VEGETATION COVER CHANGE IN DESERTIFIED KERQIN SANDY LANDS, INNER MONGOLIA

Kazuhiko TAKEUCHI*, Kazuhiro KATOH*, Yinhao NAN** and Zenwu KOU**

Abstract Historical and recent land degradation has been caused by human activities in semi-arid Kerqin Sandy Lands, Inner Mongolia. The purpose of the present study is to outline the process of land degradation in this area and to assess the efficiency of desertification control measures on recuperating process of vegetation cover. Historical documentation and field evidence suggest a long history of land degradation in the Kerqin Sandy Lands where Quaternary sand deposits with a depth of some 200m are widely distributed. Remnant forest patches dominated by *Quercus mongolica* and *Pinus tablaeformis* on isolated hills and *Ulmus pumila* on sand dune fields provide evidence of the previous landscapes in the forest-steppe transitional bioclimatic vegetation zone. In addition to the historical vegetation degradation, rapid expansion of denuded landscapes since World War II is obvious. Comparison of maps shows remobilized sand dune fields to have expanded 2.3 times in area in the last 50 years. Demographic data for the Wulan-Aodu settlement area at the center of the western Kerqin Sandy Lands shows that human and livestock population drastically increased in the 1950-60s, and this is thought to be the main cause of land degradation in this area. Livestock population has decreased since the 1970s but land degradation has continued because of a period of dry climate which started in 1971. Land use management such as grazing control is a most effective countermeasure against land degradation. Wulan-Aodu Grassland Ecosystem Research Station, Institute of Applied Ecology has set up fenced experimental fields on remobilized sand dunes and in interdune depressions within which grazing has been controlled. Remarkable vegetation restoration can be observed in fields conserved for about five years, though appearance of woody species is still insufficient even after 20 years' protection. Spatial variation in vegetation between sand dunes and interdune depressions can be observed in the protected area: *Caragana microphylla* and *Artemisia holodendron* are typically dominant on dunes and *Thypa minima* and *Salix* spp. are frequently dominant in interdune depressions. Well-developed vegetation in protected lowlands comprises far more species than other vegetation in the study area does. In unprotected area *Caragana microphylla* and *Setaria viridis* dominate both on dunes and in interdune depressions, and also in flat lowlands.

* Department of Agrobiology, The University of Tokyo
** Institute of Applied Ecology, Chinese Academy of Sciences

Therefore, the effectiveness of grazing control on vegetation restoration is indicated, though on dune ridges, where sand movement is very active, other strategies such as artificial revegetation works are also desirable to support and promote vegetation restoration.

Key words: desertification, sand dune remobilization, vegetation restoration, grazing control, Inner Mongolia

1. Introduction

In June 1994 an International Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, particularly in Africa, was ratified in Paris. This Convention defines the term desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". Desertification is now recognized by the international community as a serious global environmental issue to be solved through establishing sustainable resource management systems and land use systems.

Decrease in vegetation cover is a significant phenomenon in desertified lands (Hytterborn and Skarpe, 1992). Recent studies have been carried out to further understanding of the process of vegetation cover change and to find ways for conserving and/or restoring vegetation. Studies in African savanna areas reveal that grazing control is important for restoring vegetation (*e.g.*, Backeus *et al.*, 1994; O'Conner, 1994). Grazing is also reported to be a factor in causing decrease in vegetation cover in other area (*e.g.*, Diaz, *et al.*, 1994 in Argentina montane grassland; McIntire and Lavorel, 1994 in temperate Australian grassland). The ecological meaning of grazing, however, differs for different areas. For example, in temperate and fertile grasslands such as those in Great Britain, vegetation can be controlled under species rich conditions by grazing; furthermore the impact of grazing on grassland varies with intensity, season of grazing and fertility of grassland (Smith and Rushton, 1994; Bullock *et al.*, 1994).

When we consider the problem of desertification and associated vegetation cover change, the Asian Continent is worthy of note. It is characterized as a region with vast areas of desertified drylands. UNEP/GRID reported in 1991 that Asia contained nearly two billion ha or 32% of the world's drylands, which was almost the amount reported in Africa (Dregne *et al.*, 1991). More than 70% of Asian drylands are exposed to the threat of desertification/land degradation. Therefore, the preparation of action programs based on scientific and technological knowledge to combat desertification in Asia is highly recommended. For this purpose, Environment Agency, Japan has started in 1992 desertification control studies in India and in China with the cooperation of national research institutes such as the National Institute for Environmental Studies and the National Institute for Agro-Environmental Sciences. The authors in this paper joined in this research project and selected China as their study region.

The possibility of natural restoration of vegetation varies for different areas. Therefore, it is important to understand how vegetation will change in each region after disturbances such as grazing cease. If sufficient individual studies of vegetation restoration are accumulated, it will be possible to evolve a general theory. In the present study, the authors selected semi-arid sandy land in northeastern China. It has a long history of pastoral, agricultural and silvicultural land uses. Post-war socialistic land reform and land development have resulted in unique characteristics in land use changes.

The significance of selecting northeastern China as a field for the studies of desertification and its control is that the influence of natural and human impacts on the land can easily be evaluated through assessing the drastic landscape changes in the recent decades with reliable records. Since the 1970s the Chinese government and many local governments have managed land use so as to control soil erosion and to restore vegetation (Zhu, 1988). Today recovery of vegetation can be observed in many plots, though large area are still left with poor vegetation. This situation is just suitable to evaluate the efficiency of desertification control measures. In this paper desertification status and vegetation restoration are studied on the Kerqin (or sometimes referred to as "Horqin") Sandy Lands, Inner Mongolia, wherein typical land degradation phenomena as indicated by sand dune remobilization are observed.

2. Objective of the Study and the Features of the Study Area

Objective of the study

Sand dune remobilization is one of the most significant phenomena of desertification worldwide. In Africa desert encroachment was seriously recognized in the Sudano-Sahelian zone in the early 1970s, and this stimulated establishing desertification control strategies (Grantz, 1977). However, sand dune remobilization has also been observed in other continents. For example, Toya *et al.* (1985) summarized the extensive sand dune remobilization caused by European settlement in Australia. In Asia fixed sand dune fields occur in semi-arid zones mainly in India and those in China. They also suffer from sand dune remobilization problem. A case study in China, therefore, can present another example of sand dune remobilization and associated vegetation cover change.

China is characterized as an area having a long history of desertification. However, recent land use change caused by increase in population and alteration in social structure have drastically transformed the land cover. Denuded and/or degraded landscapes have expanded on settled semi-arid zones where vegetation cover used to be sustainably maintained. Especially, in Inner Mongolia, intensive sand dune remobilization has occurred because of various human impacts. It is worth studying this area to understand the process of desertification and change in vegetation cover. In this paper the authors try to understand the actual status of vegetation cover and process of its change, brought by recent desertification / land degradation, and to assess the efficiency of desertification control measures taken in this area. Wulan-Aodu Grassland Ecosystem Research Station, Institute of Applied Ecology, Chinese Academy of Sciences, located at the center of western Kerqin Sandy Lands has been selected as the base of the present study. Field surveys were performed as joint research work between the University of Tokyo and the Institute of Applied Ecology in 1992-1994 in Wulan-Aodu and its surrounding area.

