Mongolian high pressure. Threshold winds (≥ 6 ms^{-1}) occur from April to September, mainly in April, May and June.

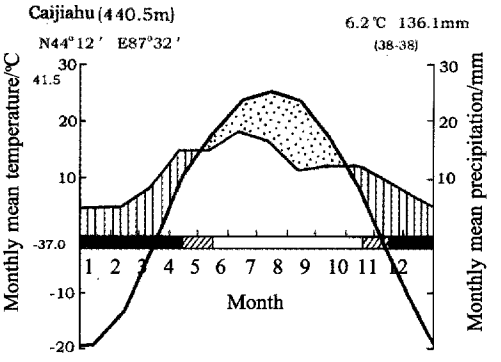

Figure 2 Walter climatic diagram of the south edge of Gurbantunggut Desert (Caijiahu 1961-1999)

2.2 Study method

The dune we monitored is located at southern part of the desert proper (44°32'30"N, 88°6'42"E). The ridge orientation is NW18°, ridge height 23 m and wave length 210 m. Its has a dome-shaped top and the western slope is gentler than the eastern, therefore it has an asymmetric section. According to the differences in geomorphic position and plant distribution the sand ridge section was divided into 6 units (Figure 3), namely interridge, west mid-down slope, west upslope, ridge top, east upslope and east mid-down slope. Long-term monitoring quadrats were arranged in each unit, tree-shrub quadrats are 10×10 m and three small quadrats in size of 1×1 m were arranged in each large quadrat for herbaceous survey. Various indexes including plant species, height, crown diameter, and coverage etc. were surveyed at 15-20-day interval from late March to August in 2002. Wind regime data for analysis were collected from the Cainan Meteorological Station (44°59'N, 88°09'E) in the hinterland of the desert and observed at 10 m height from October 1994 to September 1995. The cumulative value of threshold wind velocity for sand particle movement ($\sum$ v) during the corresponding time is defined as the intensity index of aeolian sand activity (Geng, 1985) and used in the comparison of the temporal changes of relevant indexes. An engineering-disturbed section, 200 m long and 1 m wide, was selected for the investigation of natural invasion of ephemeral plants on the disturbed dune surface from 2001 to 2002.

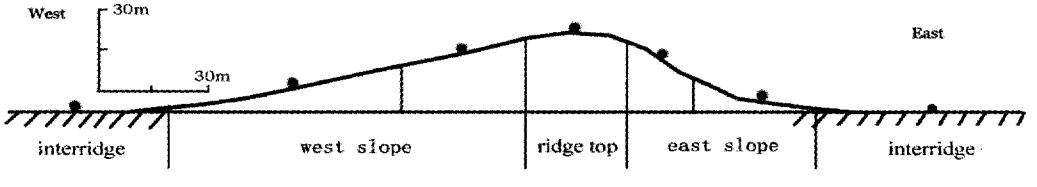

Figure 3 The section of monitored dune ridge and quadrats arrangement on dune surface in Gurbantunggut Desert

3 Results and analysis

3.1 Composition of ephemeral plant species

Ephemeral plants include ephemeretum species and ephemeroid species. The former completed the life-circle in current years and produced new individuals from seeds in the next spring. The above-ground parts of the latter died off in current years, but their underground organs remained alive and produced new individuals from underground buds or seeds in the next

Table 1 Composition and distribution of plant species in the southern part of Gurbantunggut Desert (2002)

