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ORIGINAL ARTICLE

Change trends for desertified lands in the Horqin Sandy Land at the beginning of the twenty-first century

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Abstract The dynamics of desertification in the Horqin Sandy Land between 2000 and 2005 were analyzed using Landsat TM/ETM images and the data-processing function of geographical information software. The results showed that the extent of desertified land decreased at a rate of slightly more than 0.1 km^2 year^{-1}, from 22,423.1 km^2 in 2000 to 22,422.4 km^2 in 2005, indicating that desertification has been controlled in this area and that desert areas may be approaching a steady state. The dynamics of desertification differed among land types. Desertification decreased most obviously in areas of previous desert land. The area in which desertification was ameliorated was higher than the area that underwent further degradation, but non-desertified land (113.3 km^2) deteriorated at a rate of 22.7 km^2 year^{-1} during this period. This significant change requires careful attention by managers in the study area.

Keywords Desertification · Horqin Sandy Land · GIS · Remote sensing · China

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Introduction

Preliminary studies of the dynamics of desertification in the Horqin Sandy Land focused on field investigations. In these studies, desertification was evaluated by comparing the areas of desertification obtained from aerial photographs and conversions at different periods of time (Ren et al. 2004). No investigations were done in this area before the 1980s. With increasing availability of satellite images and use of the geographical information system (GIS) technique in desertification research, studies of spatial and temporal variation in desertification have been developed, and more and more researches on the dynamics of desertification have been performed for areas such as China's Horqin Sandy Land (Gerile and Wulantuya 2004; Wu 2000).

The area of desertified land has expanded continuously and the degree of desertification has increased in northern China in the past 50 years (Wu 2000; Wang et al. 2002, 2004a). During this period, desertification accelerated rapidly in the Horqin Sandy Land, with the total area of desertified land reaching 9,084 km^2 between the late 1950s and the mid-1970s and 9,624 km^2 between the mid-1970s and the late 1980s (Wu 2000; Wang et al. 2004b). However, the trend reversed during the 1990s, with the area of desertified land decreasing by 10,866 km^2 by the late twentieth century (Wu 2000; Wang et al. 2004a). Desertification, thus, appears to have followed a trend of developing, further development, and reversal during the past 50 years (Wang et al. 2004a, b; Xu 2003; Wang, 2003).

No research on the dynamics of desertification has been done in the Horqin Sandy Land during the twenty-first century. In order to determine whether the reversal trend is continuing, we used remote sensing and GIS software to monitor desertification in the Horqin region from 2000 to 2005 and develop relevant databases. The study will be helpful for monitoring and evaluating future trends in desertification processes in this area.

Study area

The study was conducted in the western region of Northeast China (113°30′E–123°30′E, 42°20′N–44°28′N), which comprises the ecotone from the Inner Mongolia Plateau to China's Northeastern Plain. The study area extends from east of Qilaotu in the Yanshan mountains to west of the Songliao Plain and from south of Nuluerhu Mountains to north of Daxinganling Mountains.

The landscape is characterized by gently undulating topography covered by shifting and semi-shifting dunes and fixed dunes. The region's climate is a temperate continental semi-arid monsoon regime, and is characterized by alternating dry and humid seasons and a high sandstorm frequency (Wang et al. 2004a). The representative soil is a millet calcium, chernozem, and millet brown soil, and some areas have deteriorated into sandy soils as a result of loss of fine particles during desertification. The Horqin Sandy Land is located at the boundary between the semi-arid and semi-humid parts of the study area, where the vegetation consists largely of low and open shrubland. The original grassland community had high biodiversity, a stable structure, and a high coverage of the soil surface (Chang et al. 2005a), with layer slice developing obviously. However, during the past 100 years, the primary vegetation has been largely destroyed as desertification became increasingly serious. As a result, areas of grassland characterized by plentiful trees and grasses degraded into areas of mobile sand, and the dominant vegetation from early periods was replaced by sparser and less diverse vegetation communities. The tree layer disappeared, the herbaceous layer degenerated, and areas of shrubs developed quickly (Dong et al. 2001; Zhao et al. 2000, 2004; Cao et al. 2004; Zhang and Zhao 2003). The biodiversity decreased and the structure of the ecosystem became simplified as a result of the deteriorating environment.

