Sandy grassland blowouts in Hulunbuir, northeast China: geomorphology, distribution, and causes*

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Abstract A sandy grassland blowout consists of an aeolian depression formed in top soil and the underlying sand deposit underlie, and the adjoining redeposit of sand derived from the depression. Research based on field survey and topographic mapping combined with aerophotograph interpretation reveals that: (1) All the three sand land tracts in Hulunbuir Grasslands are composed of blowout depressions and adjoining dunes, with interlaying remnants of sandy grasslands as background; (2) blowout depressions and their adjoining dunes can be classified according to their morphometric characteristics, development stages, and initiating factors; (3) blowouts develop mostly in the upper parts of sidelong aweather and sunward slopes inclining southwestward when west wind prevails; (4) initiation of blowouts is closely related with the coupling of extreme droughts and wide spread intense human disturbance to the fragile topsoil layer. The investigations indicate that key factors to prevent desertification are to protect grassland vegetation and topsoil.

Keywords: Hulunbuir, sandy grassland, blowouts, desertification.

In desertification research, most former studies have focused on the aeolian deposit form of dunes. Desertification survey, monitoring and harness work have also been concentrated on the ratio or proportion and change of areas of dunes at different states of mobility. Little attention was paid to the aeolian erosion forms[1,2]. Soil erosion researchers have paid attention mostly to the rate and infection factor of erosion[3], or measurement on the changes of material or texture of soil[4], with erosion forms neglected. Dong et al. suggested in the 1980s, based on soil erosion tests in wind tunnel, that soil erosion is the most important stage in the process of sandy desertification[5]. However, this hypothesis has not been verified by field experiment and survey, and further studies are necessary. As to the typical aeolian erosion form of blowouts, recent studies are mostly focused on those developed on foredune along coast[6—11]. Grassland blowouts are seldom touched on[12,13], without any report of detailed research till now.

Hulunbuir sandy grasslands are now at the transition stage from sandy grasslands to sand lands. There are many blowouts of different scales, types, and development stages, and this is an ideal site for research on aeolian erosion forms. Therefore, the research on blowouts in Hulunbuir sandy grassland should be helpful. The aim of this study is to understand the mechanism and the process of grassland desertification, and at the same time, to understand and evaluate the influence of human activities on the evolution of grassland geomorphology in Anthropocene. It is also significant for designing and evaluating new desertification monitoring and control methods as well as for rational utilization of grasslands.

1 Methods

The experiment sites are located north to the three sand land tracts of Hulunbuir Grasslands (Fig. 1). The climate is semiarid with rainfall between 240 mm and 350 mm, concentrating mainly from July to September, and at annual even temperature of −1℃—−3℃. It is dry and cold in the winter, with little rain and gusty in the spring, and a short cool summer. The annual gusty days are 20 d to 40 d, mostly from NW between April and May, and from

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SW between September and October, with a mean wind velocity of 4—5 m/s. Landforms are gentle with gradients from 0.005 to 0.02. Thickness of chestnut soil layer is between 0.1 m and 0.3 m, with calcic horizon at the bottom[14]. Under the topsoil, it is loose deposit of medium to fine sands, loessial sandy loam and silt of Hailar Formation of late Pleistocene, with an average thickness of 38 m. Based on field investigation of typical wind erosion areas, three test sites were selected and mapped with SOKKIA SET2110 total station for measurement of topography and geomorphology of blowouts. Structure and thickness of top soil were measured using spade and steel tape. Combined with aerophotograph interpretation and analysis of data obtained from fieldwork, blowouts' morphology, distribution, and cause of formation were studied and drafts of blowouts and tables on geometric data were prepared for further analyses.