Life form	Plant name	Family	Spatial distribution					Length (cm)	
			Inter-ridge	West Mid-slope	Ridge top	East up-slope	East low-slope	Above surface	Below surface
Dwarf tree	*Haloxylon persicum*	Chenopodiaceae		+	+	+		150	>250
Shrub	*Calligonum leucocladum*	Polygonaceae	+	+	+	+	+	55	58
	Ephedra distachya	Ephedraceae	+	+			+	33	31
Dwarf	*Artemisia arenaria*	Compositae	+	+	+	+	+	52	42
sub-shrub	*Seriphidium terrae-albae*	Compositae	+	+	+	+	+	33	28
Perennial	*Aristida Pennata*	Gramineae		+	+			37	5-50
herb	*Astragalus* sp.	Leguminosae	+	+	+			22	33
	Allium sp.	Liliaceae	+	+		+	+	35	18
Annual	*Agriophyllum squarrosum*	Chenopodiaceae			+	+		23	21
plants of	*Corispermum lehmannianum*	Chenopodiaceae	+	+	+	+	+	17	23
long	*Salsola pestifer collina*	Chenopodiaceae	+	+	+	+	+	23	31
vegetative	*Horaninowia ulicina*	Chenopodiaceae	+	+	+	+	+	18	20
period	*Ceratocarpus arenarius*	Chenopodiaceae	+	+		+	+	8	19
	Bassia dasyphylla	Chenopodiaceae				+	+	22	28
	Kirilowia eriantha	Chenopodiaceae	+	+				23	18
	Hyalea pulchella	Compositae	+	+	+	+	+	33	23
Epheral	*Alyssum linifolium*	Cruciferae	+	+		+	+	25	22
plants	*Torularia torulosa*	Cruciferae			+	+		28	14
	Isatis violascens	Cruciferae	+				+	50	44
	Erysimum cheiranthoides	Cruciferae			+	+		38	22
	Lactuca tatarica	Compositae	+				+	13	20
	**Tragopogon sablosus*	Compositae	+	+			+	23	27
	Echinops gmelinii	Compositae		+		+		18	19
	Senecio Subdentatus	Compositae		+	+	+	+	15	23
	Garhadiolus papposus	Compositae					+	15	17
	Lappula rupestris	Borraginaceae	+	+	+	+	+	16	30
	L. semiglabra	Borraginaceae	+	+		+	+	20	28
	Onosma sp.	Borraginaceae	+	+			+	12	30
	Arnebia sp.	Borraginaceae	+	+		+	+	20	28
	Eremopyrum orientale	Gramineae	+	+		+	+	13	25
	Schismus arabicus	Gramineae	+	+		+	+	8	12
	Trigonella tenella	Leguminosae	+	+			+	6	25
	Astragalus oxyglottis	Leguminosae	+	+			+	5	14
	Nepeta micrantha	Labiayae			+			22	28
	Nepeta pungens	Labiayae					+	28	21
	**Gagea* sp.	Liliaceae	+				+	17	18
	**Eremurus anisopteris*	Liliaceae		+	+	+		65	20
	Hypecoum parvifiorum	Papaveraceae	+	+	+	+	+	17	17
	Plantago minuta	Plantaginaceae	+				+	5	9
	Chrozophora sabulosa	Euphorbiaceae	+	+	+	+	+	10	19
	Erodium oxyrrhynchum	Geraniaceae	+	+		+	+	20	21
	**Soranthus meyeri*	Umbelliferae	+	+		+		40	33
	**Carex physodes*	Cyperaceae	+	+	+	+	+	12	17
	**Ixiolirion tataricum*	Amaryllidaceae	+	+			+	26	30
	Cerastium sp.	Caryophyllaceae			+			13	15

Note: * indicates ephemeroid species

spring. A total of 45 plant species were identified in the study area, including 6 life forms, namely, dwarf subtrees, shrubs, subshrubs, perennial herbs, annuals with long vegetative period and ephemeral plants. Among them, 29 species are ephemeral plants, mainly consisting of *Cruciferae*, *Compositae*, *Borraginaceae*, *Geraniaceae*, *Leguminosae* and *Liliaceae*, and belong to 15 families (Table 1). There were 23 ephemeral species growing in the interridge zone and on the middle to lower parts of a dune, 11 species on ridge tops and 18-21 species on both sides of upslope. *Lappula rupestris*, *Hypecoum parvifiorum*, *Chrozophora sabulosa* and *Carex physodes* extensively occurred in various geomorphic positions; *Torularia torulos*, *Erysimum cheiranthoides* and *Eremurus anisopteris* only occurred on semi-fixed sand surface at upper and top parts of the dune ridges; *Isatis violascen*, *Lactuca tatarica*, *Tragopogon sablosusa*, *Garhadiolus papposus*, *Plantago minuta* and *Gagea* sp. only occurred on the fixed sand surface in the interridge zone and middle-lower parts of the dunes. The length of the above-ground and underground parts of ephemeral plants were concentrated within the 30 cm of sand surface. They were small in size but distributed uniformly.