Physical setting

In China the term "sandy lands" is different from the term "desert" and is used for the extensive sand dune fields bioclimatically covered with vegetation. However, because of historical and recent desertification/land degradation, vegetation cover on sandy lands has decreased rapidly. The Kerqin Sandy Lands located in the western part of Northeast China is one of the largest sandy lands in China. It covers an area of 43,000km^2, within 118°30' to 123°30' E longitude, 42°20' to 44°20' N latitude, and is considered to be in the forest-steppe transition zone (Kou, 1994). The origin of aeolian sands are thought to be alluvial and lacustrine deposits with a thickness of some 200m (more than 200m in Wulan-Aodu) along the Shilamulin /Xiliao Ho (River) formed in the Middle and Late Pleistocene period, and fixed dunes were formed associated with soil development during the Holocene period (Zhu *et al.*, 1988), which made vegetation growth possible.

The Kerqin Sandy Lands are located in an arid to semi-arid temperate climatic zone. Annual rainfall in the Kerqin Sandy Lands is about 300mm in the west and 500mm in the east. Mean annual rainfall in Wulan-Aodu is 340mm, 70% of which concentrates in the period June-August with 2,500mm of mean annual evaporation (Nan, 1994). Mean annual temperature is 6.3℃, but the annual variation is very large because of continental inland climate. In summer mean temperature is over 20℃, while in winter often below -10℃. A climatic diagram based on the data 1981-1984 (Fig. 1) shows that rain-

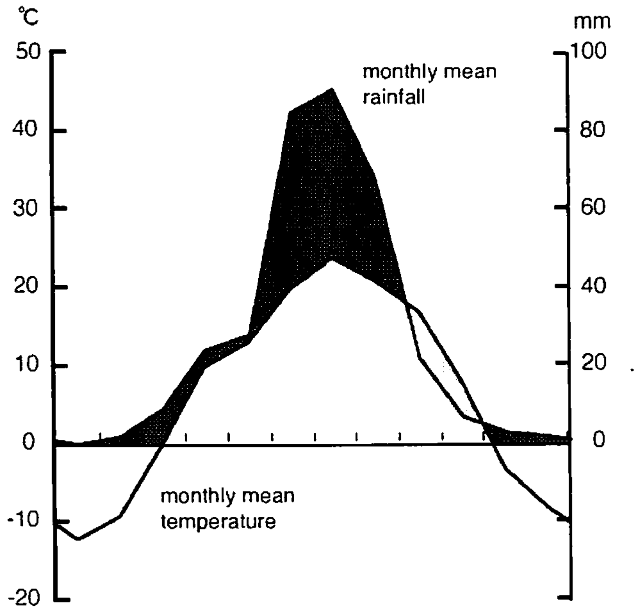


Fig.1 Climatic diagram of Wulan-Aodu based on the data 1981-1984

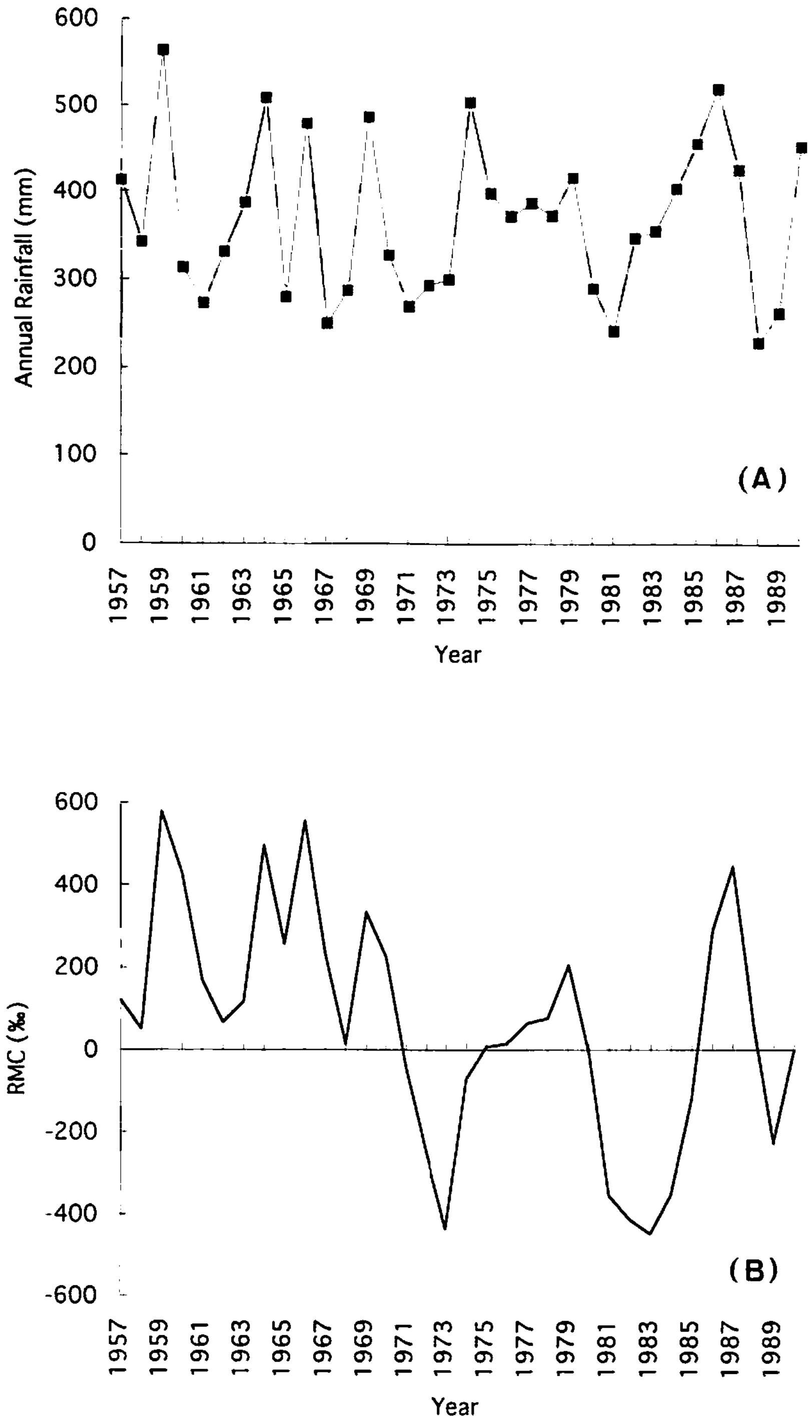


Fig. 2 Mean annual rainfall (above) and residual mass graph (below) in Wutan from 1957 to 1990

fall is enough for vegetation growth but a relatively dry period appears in autumn, which stimulates the withering of herbaceous plants from the middle of September.

Relatively long term climatic records are stored in Wutan Meteorological Station that is close to the study area. Variability of mean annual rainfall is high, with a range of 229-564mm (Fig. 2-a), but does not immediately present evidence of climatic fluctuation. However, the residual mass (RM) graph shows the existence of a wet period from 1958 to 1970 and a dry period from 1971 to 1985 (Fig. 2-b). The RM graph can reveal continuous dry or wet period and turning points between them, and it is often used for the analysis of long-term rainfall records in arid and semi-arid Australia (Iwasaki, 1985). The RM graph is given by plotting Xi, which is calculated by the following equation, against the time scale.

$$Xi = 1000 \times \sum_{n=1}^{i} \left(\frac{r_n - \bar{r}}{\bar{r}} \right)$$

where r_n is the annual rainfall for the n-th year of the record. In the present study the mean annual rainfall $\bar{r}$ was computed for the 34 years period from 1957 to 1990.