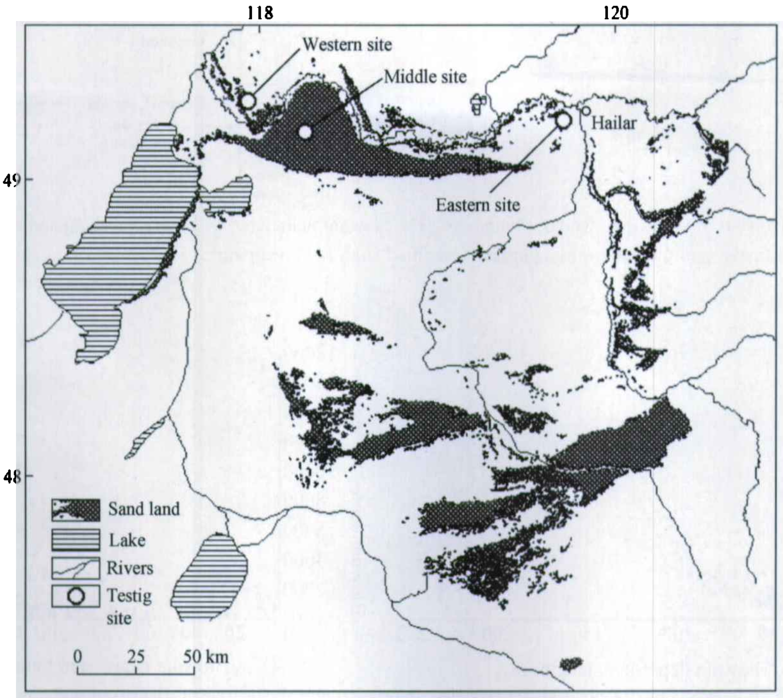

Fig. 1. Distribution of sand lands, bare or fixed by vegetation, interpreted from TM satellite images of 2003, and location of test sites of this research, in Hulunbuir Grasslands.

2 Results and analyses

2.1 General form of blowouts

All of the three sand land tracts on Hulunbuir Grasslands are characterized by wind erosion depressions developed by blowouts, dunes formed by sands derived from their associating depressions, and remnants of even sandy grasslands as topographic backgrounds. The overall plane shape of a blowout is oval, with its long axis consistent with the direction of the prevailing wind. Brims of side walls of a blowout depression (blowout in the narrow sense of the word) are vertical ruptures, which are formed by breaking and falling off of the top soil layer along sand wedges due to basal sapping of the underlying loose sand by wind. The rest part of the side walls form slopes of sand with an angle of rest. The bottom of a blowout is usually the surface of part of an ellipsoid, and it turns flat when downward erosion by wind is restricted by moist sand or by silt or clay interlayer. Sand derived from the depression is transported leeward and deposited around the depression, forming a sand mound usually in the form of a low parabolic dune, covering grassland vegetation with an area up to 8 times that of the depression (Fig.2).

A positive relationship between the area and the length of depression of modern blowouts has not been found in this study. Increase of the area of large scale blowout depression comes mainly from the increment of their width. Although the distribution of the direction of long axes of small blowouts at their bare land stage is scattered, with the growth of the scale of blowouts, orientations of their long axes approach the direction of prevailing west wind gradually. The average ratio of length to width to depth of the blowout depression changed regularly in accordance with their causes of formation and development stages (Fig. 3 (a) and (b), Table 1).

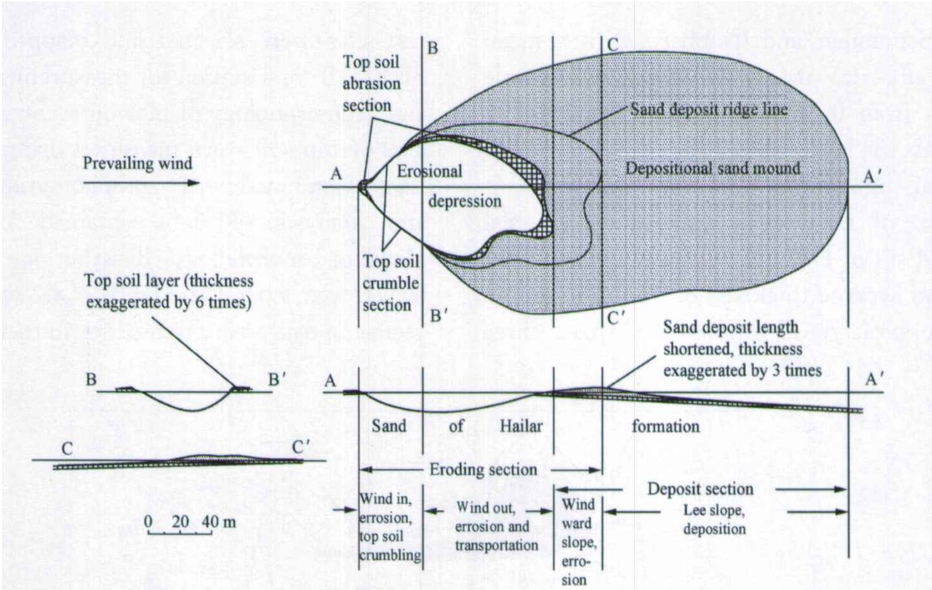

Fig. 2. Sketch of a blowout in sandy grassland of Hulunbuir. The blowout is initiated by human dwelling and cultivation. Thicknesses of top soil layer and depositional sand mound are exaggerated (modified from field mapping).