3.2 Temporal and spatial distribution of ephemeral plants

Ephemeral plants successively sprouted from the end of March. Except the tops of the dune ridge, the mean vegetation cover at other parts of the dune ridge could reach 5.3% in early April, with a plant height less than 3 cm. Mean vegetation cover in late April was 20.8% and mean plant height was about 10 cm and corresponding values in mid-May were 40.2% and 20 cm respectively. In mid-June most ephemeral plants gradually became declined and the mean vegetation cover reduced to 14.1% (Figure 4). By early July, the above-ground parts of all ephemeral plants died away.

The spatial distribution of ephemeral plant appears to have a certain pattern on isolated sand dunes. Interridge zone and mid-down slope occupied about 60% of total area of a dune, where mean vegetation cover in mid-May reached 51.8% and main plant species were *Erodium oxyrrhynchum*, *Alyssum linifolium*, *Trigonella tenella* and *Carex physodes* with coverage of 17.4%, 15.2%, 3.9% and 1.8% respectively. The upslope of both sides of dune occupied about 25-30% of total area of a dune, where mean vegetation cover in mid-May reached 38.2% and main plant species were *Carex physodes*, *Trigonella tenella*, *Hypecoum parvifiorum*, *Eremurus anisopteris* and *Lappula rupestris*, with coverage of 17.2%, 8.3%, 7.7%, 3.1% and 2.6% respectively. Ridge top was a zone with the strongest surface mobility and occupied 10-15% of the surface area. The coverage of ephemeral plant was less than 4.4% and main species were *Carex physodes*, *Nepeta micrantha* and *Hypecoum parvifiorum* with coverage of 3.5%, 0.3% and 0.2% respectively. The temporal changes of the height of main ephemeral plant species are presented (Table 2).

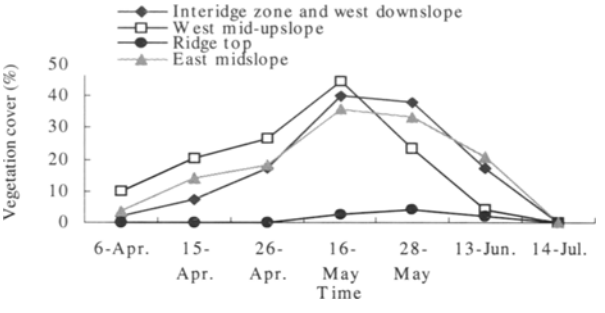

Figure 4 Temporal and spatial distribution of ephemeral plants on dune ridge surface at south part of Gurbantunggut Desert (April 2002-August 2002)

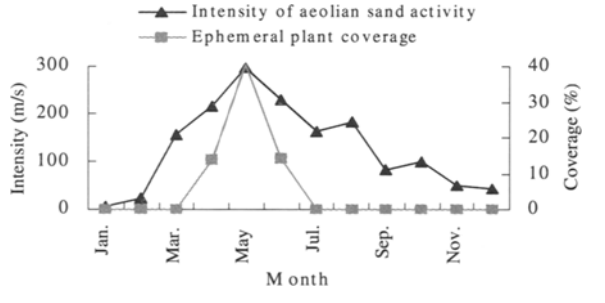

Figure 5 Temporal changes of the intensity of aeolian sand activity and coverage of ephemeral plants (recorded at Cainan Meteorological Station from October, 1994 to Septmber, 1995)

Table 2 Temporal changes of the height of main ephemeral plants in Gurbantunggut Desert (2002)