The parent material in the Horqin Sandy Land is a fluviolacustrine Quaternary sediment (Wulantuya et al. 2002). The soils are very friable, and this undoubtedly weakened the region's ecosystems. The stability of the surface soils decreased because of environmental variations, especially climatic factors, leading to the spread of desertification. Furthermore, since the Quanxin Lifetime, interaction between the natural environment and human activities has induced an imbalanced state in which human use of the land exceeded its carrying capacity, which accelerated desertification processes (Zou et al. 2001). Therefore, the region provides a representative area to study desertification processes and dynamics.

Sources of data and analytical methods

Data sources

China's national forestry department has recommended monitoring the progress of desertification throughout the country using 5-year periods. Our study of desertification in the Horqin Sandy Land used the period from 2000 to 2005. Data for this period represented false-color data from wavelength bands 4, 3, and 2 of the Landsat TM/ETM images for this period. This raw data were compared with the relevant statistics for the study area (e.g., field data on vegetation cover) and 1:250,000 maps.

Analysis of the TM image

To measure the trends in desertification, image analysis of the remote-sensing images was performed followed by visual interpretation of the results, as described in the rest of this section. Based on this information, we further analyzed the interpreted results to establish a desertification chart and related databases.

Analysis of the remote-sensing images

Satellite images can include errors related to variations in the radiation environment and geometric deformations in the image that result from attenuation of sensor data, atmospheric effects, and the position of the satellite. To correct the images used in the analysis, the images were orthorectified using points on the topographical maps whose positions could be identified accurately. The ERDAS IMAGINE Objective software (ERDAS Inc., Atlanta, GA) was used in the analysis; geometric corrections were performed using the Image Geometric Correction function of the Data Preparation module. We reprojected the image data after this transformation before continuing analysis. The resulting image was adjusted to have the same coordinates as the map, providing a precise match with relief map as a result of coordinate conversion and repetitive sampling.

In order to extract more information from the images, we identified the best combination of bands of TM4, TM3, and TM2 to produce the false-color images. These bands are most sensitive to vegetation, soil, and soil moisture, respectively. The spectral coverage of TM2 is 0.52–0.60 μm, TM3 is 0.63–0.69 μm, and TM4 is 0.76–0.90 μm. TM4 reflects the trait of the vegetation of different desertification sand land; TM3 reflects the higher brightness of the sand soil and the phenomena that pickled soil gets white. TM2 is sensitive to the reflection of the vegetation, divisoning forest mode land the category of the tree.

Cover types and image interpretation

Identifying the type of land cover and the corresponding degree of development of desertification is the basis for determining trends in desertification. To perform the identification, we established criteria for judging the land cover category and used changes in this category to monitor trends in the development of desertification.

Differences in the chemical composition and physical structure of objects detected by the satellite images will cause differences in the spectral absorption and reflection of these objects, giving each object unique spectral characteristics. Previous studies (Wu 2001; Bayaer et al. 2004; Bao et al. 2004) have shown that sandy surfaces have high (30–50%) reflectivity in the 0.5–2.4 μm wavelength band, and in air photo images and satellite images, these surfaces have high reflectivity and light tones, whereas vegetation, water, and rock outcrops have lower reflectivity and a darker color. The difference helps to reveal the presence of sandy surfaces. For this reason, we used variations in the lightness of pixels in the remote-sensing images as the main factor for identifying desertification (Hu 1991).

Using this and other differences, interpretation guide was developed shown in Table 1. Based on these criteria, we defined four categories of desertification (Table 2) in the Horqin Sandy Land and used this information to create a database of desertification dynamics.