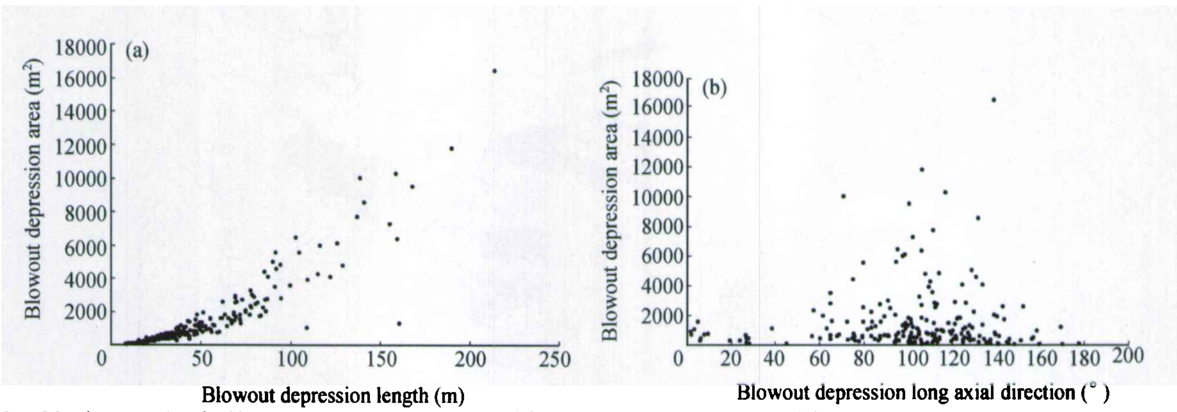

Fig. 3. Morphometric data for blowouts in Hulunbuir Grasslands. (a) Depression area versus length; (b) depression area versus long axial direction.

Table 1. Average morphometric data for blowout depression and the whole blowout bare sand patch of different causes at different stages of development in the west of Hailar, Hulunbuir Grasslands

Stage of development of blowouts	Cause of formation	Depression of blowout					Sand patch (depression and dune of a blowout)				
		Length (m)	Width (m)	Depth (m)	L:W:D	Position of long axis	Length (m)	Width (m)	Height (m)	L:W:H	Position of long axis
Bare land	Plowing	33.9	21.3	1.0	32:21:1	115.1					
	Free road	27.0	13.4	0.8	32:16:1	115.0					
	complex	19.1	10.6	0.6	32:18:1	118.2					
	Average	26.7	15.1	0.8	33:19:1	116.1					
Active developing	Plowing	58.9	36.5	4.2	14:9:1	97.9	154.3	70.0	1.1	140:64:1	85.7
	Free road	78.1	33.4	4.5	18:7:1	100.4	247.0	111.7	1.6	152:68:1	93.0
	complex	84.6	44.8	4.8	18:9:1	102.4	324.0	140.7	2.6	127:55:1	106.8
	Average	73.9	38.2	4.5	16:8:1	100.2	241.8	107.5	1.8	140:62:1	95.2
Fixed	Plowing	21.6	16.0	1.2	18:13:1	91.8					
	Free road	30.8	17.6	1.8	17:10:1	109.1	74.2	34.2	0.7	102:47:1	87.1
	Unknown	58.4	32.8	2.2	26:15:1	116.2	288.8	119.7	1.2	245:101:1	97.6
	Average	36.9	22.1	1.7	20:13:1	105.7					
Reactivated	Plowing	37.3	25.1	2.5	15:10:1	64.6	82.3	38.7	0.9	88:42:1	98.6
	Free road	54.8	26.3	2.3	24:12:1	104.5	88.0	48.2	0.9	95:52:1	93.3
	complex	48.5	32.9	2.8	17:12:1	104.1	130.9	65.8	1.4	92:46:1	101.9
	Average	46.9	28.1	2.5	19:11:1	91.1	100.4	50.9	1.1	92:47:1	97.9
Dying out	Unknown	140.1	72.8	4.4	32:17:1	127.4	370.2	150.5	3.6	103:42:1	119.8
	Average	64.9	35.3	2.8	24:14:1	108.1	237.5	103	2.2	112:50:1	104.3

2.2 Types, distribution, and causes of blowouts

According to their shapes and interrelationships, blowouts can be classified into the simple styles such as oval blowouts, tandem blowouts, and band or trough blowouts, or classified into the compound styles such as bare land blowouts, kidney shaped blowouts, flower shaped blowouts, bottle shaped blowouts, palm shaped blowouts, and rectangle blowouts (Fig.4). They can also be classified according to their stages of development into active developing, fixed or dying out, or reactivated blowouts. According to their causes of formation, blowouts can be classified into natural blowouts and human initiated blowouts, and the latter divided further into plowing, road, and residential types of blowouts. Blowout adjoining deposit of sand can be classified according to their shape, thickness, or degree of conjunction with each other into sand shadow, sand sheet, or sand mound.