Plant name	Plant height (cm)					
	March 28	April 15	April 26	May 16	May 28	June 13
Erodium oxyrrhynchum	0.5-1	1-1.5	2-2.5	5-8	22-24	15-20
Alyssum linifolium	1-3	3-6	8-14	18-24	20-24	15-20
Trigonella tenella	-	0.5-1	1-1.5	3-5	3-5	-
Carex physodes	-	6-10	10-14	10-15	12-16	3-5
Hypecoum parvifiorum	-	0.5-1	1.5-2	8-12	15-18	-
Eremurus anisopteris	3-5	8-12	10-14	18-22	25-35	40-50
Lappula rupestris	-	1-2	2-2.5	12-15	14-16	15-20

3.3 Significance of ephemeral plants in dune surface stabilization

According to the statistics of meteorological data observed at Cainan Station in the hinterland of the desert during 1994-1995, sand-rising winds were strongest in April, May and June (Figure 5). The intensity indexes of aeolian sand activity during each month were 218 ms^{-1}, 296 ms^{-1} and 229 ms^{-1} and occupied 14.0%, 19.1% and 14.8% of whole years' total intensity. The mean coverage of ephemeral plants on most area of dune surface reached 20% or more. Interridge zone and middle to lower parts of dune ridge with *Ephedr distachya* as dominant species reached a coverage of 8.9-10.0% in the mid 10-day period of May; middle to upper parts of dune ridge with *Haloxylon persicum* as dominant species reached a coverage of 12.2-21.4%; ridge top with *Calligonum leucocladum* and *Artemisia arenaria* as dominant species reached a shrub coverage of 1.7-4.8%, while the herbs with long vegetation period such as *Aristida Pennata*, *Corispermum lehmannianum* and *Agriophyllum squarrosum* reached a coverage of less than 7.1%. Different geomorphic positions had different synusia structures, but during the period of strongest aeolian sand activity from early spring to the end of June the ephemeral plants on much of the dune ridge surface held an absolute predominant position in the under-story of the communities. Total vegetation cover at different geomorphic positions was mainly affected by the distribution of ephemeral plants (Figure 6).

Numerous studies demonstrated that vegetation could control wind erosion effectively and reduced the mobility of sand dune surface (Chepil W S *et al.*, 1963; Lee J A, 1990; Wolf S A *et al.*, 1993; Dong *et al.*, 2000; Liu *et al.*, 2002). With the increase in height and density, standing vegetation dissipates large amount of wind energy and reduce the shear force on exposed sand bed. Wind tunnel experiments showed that vegetation of 30% coverage can greatly weaken wind erosion and almost no wind erosion evidence can be found when the vegetation cover reaches 35-40% (Wasson R J *et al.*, 1986). Under the condition of same vegetation cover, uniform distribution yields a high roughness than tussock one (Dong *et al.*, 1996). The study of the relationship between sand surface mobility of linear dunes and vegetation cover in Kalahari Desert (Gils F S, 1995) showed that the coefficient of dune surface mobility tends to become stable if the vegetation cover is higher than 14%. This value is also consistent with the threshold vegetation cover observed in the fixed and semi-fixed dune fields in the Gurbantunggut Desert (Zheng, 1960). The plants that form the ephemeral plant synusia are uniformly distributed and their coverage exceeds 14%, especially reach the coverage of over 40% in May, while the total coverage of trees, shrubs and herbs of long vegetation period in much of dune ridge surface is less than 10%. Hence, ephemeral plants are the major contributor to dune surface stabilization.

In recent years some projects of engineering, such as oil field, road and water diversion channel, are under construction in the interior of Gurbantunggut Desert. It is most likely that this will inevitably disturb or even destroy natural vegetation. Therefore, the establishment of protective forest system and the restoration of natural vegetation have become a concerning matter. Observation and investigation of dune surface disturbed by engineering construction in

two consecutive years showed that 15 species recolonized the disturbed sand surface, of which 8 species were ephemeral plants, 6 species were herbs of long vegetation period and one species was dwarf sub-shrub in 2001. By 2002, 19 species recolonized the disturbed dune surface, of which 12 species were ephemeral plants, 6 species were herbs of long vegetation period and 1 species was dwarf shrub. Of this total number of invaded plants, ephemeral plants occupied 84.2%. By the end of June ephemeral plants completed their life-circle and annual plants of long vegetation period became the main colonizers (Wang, 2002). From this it can be seen that ephemeral plants entrance the disturbed dune surface firstly as the pioneer vegetation.