Interpretation of the remote-sensing images

The monitoring of the extent and severity of desertification in the study area depended mainly on visual interpretation of the false-color satellite images according to the following method. Based on the interpretation criteria described in "Cover types and image interpretation", the ArcView image processing software combined with the ArcInfo GIS software (ESRI, Redlands, CA) was used to interpret TM images obtained in August 2000 and August 2005 by means of supervised classification. The visual information was interpreted automatically using blended image elements and our knowledge of the actual land surfaces. The smallest image spot is 10 × 10 entries image

Table 1 Interpretation criteria for the cover type classes used to assess the extend of desertification

Surface cover type	Image characteristics	Other characteristics
Agricultural land	Linear borders and gridding; bright red or light red color	Clear linear objects such as roads and livestock enclosures
Meadow	Large areas with irregular shape; pink, red, and off-white colors	Patches of bare soil
Holt	Irregular shape; red, henna, or brown color	Red and green ridges, strips along a river
Orchard	Regular shapes; henna color	Distinct boundaries; homogeneous color intensity and brightness
Residences	Regular geometry; blue, ashen, or light blue color	Blurry boundary
Lakes or reservoirs	Irregular shape; blue and black colors	Distinct boundaries
Sand dunes	Meniscus or gridded shapes, with undulating patterns; light lark or ash color	Distinct boundaries; homogeneous color
Salt and alkali land	Irregular shapes; white or off-white in color	Patchy coloration; distinct boundaries
Bottomland	Linear strips; usually homogeneous white color, but sometimes light red	Usually found along rivers
Uncovered	Diamond-shaped or linear strips; ash and green or blue and gray in color	Linear cyan strips, with distinct boundaries
Snow	Irregular shape; homogeneous white color	Blue strips
Lightly desertified	Irregular shape; light red in color	Red spots in areas with a light red tone
Moderately desertified	Irregular shape; light red in color	Uneven surface, dunes present
Heavily desertified	Irregular shape; brown and yellow in color	Clear dunes, with shrubs present in some places
Severely desertified	Large irregular areas; brown and yellow in color	Clear dunes and sand ridges

Table 2 The classification system developed based on remote sensing and used to monitor sandy desertification in the Horqin Sandy Land region of northern China

Severity of the desertification		Cause of the desertification				
		Dune activation or quicksand inbreak	Shrubby desertification	Shingle desertification	Aeolian desertification	Agricultural desertification in dry land
Lightly desertified	Code	101	102	103	104	105
	Trait	Aweather slope of dune producing aeolian hole; quicksand 5–25%	Risk shrub, producing piled quicksand, and Shazui relief	Gravel, obvious enrichment in coarse surface materials	Aeolian holes but no obvious formation of steep ridges	Some accumulation of sand in channels during the spring, obvious signs of aeolian erosion
Moderately desertified	Code	201	202	203	204	205
	Trait	Obvious dunes, aeolian slopes, and dropping sand; quicksand 25–50%	Sand piles no longer covered by shrubs, a weather side producing obvious sand flow, flat areas producing floating sand and sandy gravel among the sand piles	Surface covered by thick sand, with sparse vegetation; grass covers more than 25% of the surface; gravel fields present	Largely bare, aeolian holes, obvious small but steep slopes	Loess farm producing obvious flake quicksand, aeolian ply of land, humus content more than 50%
Heavily desertified	Code	301	302	303	304	305
	Trait	Areas with flowing sand; quicksand more than 50%	Mostly dead shrubs; less than 25%, quicksand less 50%	Surface wholly covered by gravel, with a little sand; vegetation cover 10–25%	Surface producing aeolian remnant frusta and aeolian remnant dunes, no grass, discarding gravel farm	Farm humus degraded, calcium lamination and venter thing coming out, quicksand more than 25%, largely discarded
Severely desertified	Code	401	402	403	404	405
	Trait	Mobile dunes, less than 10% vegetation cover	Mobile sand and sand ripples, less than 10% vegetation cover	Gobi, less than 10% vegetation cover	Yadan relief	Flat sand or gravelly sand, less than 10% vegetation cover

element. The contour line error of image spot is not more than a element in the process of the interpretation (15 m × 15 m).