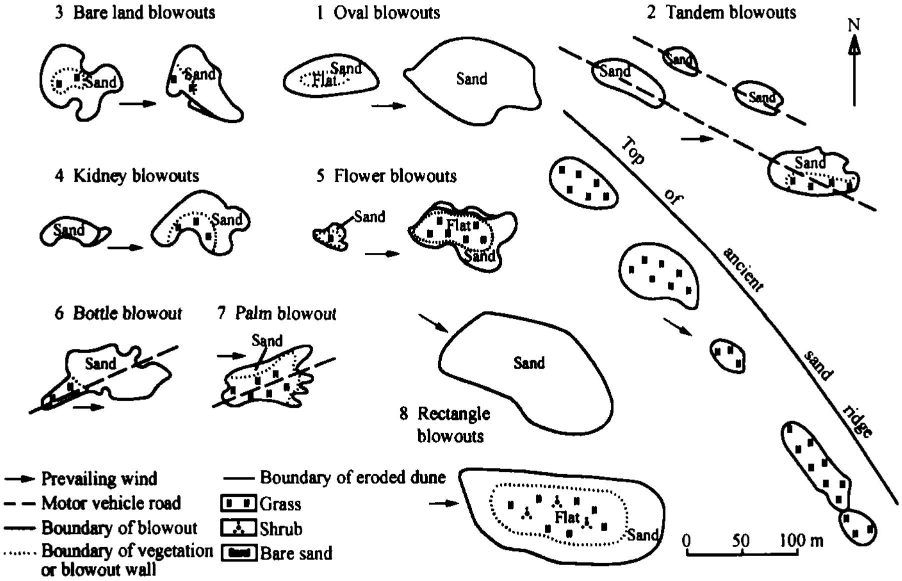

Fig. 4. Morphologic classification of blowout depressions in Hulunbuir Grasslands. Showing plane sketch of simple (Types 1 and 2), and compound (Types 3 to 8) depressions.

Blowouts distributed on slopes, flat lands, and heights on grasslands account for 60%, 22%, and 17% of the total, respectively (Table 2). There are 48% of slope blowouts developed on SW slopes, 20% of them on S slopes, and 27% of them on NW, N, and NE slopes. Whereas 54% of slope blowouts develop on the upper part of slopes, 31% of them on the middle part, and 15% on the lower part (Table 3). The reasons of the high rate of occurrence of blowouts on the upper part of SW slopes may be due to the unfavorable water condition, stronger wind erosion, low coverage of vegetation, and weakness of top soil layer (Table 4).

Table 2. Distribution of blowouts on different scales at different microrelieves west of Hailar, Hulunbuir Grasslands

Blowouts of different scales (m)	Number of blowouts at different microrelieves													Total
	Slope								Height			Flat	Low-land	
	W	NW	N	NE	E	SE	S	SW	W-E ridge	N-S ridge	Hum-mock			
Small (Length<40)	3	4	4	1			13	26	4	9	1	24	1	90
Medium (40≤Length<70)		4	5	1		1	5	13	7		1	8		45
Large (70≤Length<100)		1	2			1	1	5	1		1	3		15
Huge (Length≥100)		1		3				2	2	1	1	1		11
Subtotal	3	10	11	5		2	19	46	14	10	4	36	1	
Total				96						28		36	1	161

Table 3. Distribution of blowouts at different parts of slopes facing different directions west of Hailar, Hulunbuir Grasslands

Part of slope	Inclination of slope								
	W	NW	N	NE	E	SE	S	SW	Total
Upper	3	2	6	1		2	6	32	52
Middle		2	5	4			10	9	30
Lower		6					3	5	14

Table 4. Average thickness of top soil at different microrelieves on sandy grassland west of Hailar, Hulunbuir Grasslands

Microrelief	S-slope	Heights	W-slope	Flat	N-slope	E-slope	Low-land
Thickness of top soil (m)	0.15	0.21	0.22	0.3	0.31	0.33	0.4

It has been discovered that 87% of blowouts are caused by human activities, with plowing, motor vehicle grassland free road and residential (include inhuming) activities accounting for 35.8%, 34.8%, and 16%, respectively. Up to 73% of the NW, N, and NE slope blowouts are caused by motor vehicle free roads, and 89% of flat land blowouts are caused by road, plowing, and residential activities. Blowouts caused by plowing and motor vehicle grassland free roads mostly gather around towns or cities, but those caused by historic residential activities are generally scattered.