Wind records from 1957 to 1990 are also stored in Wutan Meteorological Station. Average wind speed in Wutan is 3.1m/sec. In spring before plants start growing wind

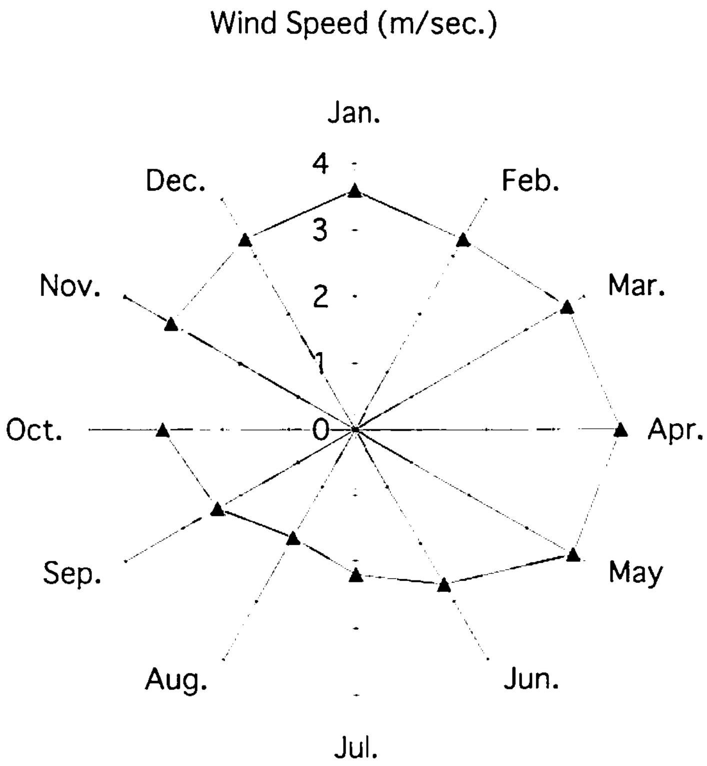


Fig. 3 Monthly change in wind speed in Wutan

speed is relatively high (Fig. 3), which is considered to cause the active sand drift, in particular on denuded sand dune surfaces. Wind direction in spring is northwest, which corresponds with longitudinal sand dune direction.

Human activities

The eastern part of the Kerqin Sandy Lands is a marginal zone between the Mongolian grazing zone and the Chinese agricultural zone, while land use in the western part of the Lands is dominated by Mongolian grazing. Formerly nomads, people have settled after the World War II, following the Chinese governmental land policy.

Wulan-Aodu Village, belonging to Nashihan Township, Wengnuite County, Chifeng City, has an area of 7,350 ha, 170 families, 751 people of whom 98% are Mongolian, and 7,567 livestock (Kou, 1994; Photo 1). Ninety percent of family income comes from livestock husbandry. Livestock dung is used for fuel, which is different from the Chinese custom of using firewood as fuel. However, during the time of the "Great Leap Forward", when iron smelting was promoted and the construction of Hongshan Reservoir was taking place from 1958 to 1961, great amount of trees were cut intensively for firewood, and this is said to have caused the decrease in vegetation cover.

Photo 1 Settlement of Wulan-Aodu
Mongolians are collecting forage grasses and livestock dung at home garden. Tall trees behind the settlement were planted by the Institute of Applied Ecology. Far behind remobilized dune fields are observed.

3. Process of Vegetation Cover Change

Historical change in vegetation

No scientific records exist of the floristic composition of the vegetation cover of the Kerqin Sandy Lands before the overexploitation started. It is believed, however, that the area was covered with rich grassland vegetation and partly with woodlands. Zhu *et al.*(1988) have summarized past human activities in the Kerqin Sand Lands since the Neolithic Age, some 4,000 to 5,000 years ago. Near the Hongshan settle-

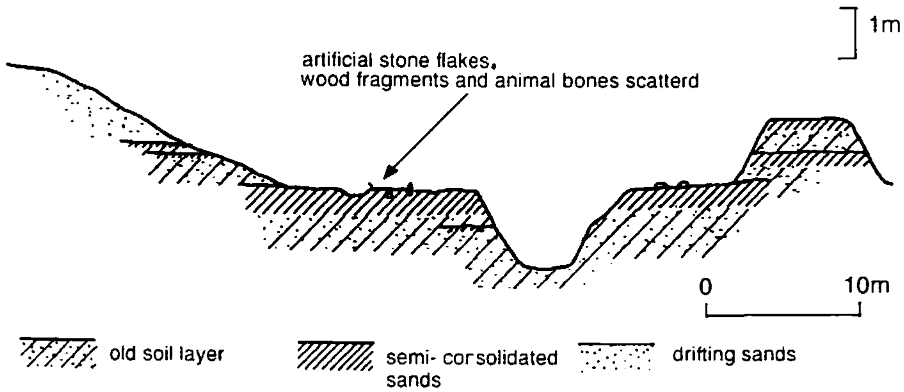


Fig. 4 Distribution of dark semi-consolidated sand layer at the deflation plain near Hongshan

Photo 2 Artificial stone flakes, cemented wood fragments collected on dark semi-consolidated sand layer

ment, a deflation plain is revealed because of recent sand drifts. There are many artificial stone flakes, wood fragments and animal bones scattered on a dark semi-consolidated sand layer formed during the period of Hongshan Culture (Fig. 4; Photo 2).

Several dark colored semi-consolidated sand layers are widely distributed in the Kerqin Sandy Lands and are considered to be a relict soil layer (Zhu *et al.*, 1988). Soil analysis by the authors, however, shows that even the darkest layer distributed in the Wulan-Aodu area contains 0.439 of C and 0.0338 of N, and C/N ratio is 13.0, which is insufficient to conclude that the layer is relict soil. Further investigation is required