Results and discussion

Distribution of changes

The severity of desertification changed throughout the Horqin Sandy Land during the monitoring period, and the changes is illustrated in Fig. 1.

The dynamics of desertification changed greatly near the boundary between Keyouzhongqi and Zhaluteqi and between Kezuozhongqi and the areas south of Kezuohouqi. This change was also seen north of Kezuohouqi, north of and in the middle of Kulunqi, northeast of Alukerqinqi, and near the borders of Balinyouqi, Wengniuteqi, and Alukerqinqi. Desertified land was distributed in scattered patches in other areas.

The parent materials in the Horqin Sandy Land are fluviolacustrine Quaternary sediments, which are very friable. The vulnerability to erosion is the main reason for the distribution of desertification in the study regions. In the area, the western part was seriously desertified, with shifting and semi-shifting dunes distributed widely throughout the area. The eastern and middle parts were moderately desertified, and quicksand scattered intermittently in the fixed dunes, with the quick sand extending from west to east and distributed alternately. The northern part was slightly or moderately desertified, and represented the least severe degree of desertification in the study area (Cao et al. 2004). The distribution of desertification dynamics appears to have been concentrated in the

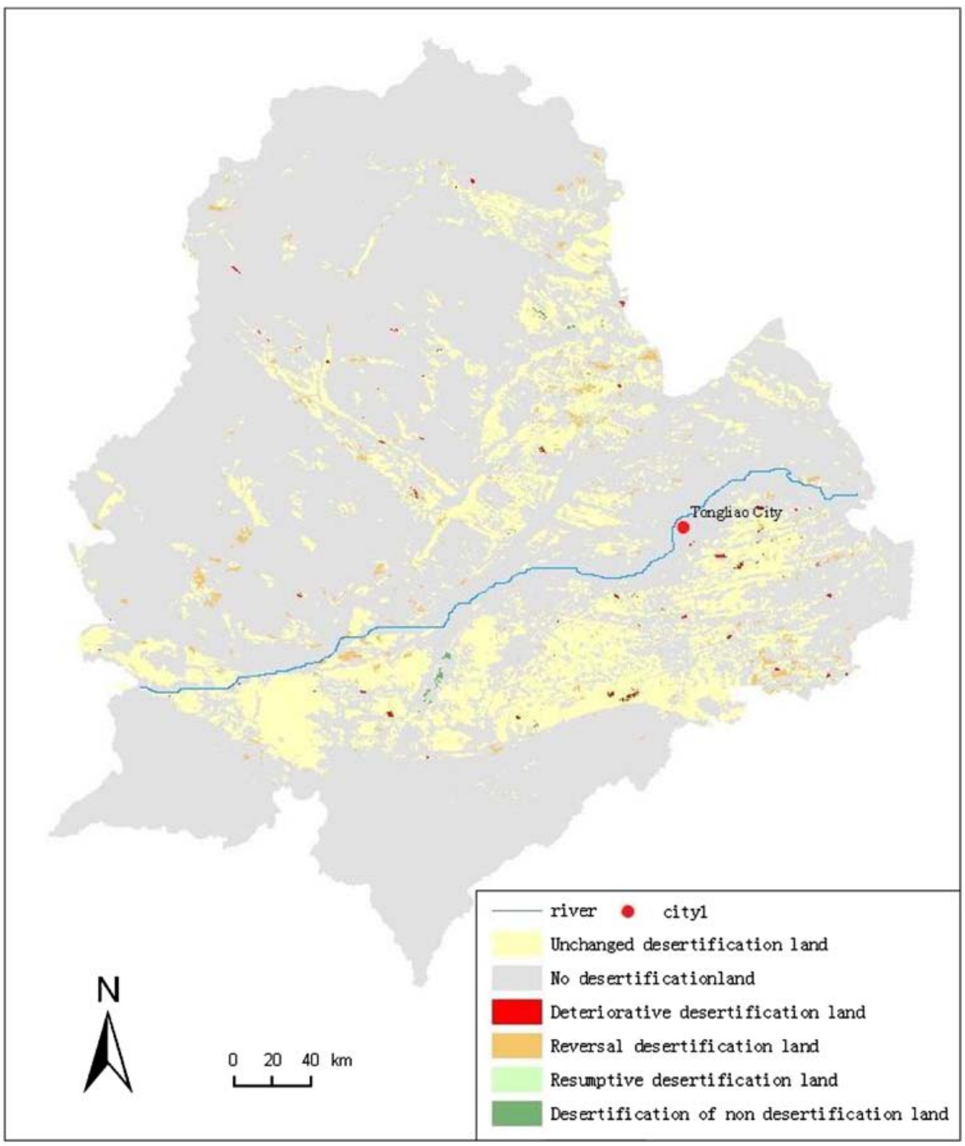

Fig. 1 The spatial distribution of changes in the extent and severity of desertification land in the Horqin Sandy Land from 2000 to 2005

aforementioned regions as a result of the double impacts of natural factors (increasing aridity and stronger wind regimes) and unsustainable human activities (Chang et al. 2005b).

Trends in the dynamics of change