3 Discussion and conclusions

It was discovered in field work that when the sand mounds adjoining some road-initiated blowouts were re-eroded by wind, preexisting furrows and traces of plowing on soil were uncovered. In some places furrows can be up to three directions, which indicates that road and plowing come first, and the development of blowouts is simultaneous or later. Considering that the area had been opened up on large scale for cultivation in 1960, and then due to "Black Storm" discarded in 1962[15], and the repeated practice of cultivating and abandoning in the area near Hailar1), it could be inferred that the mass occurrence of modern blowouts was during the early 1960s to the early 1970s, when motor vehicle and heavy agricultural machinery were brought into grasslands and widespread reclamation was on a large scale. Li et al. had also concluded that the large scale desertification in the area was from the 1960s due to large scale grassland reclamation, when they had the top modern aeolian sands' age of optical dating of 40 a in 2002[16]. Therefore, it can be concluded that blowouts are the result of the combined effect or coupling of environmental events of arid climate, strong wind, with intense and widespread human activities of plowing of grasslands, and large scale increase of motor vehicle grassland free roads.

The total area of land desertification of Hulunbuir Grasslands increased from 8065 km^2 in 1989, to 20893 km^2 in 2000, a leap of 159%[17,18]. Meanwhile, 3613 km^2 of grasslands was reclaimed for cultivation from 1986 to 1996, the total cultivation area increased by 34.8%, and the center of gravity of farmland moved 33.5 km northwestwards, approaching the central part of Hulunbuir Grasslands[19]. According to the studies of Wang[19], Feng and Wang[20], we can estimate that 79.7% of the newly reclaimed farmlands are from grasslands in south Xin Barag Left Banner and southeast Ewenki Autonomous Banner, which are mostly sandy grasslands and highly in danger of desertification. At the same time, livestock capacity in unit of sheep on the shrinking grasslands increased from 2.71 million to 4.8 million from 1989 to 1999[21],2). Now a new round of project inductive grassland cultivation for forage field is underway, and the grassland ecology and geological environment of Hulunbuir Grassland will again face a new and more cruel challenge.

In conclusion, geomorphological expressions of desertification in Hulunbuir Grasslands are mainly development of blowouts and expansion of quicksands. Anyhow, blowouts are the source of dunes on various scales and stages of fixation. To fight against the land desertification, we should not only take the sand

1) According to Wu Shu-zeng, age 81, immigrated from Hebei Province in 1955: The area of grasslands was opened up on a large scale in 1964—1966 for vegetables and melon. There was no need of watering for the sake of plenty rain fall at that time. Dust storms were rampant in 1966—1970, and governments sent work groups to drive farmers away in 1967. At the very beginning there were only two roads. The number of roads grows quickly in recent yeas.

2) Statistics Bureau of Hulunbuir League. Hulunbuir Yearbook. Hailar, 1999.

dunes at different stages of mobility into account, but also pay much more attention to the wind erosion forms. Otherwise, we would get half the result with twice the effort, or even worse.

The crux of the formation of blowouts is destroying and vanishing of the grassland vegetation and the topsoil layer, and the grassland vegetation and top soil layer ecosystem in arid sandy grassland areas is fragile but is also the most precious natural resource. It is necessary for us to inherit the good tradition of Grassland Culture[22,23], for example, apply the fundamental principle of grassland vegetation and topsoil protection to all human activities, whether in ecology protection or in natural resources utilization. By doing so, we can slow down or even check the expansion of sandy desertification. In view of the trend of climate warming and drying in recent decades[24], the management system of rational and efficient utilization of grassland should be put into practice. In addition, all the cultivated land in the wind eroding grassland area west of Great Hinggan Mountains should be returned to grass, or carry out the zero tillage system to avoid top soil wind erosion. At the same time, the number or quantity increase orienting policy in live stock husbandry must be abandoned to give grassland ecology the elastic space of self-rehabilitation, so as to eliminate destruction of grassland vegetation and top soil layer and correspondingly, prevent desertification generated by blowouts.

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