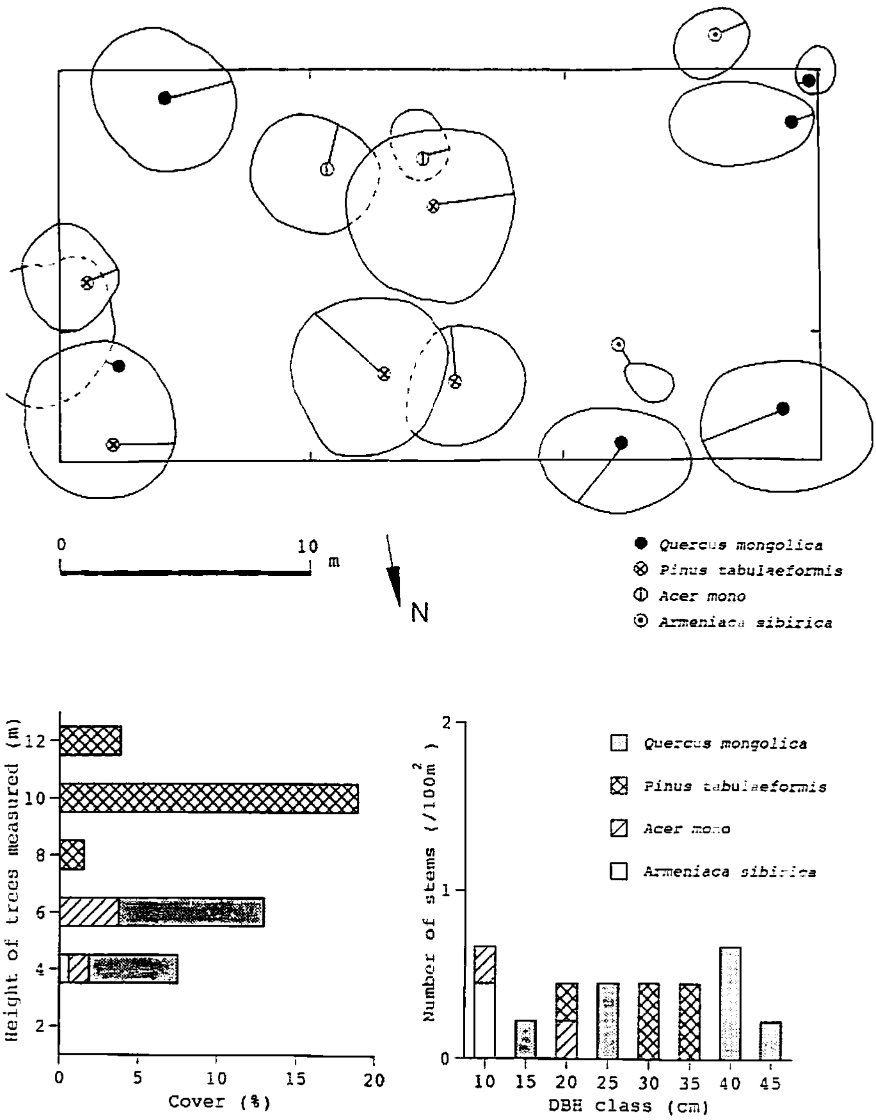


Fig. 5 Vegetation structure (crown projection diagram, crown projection cover and DBH class) of *Pinus-Quercus* forest remained on relict hills

about the origin of the sand layers.

Before the recent expansion of desertified lands, forests and woodlands are said to have distributed widely on isolated hills and sand dune fields. There are some remaining remnant forest/woodland patches in the Wulan-Aodu area. Fig. 5 shows the vegetation structure of a *Quercus-Pinus* forest patch remaining on an isolated hill in this area. Fig. 6 shows the vegetation structure of *Ulmus pumila* woodland developed on sand dune fields (Photo 3). Because of the influence of intensive grazing there was no evidence of regeneration in either the forest or the woodland patches. So the maintenance of such vegetation in the future is not guaranteed.

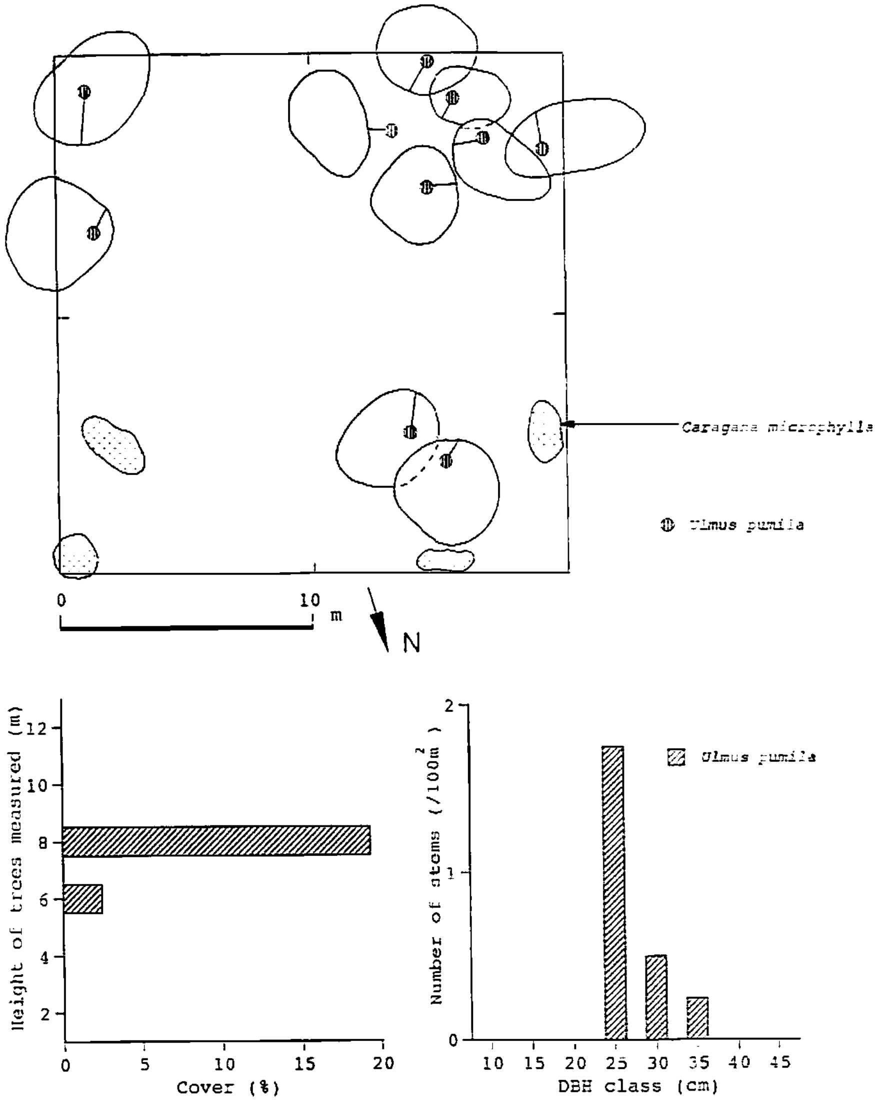


Fig. 6 Vegetation structure (crown projection diagram, crown projection cover and DBH class) of *Ulmus* woodland remained on sand dune fields

Photo 3 Remnant *Ulmus pumila* woodland patch distributed on sand dune fields with *Caragana microphylla* on disturbed land surface.

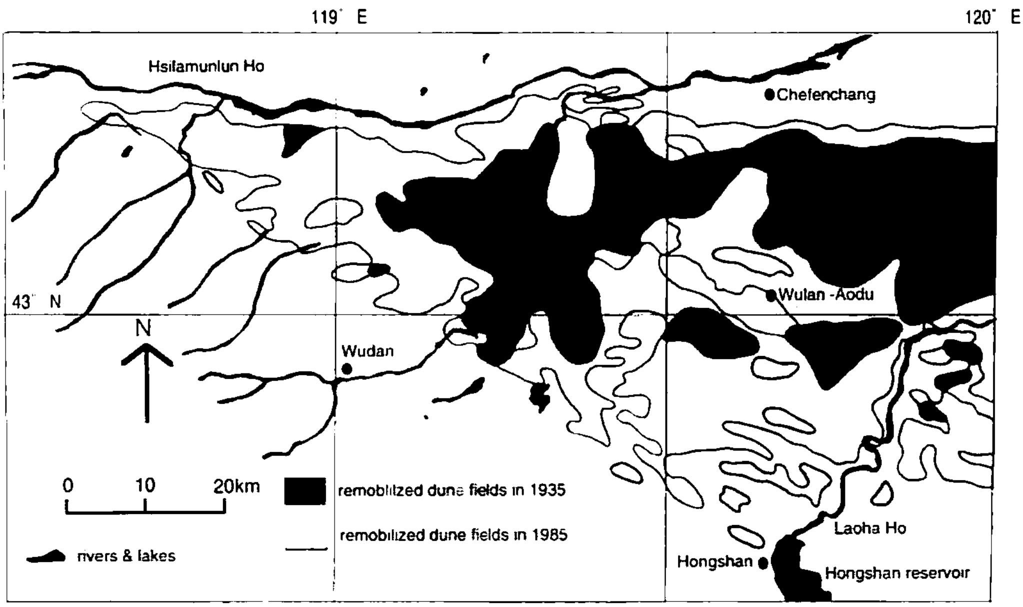


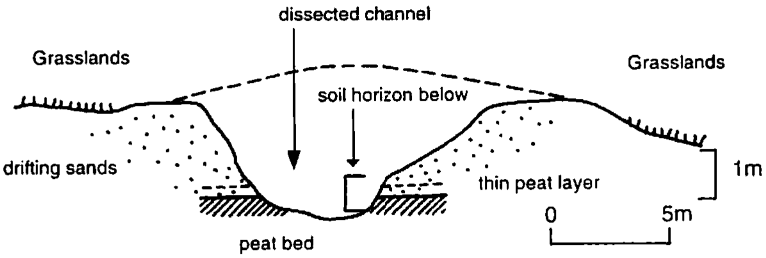
Fig. 7 Expansion of remobilized dune fields in the western Kerqin Sandy Lands in a recent 50 years period, 1935-1985