During the monitoring period, the area of desertification decreased slightly, from 22,423.1 km^2 in 2000 to 22,422.4 km^2 in 2005 (Table 3). This represents a decrease of only 0.7 km^2, and a rate of decrease equal to only 0.14 km^2 year^{-1}. The result indicates that overall desertification appears to have stabilized during the study period, and that the desertification dynamics appear to have reached a steady state that balances desertification with the reversal of desertification.

Analysis of the remote-sensing data (Table 3) showed that the areas of desertified land caused by activation of sand dunes or invasion of drifting sand and by dry-land farming both decreased, at rates of 2.7 and 6.6 km^2 year^{-1}, respectively. However, desertification of land covered by shrubby vegetation increased at a rate of 10.26 km^2 year^{-1}. During the study period, the proportions of these three kinds of desertification were not obvious (Fig. 2), with values of 2.8, 14.3–14.4, and 82.8–82.9%, respectively.

Analysis of the climatic characteristics from 1961 to 2001 in the study area at the Naimanqi meteorological station indicated that the mean annual temperature averaged 6.8°C (± 0.71°C), with a coefficient of variation equal to 0.10, indicating that the temperature has not fluctuated greatly during this period. However, the mean annual temperature has increased gradually during this period, rising by nearly 1°C (Fig. 3).

The changes in annual precipitation were more dramatic than those in annual air temperature, but the pattern of change resembled a periodic oscillation rather than a steady increase or decrease (Fig. 4). Annual precipitation averaged 366.3 mm during the study period (±89.2 mm), and the coefficient of variation was 0.24, indicating that precipitation has fluctuated greatly during the study period.

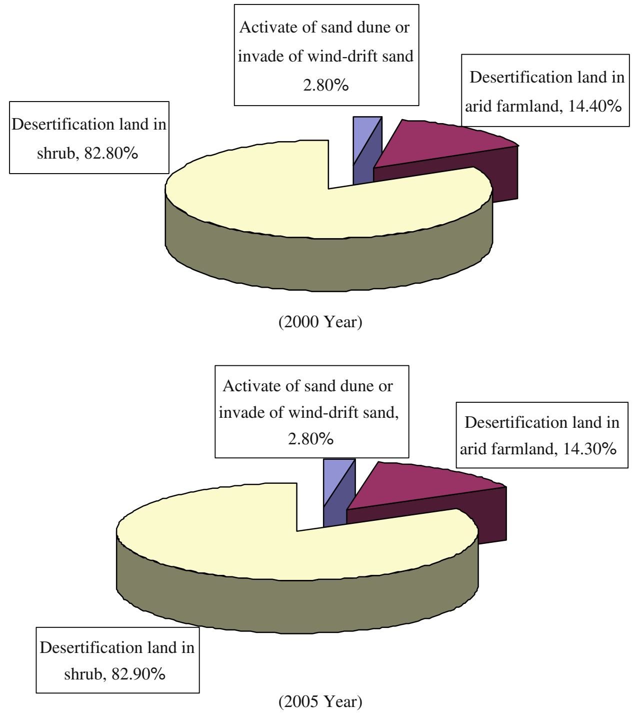

Fig. 2 The proportions of the various kinds of desertification in 2000 and 2005 year