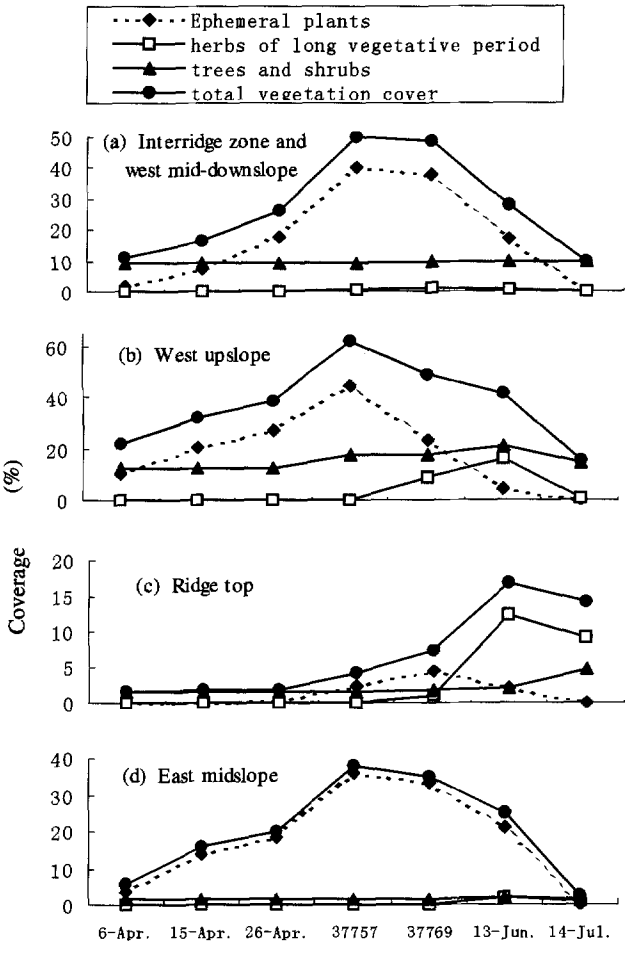

Figure 6 Temporal changes of plant community structure in southern part of Gurbantunggut Desert

4 Conclusions

(1) Ephemeral plants are an important and unique component of desert flora in China. There were 45 plant species in the study area, 29 of which were ephemeral plants. They appear to be selectively distributed, 23 species occurred in interridge zone and mid-down slope, 21 species occurred on both sides of up-slopes and 11 species occurred on the ridge tops. The spatial distribution patterns of ephemeral plants on the isolated sand dune showed that their coverage was high in the interridge zone and on both sides of the ridge but low on the ridge top. The above-ground parts and under ground parts of the overwhelming majority of ephemeral plants were concentrated within 30 cm from the dune surface.

(2) Ephemeral plants sprouted in early April and completed the life-circle in about two months. In April, May and June their mean coverage reached 13.9%, 40.2% and 14.1% respectively, with mean plant height of 10-20 cm. In the mid May the mean coverage of ephemeral plants in interridge zone, on both sides of upper ridge slope and ridge top was 40.2%, 44.9% and 4.4% respectively.

(3) The unique temporal and spatial distribution patterns of ephemeral plants have a great significance for dune surface stabilization and environmental improvement. The period from April to June is the stage of strongest aeolian sand activity in the desert regions of north Xinjiang, this just corresponds to the ephemeral plant cover of over 14%, while the total coverage of trees, shrubs and herbs of long vegetative period is less than 10%, hence the ephemeral plants are the major contributors to the dune surface stabilization.

(4) Observations and investigations of the engineering-disturbed dune surface in two consecutive years showed that 15 plant species recolonized the disturbed dune surface in the

first year, of which 8 species were ephemeral plants; in the next year about 19 plant species invaded the same field, of which 12 species were ephemeral plants. Of this total number of invaded plants, ephemeral plants occupied 84.2%, therefore they are the pioneer plants first invaded the human-disturbed dune surface.

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