Recent vegetation cover change

It is said that desertification/land degradation has escalated since the World War II. To understand the magnitude of post-war expansion of remobilized dune fields, two maps in which the study field is drawn were compared. One is a topographic map at 1:100,000 made in 1935 by the former Japanese Army who invaded Northeastern China at that time. The other is a desertification hazard map at 1:500,000 made in 1985 by the Institute of Desert Research, Chinese Academy of Sciences.

An overview figure was obtained as shown in Fig. 7. The result shows that the area of remobilized dune fields comprised 1,160 km^2 in 1935, and 2,710 km^2 in 1985. Remobilized dune fields in 1985 are 2.3 times in area than in 1935, which shows that recent sand dune remobilization is very active. Fig. 8 shows the scheme of the recent expansion of remobilized dune fields. Here peat bed developed along a small stream is being overlaid by active sand drifts.

The main cause of the sand dune remobilization in the Wulan-Aodu area is an increase in population, both human and livestock (Photo 4). Kou (1994) has summarized the history of vegetation cover change. He says that population had expanded



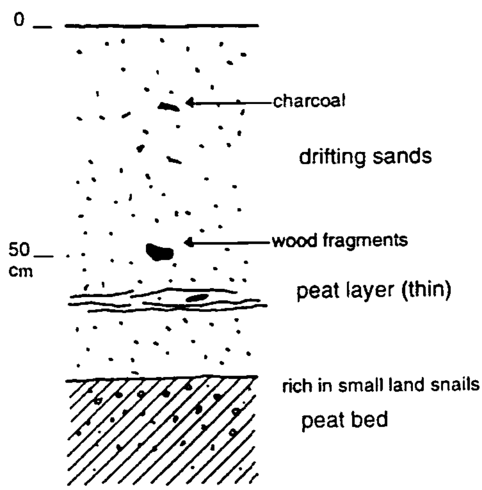


Fig. 8 Peat bed overlaid by drifting sands at the northern margin of the western Kerqin Sandy Lands along the Hsilamunlun Ho

Photo 4 Overgrazing of livestock brings land degradation

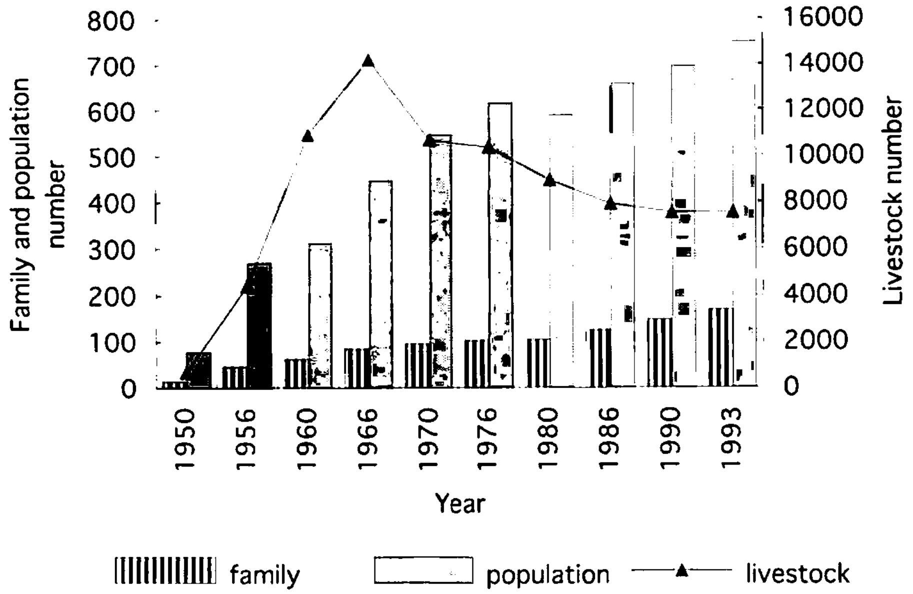


Fig. 9 Change in number of families, population and livestock in Wulan-Aodu Village since 1950 (after Kou, 1994)

to more than 300 persons by 1960 (Fig. 9) and a lot of trees mainly *Salix* spp. in inter-dune depressions and *Betula* spp. on sand dunes had been cut down for housing construction, buildings for livestockfold and so forth, with the consequence that has become 10% of the area desertified, whereas it was less than 1% in the early 1950s. Cutting of trees for firewood during the time of the "Great Leap Forward" and construction of the Hongshan Reservoir may have accelerated this degradation process. Desertified lands increased up to 20% in 1966 when the number of livestock peaked (Fig. 9).

Livestock population decreased rapidly from 1970 to 1986. Nevertheless, Kou (1994) reported that desertified lands continued to expand to occupy 60% of the area. The period corresponds to the period of dry climate already mentioned. Therefore, climatic change is considered to have accelerated the desertification and associated vegetation cover change in this area.

The shape of the remobilized sand dunes is Barchan type and they move in a southeast wind direction (Fig. 10). The remobilized dune ridges are often more than 15m high. Steep slopes are formed on the leeward side of dunes. Dune movement is 3-5 m/year and often buries roads, which are most important lifelines in this area (Photo 5).

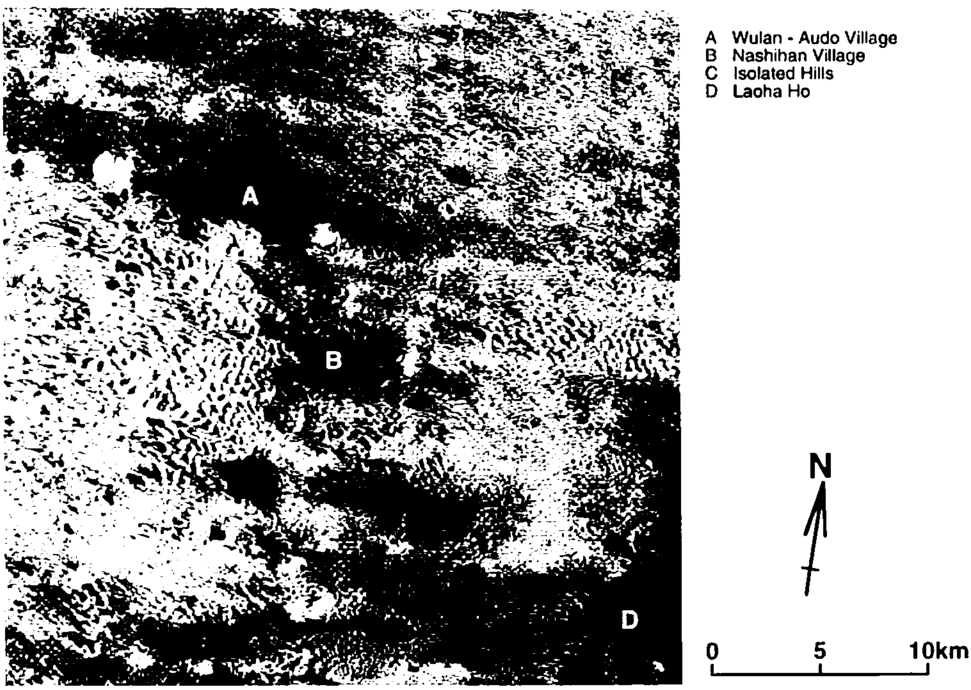


Fig. 10 Landsat image showing the actual status of desertification/land degradation in Wulan-Aodu and its surrounding area in 1992 (compiled by the National Institute of Agro-Environmental Sciences)

Photo 5 Remobilized sand dunes often interrupt traffic
Former road was recently buried beneath the remobilized dune

Photo 6 Present situation of dune fields protected since 1977
Woody species such as *Betula microphylla* start growing. *Phragmites communis* community develops in interdune depression.