The primary factor underlying the desertification dynamics appears to be the semi-arid to semi-humid climate of the Horqin Sandy Land (Chang et al. 2005a). However, unsustainable agricultural activity was another factor for desertification in the area. The mode and intensity of land use have changed in recent years in response to government policies designed to combat desertification. This change has reduced the pressure on the land in the region, thereby stabilizing the rate of desertification.

In the eastern part of the Horqin Sandy Land, agricultural and pastoral areas are interlaced, with cultivated land and pastures representing the main land use types (more than 70% of the total). During the study period, the land's carrying capacity has strengthened and human being activity has intensified as the population has increased. Pastures have mostly been transformed into cultivable land

Table 3 Area and pattern of desertification in 2000 and 2005

Year	Area (km^2)			
	Activation of sand dunes or invasion of drifting sand	Desertification of land covered by shrubby vegetation	Desertification of arid farmland	Total
2000	632.3	18,549.9	3,235.7	22,423.1
2005	618.8	18,600.8	3,202.8	22,422.4
Total	−13.5	50.9	−32.9	−0.7

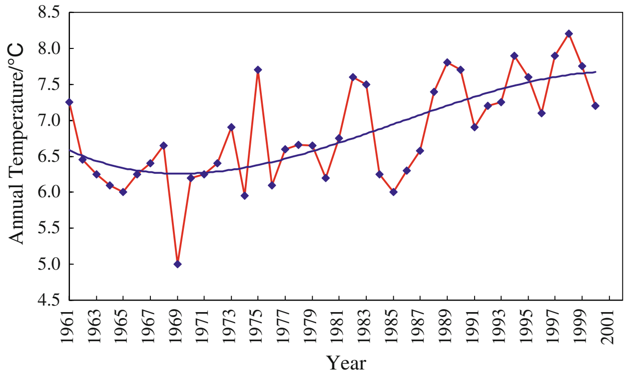

Fig. 3 Changes in mean annual temperature from 1961 to 2001 in Naiman County

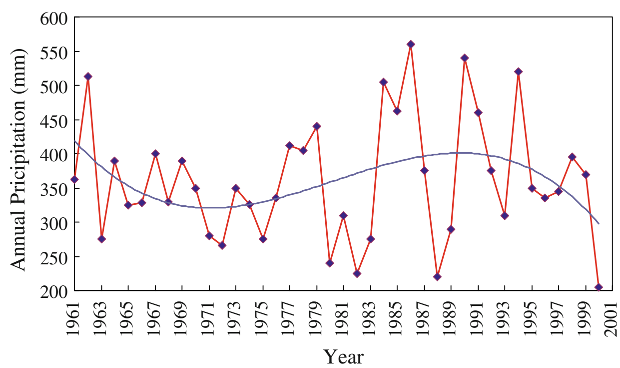

Fig. 4 Changes in mean annual precipitation from 1961 to 2001 in Naiman County

and forest; the area of natural pasture has greatly decreased, but the raising of livestock has not been sustainable. Pastures are still created where the land cannot sustain this use, leading to decreased productivity of the soil. Bare soil surfaces that result from excessive trampling by animals is eroded by the wind, leading to desertification and an increase in the area covered by shrubs (Wang et al. 2004a, b). The area of cultivated land that has been abandoned has greatly decreased as a result of the increase in the area's population and the limited availability of land, while some cultivable land is being used more effectively as forests. The area of desertification caused by activation of sand dunes or the invasion of drifting sand has decreased, as has the area of desertification in arid farmland.

Analysis of the dynamics of desertification

The change in the area of each kind of desertification showed that the severity of desertification decreased in the areas of primary desertified land and increased in previously non-desertified land (Table 4). The area in which desertified land improved totalled 1,186.5 km^2, whereas the area of increased desertification area increased by 227.6 km^2, at the rates of 237.3 and 45.5 km^2 year^{-1}, respectively. A total of 113.3 km^2 of previously non-desertified land became desertified, and the degree of desertification was serious.

Table 4 shows the overall pattern of changes in desertification from 2000 to 2005. The areas of the desertification of land with shrubby vegetation increased at a rate of 10.2 km^2 year^{-1}, but areas where desertification reversed equaled 204.6 km^2 year^{-1}. Areas in which desertification reversed were thus greater than areas in which desertification increased in land with shrubby vegetation, indicating that the overall degree of desertification was well controlled in this type of land use. However, the degree of desertification obviously decreased in the dry-land farming system, where the rate of reversal of desertification was 25.7 km^2 year^{-1}, versus an increase of 1.9 km^2 year^{-1}. The overall area of desertification also decreased by 5.9 km^2 year^{-1} in areas where sand dunes became activated or drifting sand occurred. In contrast, non-desertified land exhibited increasing desertification during this period, with a total increase in the area of desertification of 113.3 km^2, representing a rate of 22.7 km^2 year^{-1}.

Human activity appears to be the main factor responsible for the reversal of desertification in primary desert land and degradation in non-desertified land. In the last century, the degree of desertification was severe in some regions, such as Aohanqi, the area north of Naimanqi, Kailuxian, and the area west of Tongliaoshi. The problem received considerable attention from the regional government, and effective measures were used to prevent desertification. In contrast, the degree of desertification of previously non-desertified land increased in some areas, mainly north of Kulunqi, north of and in the middle of Kerqinzuoyihouqi, north of Wengniuteqi, and east of Liaohe. Unfortunately, the problem has received little attention in these regions.

Conclusions

Since 2000, the overall degree of desertification in the Horqin Sandy Land has decreased slightly, and the distribution of the changes appears to have been concentrated towards the center of the study area. The dynamics of desertification changed greatly at the border between Keyouzhongqi and Zhaluteqi and between Kezuozhongqi and the area south of Kezuohouqi. This change was also seen north of Kezuohouqi, north of and in the middle of Kulunqi, northeast of Alukerqinqi, and near the borders of Balinyouqi, Wengniuteqi, and Alukerqinqi. Additional

Table 4 The extent of the changes in all kinds of desertification from 2000 to 2005

Type of desertification	Area (km^2)		
	Reversal of desertification	Increase of desertification (negative values represent a decrease)	Net change
Activation of sand dunes or invasion of drifting sand	35.2	−5.8	29.4
Desertification of arid farmland	128.3	−9.7	118.6
Desertification of land covered by shrubby vegetation	1,023.0	−98.8	909.7
Desertification of previously intact land	–	−113.3	−113.3
Total	1,186.5	−227.6	958.9

smaller areas of desertification were distributed in other areas.

During the monitoring period, the total area of desertification decreased from 22,423.1 km^2 in 2000 to 22,422.4 km^2 in 2005. Thus, desertification appears to have been successfully controlled and appears to have reached a steady state between desertification and the reversal of desertification. The areas of desertification caused by activation of sand dunes or invasion of drifting sand and dryland farming have decreased. However, desertification increased in areas with shrubby vegetation. The proportions of different kinds of desertified land remained largely constant.

The dynamics of change differed among the different kinds of desertified land. The degree of desertification decreased in primary desertified land and increased in previously non-desertified land. The area in which desertification reversed was 1,186.5 km^2, whereas desertification increased in 227.6 km^2, for rates of change equaling 237.3 km^2 and 45.5 km^2, respectively. A total of 113.3 km^2 of previously non-desertified land became desertified, suggesting that this trend should be monitored closely so that the necessary corrective measures can be taken.

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