Table 1 Characteristics of the surveyed quadrats

Quadrat group	Number of quadrat	Length of transect (m)	Topography	Soil moisture (*)	Controlled period (years)
A	12	-	Lowland	Dry	0
B	8	-	Lowland	Dry	0
C	5	-	Lowland	Medium	2
D	5	-	Lowland	Medium	5
E	5	-	Lowland	Dry	5
F	5	-	Lowland	Wet	5
G	5	-	Lowland	Medium	20
H	4	-	Lowland	Wet	20
DA	21	100	Dune	Dry	0
DB	10	50	Dune	Dry	0
DC	30	50	Dune	Dry to Wet	2
DD	20	40	Dune	Dry to Medium	0
DE	15	30	Dune	Dry to Medium	13
DF	15	30	Dune	Dry to Medium	11
DG	15	30	Dune	Dry to Wet	10
DH	15	30	Dune	Dry to Medium	17

* Objectively determined in the field.

As presentative measure the Wulan-Aodu Grassland Ecosystem Research Station started grazing control and revegetation works along the roads in the 1970s. Grazing has been basically inhibited in the controlled fields to conserve vegetation, though among a few months in autumn the inhibition has been loosened in lowland controlled fields. In the controlled fields on sand dunes grazing has been inhibited throughout a year, therefore the vegetation there is just protected. As a result, remarkable vegetation restoration can be observed, details of which is explained in the next chapter. The vegetation cover on sand dunes protected since 1977 is evaluated by aged local villagers to be similar to the standard of vegetation cover in the 1950s (Photo 6).

4. The Effectiveness of Grazing Control on Vegetation Restoration

Methods of field survey

Field surveys were carried out in the summers of 1993 and 1994. Eight transects were placed on seven sand dunes taking care to cover various periods of grazing control by fencing (Table 1). Each transect was set from sand dune ridge to interdune depression, or from one dune ridge to another. The length of each transect was 30 to 100m. Along each transect 10 to 30 quadrats (2m×2m) were set to obtain vegetational data. In addition to them, vegetation in flat lowlands was surveyed with 49 quadrats (1m×1m or 0.5m×0.5m, according to vegetation height). Twenty of them were located in unprotected area. Five, fifteen, and nine quadrats were in enclosed areas where grazing has been inhibited for 2, 5 and 20 years, respectively. For each quadrat, all species

Table 2 Vegetation structure in each quadrat group

Quadrat group	Species richness	Dominant species (Number of quadrats in which the species was most dominant)	Vegetation height (cm)
A	5.8	*Setaria viridis*(6), *Phragmites communis*(5), *Aneurolepidium chinensis*(1)	10
B	10.9	*Phragmites communis*(6), *Lactuca tatarica*(1), *Equisetum arvense*(1)	40
C	18.6	*Calamagrostis epigeios*(5)	70
D	8.4	*Aneurolepidium chinensis*(5)	30
E	5.8	*Setaria viridis*(4), *Phragmites communis*(1)	20
F	8.6	*Aneurolepidium chinensis*(4), *Carex duriscula*(1)	30
G	14.2	*Puccinellia tenuiflora*(4), *Phragmites communis*(1)	60
H	18	*Adenophora tetraphyra*(2), *Hemerocallis minor*(2)	90
DA	6	*Caragana microphylla*(14), *Setaria viridis*(6)	80
DA(ID)*	7	*Oxytropis myriophylla*(1)	5
DB	13.5	*Caragana microphylla*(5), *Setaria viridis*(1), *Echinops gmelinii*(1)	70
DB(ID)*	4.7	*Caragana microphylla*(3), *Setaria viridis*(1)	60
DC	5.5	*Corispermum theregium*(6), *Pennisetum flaecidum*(5), *Senecio* sp.(5), *Caragana microphylla*(1)	20
DC(ID)*	11.3	*Thypa minima*(7), *Salix flavida*(3), *Salix microstachya*(1), *Carex duriscula*(1), *Senecio* sp.(1)	190
DD	10.5	*Agriophyllum arenarium*(5), *Caragana microphylla*(4), *Pennisetum flaecidum*(2), *Calamagrostis epigeios*(1), *Corispermum thregium*(1)	30
DD(ID)*	5.9	*Calamagrostis epigeios*(3), *Halerpestes ruthenica*(1), *Setaria viridis*(1), *Carex duriscula*(1), *Agrostis trinii*(1)	20
DE	7.4	*Caragana microphylla*(8), *Pennisetum flaecidum*(2), *Lespedeza davurica*(1)	130
DE(ID)*	7.8	*Salix microstachya*(4)	170
DF	8	*Caragana microphylla*(3), *Artemisia holodendron*(3), *Setaria viridis*(2), *Messerschmidia sibirica*(1), *Pennisetum flaecidum*(1)	90
DF(ID)*	6.2	*Artemisia holodendron*(3), *Artemisia siversiana*(1), *Phragmites communis*(1)	140
DG	3.9	*Corispermum theregium*(4), *Salix flavida*(3)	140
DG(ID)*	4.9	*Salix mongolica*(4), *Salix microstachya*(2), *Halerpestes ruthenica*(1), *Lactuca tatarica*(1)	220
DH	6.1	*Artemisia holodendron*(5), *Caragana microphylla*(3), *Cleistogenes squarrosa*(3), *Salix flavida*(1), *Phragmites communis*(1)	120
DH(ID)*	9	*Phragmites communis*(1), *Artemosia sacrorum*(1)	110

*(ID) : interdune depressions.

present were recorded with their coverage. Topography was also measured along each transect in order to draw sections.

Method of data analysis

Species compositional data were analyzed by means of Detrended Correspondence Analysis (DCA; Hill, 1979). Species which appeared in more than four quadrats were included in the analysis. This kind of treatment enhances analytical performance without any loss of important information (*e.g.*, Orlóci and Mukkattu, 1973). Major trends in compositional change were then estimated. The effect of grazing control was evaluated by comparison of DCA scores among the transects or quadrats that differed in the duration period of control. The relationship between topographic location and species composition was also analyzed in the same manner.

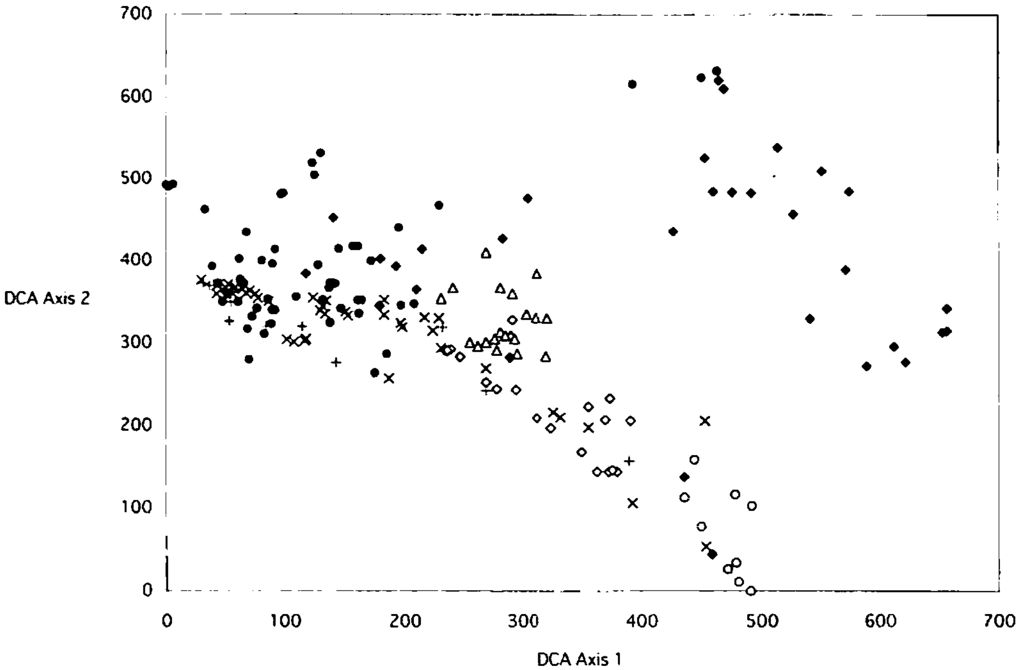


Fig.11 Scatter diagram of the DCA first and second axes indicating sample (quadrat) ordination

Open triangles: Unprotected lowland, Open diamonds: 2 to 5 years protected lowland, Open circles: 20 years protected lowland, x: Unprotected dune, Close circles: Protected dune, +: Unprotected interdune depression, Close diamond: protected interdune depression.

Results of the analysis

General attributes of vegetation

Table 2 indicates the average vegetation height, species richness and dominant species for each quadrat group classified by protected period (see Table 1) and topography. On sand dunes the species richness has a tendency to decrease with the length of protected period, presumably because of the dominance of *Salix* spp. The increase in average vegetation height with the length of protected period is also observed indicating that woody species such as *Caragana microphylla* and *Salix* spp. grow to larger size in controlled area. In lowlands and interdune depressions both species richness and vegetation height seem to fluctuate with no relation to the length of conserved period, though the vegetation conserved for twenty years and located in lowlands (group G and H) contained larger number of species.

The difference concerning topographic variation is mainly observed in dominant species. For example, *Caragana microphylla* is dominant only on dunes. Compositional variation is further analyzed in the following sections by means of ordination technique.

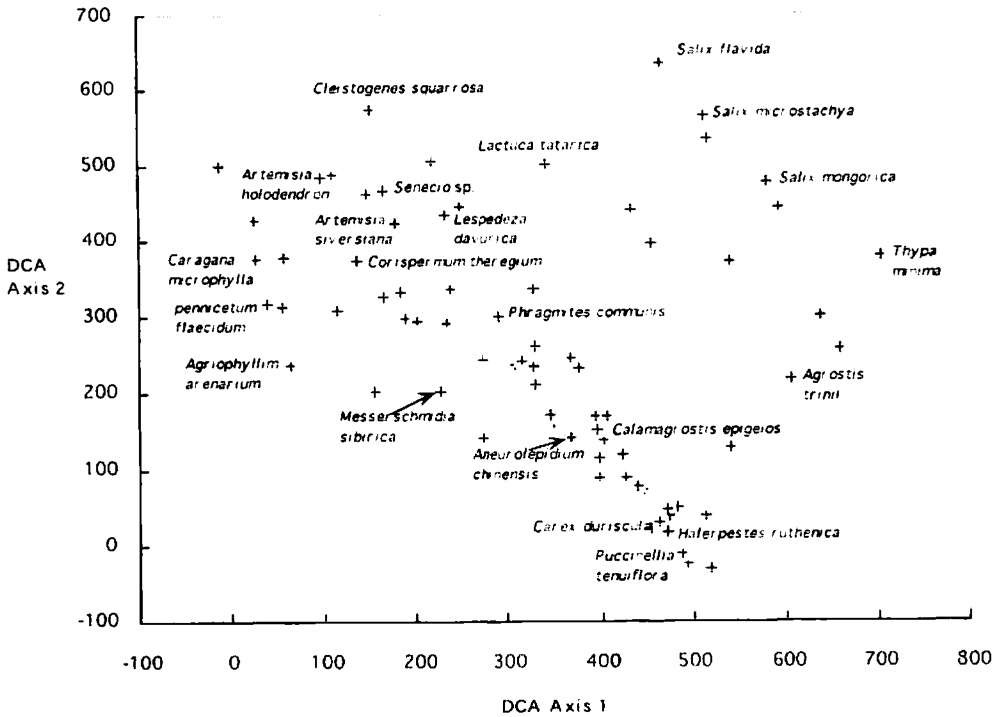


Fig.12 Scatter diagram of the DCA first and second axis indicating species ordination

Detrended Correspondence Analysis

The results of DCA are shown by scatter plots of the first and second axes (eigenvalues were 0.867 and 0.780, respectively). Figures 11 and 12 indicate the sample (*i.e.*, quadrat) scores and species scores, respectively.

The ordination of the quadrats shows a minor overlap between the vegetation controlled (conserved or protected) for different periods. As for the quadrats in the controlled areas minor overlap is also observed between topography types. The quadrats in uncontrolled areas, however, are plotted closer to one another. These results indicate that grazing control mainly influences species composition and that restored vegetation by grazing control will vary depending on topography.

The compositional difference associated with the length of controlled period is mainly reflected by the first axis, especially in the case of the quadrats in lowlands. Therefore, the first axis can be interpreted as the axis of degree of vegetation restoration. The compositional difference of controlled vegetation associated with topography is observed along the second axis, which can be recognized as the axis of topographic variation.

As for the quadrats on dunes, compositional difference between controlled and uncontrolled vegetation is not so clear. On dunes *Caragana microphylla* dominantly occurs from the earliest stage of the succession (dwarf *Caragana* community) to later

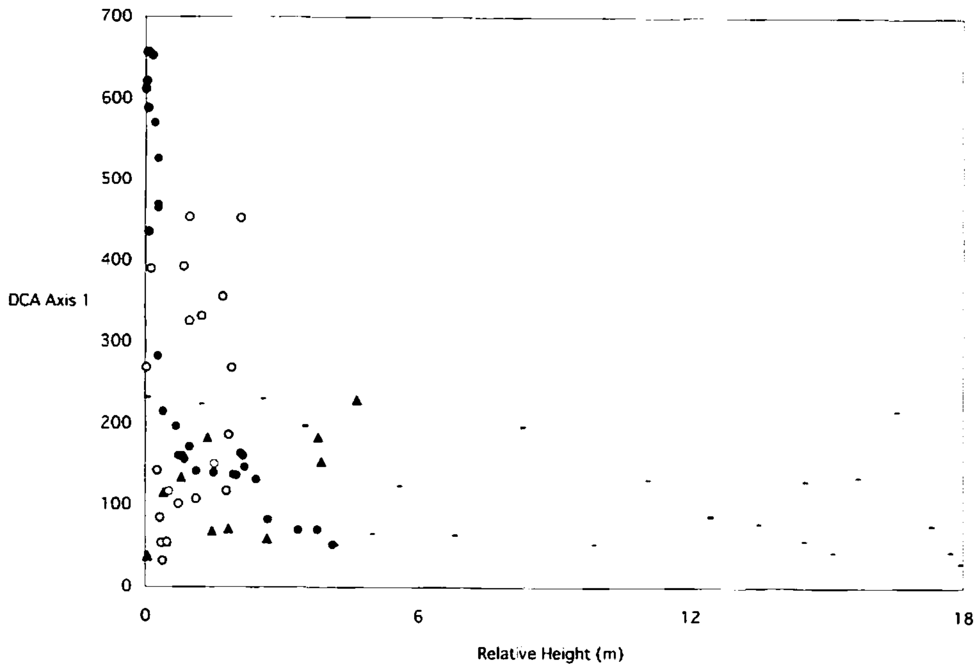


Fig.13 The spatial variation of vegetation along topographic gradient
Vegetational variation and topographic condition are indicated by the scores of the DCA first axis and relative height from depression bottom, respectively. -: Transect DA (unprotected), Close triangles: Transect DB (unprotected), Close circles: Transect DC (protected for 2 years), Open circles: Transect DD (unprotected but wetter in soil moisture than the Transects DA and DB.

stages (*Caragana* or *Artemisia* communities), while in interdune depressions and in lowlands species composition changes quickly with controlled period (Table 2). This fact is the reason for the relatively large overlap between the ordination of the controlled and uncontrolled vegetation on dunes.

By visual criteria, the quadrats having high values of the first axis, i.e., the quadrats in the controlled area, can be classified into three groups. The first is the group having low values of the second axis characterized by the dominance of species such as *Halerpestes ruthenica* and *Puccinellia tenuiflora*. The quadrats belonging to this group are mostly those located in the 20 years protected lowland. Another group is composed of quadrats showing intermediate values of the second axis, characterized by the dominance of *Thypa minima* and observed only in the protected interdune depressions. The quadrats having high scores of the second axis belong to the third group. The quadrats in this group are mainly dominated by *Salix flavida* (on protected dunes), *S. microstachya* and *S. mongolica* (in protected interdune depression).

Fig. 13, showing the relationship between the altitude of each quadrat from the bottom of its interdune depression and the first axis score of DCA, indicates that vegetation is almost constant along the transects located in the unprotected area, while developed vegetation can be observed on the protected interdune depressions. Compositional change in protected interdune depressions is apparently observed at an altitude of 1m or less from the bottom (Fig. 13). Some of the quadrats located on the protected dunes have higher scores of the second axis (Fig. 11). Within these quadrats *Artemisia holodendron* or *Salix flavida* is dominant (compare Fig. 11 with Fig. 12 or see Table 2).

The above mentioned results indicate that vegetation can readily be restored under grazing control in interdune depression and lowland where underground water level is high and soil moisture is appropriate to vegetation growth. It is also indicated that vegetation restoration is slow and/or difficult on dunes probably because of dry and degraded soil condition, and that restored vegetation is different between dunes and interdune depressions.

Discussion on Vegetation Restoration

Based on the results, it is concluded that grazing control is the key factor in promoting plant succession in the study area. Past studies concerning the effect of grazing on vegetation can be divided into two categories. One comprises studies in which grazing is a useful method to maintain vegetation in species rich status (Smith and Rushton, 1994; Bullock *et al.*, 1994). The other comprises studies in which grazing is a harmful factor, damaging vegetation restoration (*e.g.*, Backeus *et al.*, 1994; O'Conner, 1994). As for the present study field of the Kerqin Sandy Lands, grazing does affect vegetation cover and should be limited or inhibited in order to restore vegetation cover. However, on sand dunes species richness actually increases under grazing because the dominance of *Salix* spp. is prevented by grazing. On dunes in this area development of vegetation cover is more desirable than increase of species richness to control dune activity. Therefore, grazing should be controlled on sand dunes even at the expense of species richness/diversity.

It can be noted that the observed vegetation is different among topography types in the controlled area. This fact indicates that factors influencing vegetation vary according to topographic gradient and that the control strategy should be different depending on topography.

It appears that vegetation restoration is more difficult on dunes than in depressions and lowlands. The reason is probably the lack of soil moisture and the advance in soil degradation on dunes. It has been reported that soil degradation slows vegetation recovery (Backeus *et al.*, 1994).

In lowlands and interdune depressions, fencing is an effective strategy for vegetation restoration. Vegetation has been observed to restore itself spontaneously after the beginning of the grazing control. However, the authors cannot decide the minimum length of grazing control period for vegetation restoration. In wet depressions, two years of control allows the development of tall, dense and species rich *Thypa minima* community (Table 2). In normal depressions, however, 10 to 15 years of grazing control is sometimes insufficient for vegetation restoration (Fig. 11, Table 2). In lowlands, five years control is not enough to restore well-developed grassland such as has been observed in areas protected for 20 years (Fig. 2), though tree species are still rare even in such areas.

From the point of view of vegetation structure, the *Calamagrostis epigeios* community observed in the two-years controlled lowland comprises many (average 18.6) species and grows tall (average 0.7m. Table 2). If species composition, soil degradation and sand dune remobilization do not need to be considered, grazing control for two years is almost enough for restoring grassland vegetation in medium to wet lowlands and depressions in the study area.

On dunes, fencing or enclosure is not always so effective. In this case plantation is a possible way of vegetation restoration. In the present study field plantation of *Caragana microphylla*, which is a dominant shrub species on dunes, has been carried out by Wulan-Aodu Grassland Ecosystem Research Station, Institute of Applied Ecology. Nan (1994) reported that this plantation is quite effective in lowering wind effects and in fixing soil. The efficiency of the plantation, including other species than *Caragana microphylla*, on vegetation restoration should be further analyzed in order to complete the restoration strategy for this area.

5. Concluding Remarks

Overuse of the semi-arid fragile environment has changed fixed dune fields to remobilized dune fields in the Kerqin Sandy Lands. Vegetation cover has been rapidly depleted. It is concluded that the main cause of recent dune remobilization in Wulan-Aodu is overgrazing by livestock. However, climatic fluctuation seems to have accelerated the land degradation process. A similar case was reported in the Sudano-Sahelian zone where livestock population increased during a wet period of climate, causing severe damage to the environment when followed by a dry period (Grantz, 1977). These facts support the thesis that desertification is a phenomenon caused by both natural and man-induced causes.

The results of the survey on vegetation restoration suggest that grazing control is the most effective way of desertification control in this area. Revegetation works can help the progress of plant succession. Similar experiments have already been done in various semi-arid zones in the world. The cause of the problem is how to establish sustainable land use system that can support human population.

One solution to this problem is to construct a land use zoning system. In this area, topography and soil moisture (and nutrient concentration and soil texture, maybe) are the major descriptors classifying land use zones. In lowland and depressions in this area vegetation structure can develop to some extent in a few years if soil moisture is appropriate. In lowlands and depressions with appropriate soil moisture, grazing control can be loosened from today's level to adopt a rotation system allowing people to use recovered vegetation cover periodically. It should be noticed, however, that an alkalization problem accompanied by too much moisture, which can also be observed in this area and other soil degradation should be taken into account (Kou, 1994). In other lowland and depression areas grazing control of today's level is preferable. On sand dunes strict grazing control is essential and in some cases artificial revegetation works are also desired to support and promote vegetation restoration.

These criteria are still too abstract and idealistic to be applied to realistic problems. To show a model of a sustainable land use system adaptable to this region will be our next theme.

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