

# Effectiveness of ecological restoration projects in Horqin Sandy Land, China based on SPOT-VGT NDVI data

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## ARTICLE INFO

### Article history:

Received 7 February 2011

Received in revised form 10 August 2011

Accepted 18 September 2011

Available online 8 November 2011

### Keywords:

Horqin Sandy Land

Ecological restoration

Effectiveness

NDVI

SPOT-VGT

## ABSTRACT

Horqin Sandy Land is a major source of sandstorms in Northern China, especially the Beijing–Tianjin–Tangshan Region. A series of ecological restoration projects including the ‘Grain for Green Project’, the ‘Beijing and Tianjin Sandstorm Source Controlling Project’, and the ‘Three-North Shelterbelt Project’ were implemented in this region. This study assesses the effectiveness of ecological restoration projects within Tongliao City, the main body of Horqin Sandy Land. The different treatment effects of various sand dunes were assessed and compared based on Normalized Difference Vegetation Index (NDVI) from SPOT VEGETATION Ten Daily Synthesis Archive from 1999 to 2007 and the desert distribution map of China in 2000. The results showed that: (1) the fixed and semi-fixed sand dunes were the main sand dune types, which accounted for 70% of the entire sand dune area in 2000; followed by shifting sand dunes and the semi-shifting sand dunes. (2) The ecological restoration projects resulted in improvements of different sand dune types, the improved area covered 76% of the sand dune area, mainly in the southern parts of the study area. The vegetation cover of the sand dunes in Naiman Banner, Hure Banner and the south of Horqin Left Back Banner increased significantly. While mild improvement occurred in the central sand dunes of the study area. (3) The area with degraded vegetation accounted for approximately 10% of sand dune area, mainly located in the southeast of Jarud Banner and the west of Horqin Left Middle Banner. Most of these areas showed mild and insignificant degradation except for a small area of moderate degradation. (4) The types of sand dunes in degraded status were mainly the fixed and semi-fixed sand dunes, followed by the semi-shifting sand dunes and saline-alkali land. The lower the dune fixity (e.g. shifting or semi-shifting versus semi-fixed or fixed) and the more likely to contribute to sand-storms, the greater the effectiveness of restoration projects. Finally, some implications for the sustainable development of the ecological restoration projects are discussed.

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## 1. Introduction

China is facing a severe desertification problem due to a combination of physical and human factors including population pressure, climate change and reclamation (Fullen and Mitchell, 1994; Runnstrom, 2000). As one of the four largest desertification regions, Horqin Sandy Land provides a source of sand for sandstorms occurring in Northern China, especially in the Beijing–Tianjin–Tangshan Region. Formerly, Horqin region was a lush grassland, but was converted into cropland due to increasing population and food demand. In particular, the “food for the program” policy in the 1950s pushed grassland reclamation for

conversion to cropland (Song and Zhang, 2006). Beginning in 1978, the “Reform and opening up” campaign, rapid economic development and increased human activities further exacerbated grassland degradation (Ren et al., 2004; Wang and Chen, 2007). The Horqin Sandy Land is facing a larger challenge than before due to climate change and population pressure (Zeng and Jiang, 2006); previous studies showed this region was undergoing significant warming and drought. Therefore, the ecosystem in Horqin Sandy Land is extremely fragile in the environment of global warming and rapid land use change (Zuo et al., 2008).

Increasing drought and intense human activities led to the aggravation of desertification. This has begun to attract governmental and citizen concerns for ecological and environmental protection of the area. Ecological engineering aiming for restoration of ecosystems is necessary in China (Mitsch et al., 1993; Mitsch and Jorgensen, 2003). Some large ecological

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restoration projects have been implemented in recent years, such as, the “Three-North Shelterbelt Project” since 1978, the “Grain for Green Project” (also called Sloping Land Conversion Program) since 1999 (Stokes et al., 2010), and the “Beijing and Tianjin sandstorm source controlling project” since 2000. However, the effectiveness of ecological restoration projects has few been evaluated (Zhang, 2006; Li et al., 2009).

As a fragile ecosystem and typical desert region in Northern China, Horqin Sandy Land has received much attention from the government and academics. The temporal and spatial changes of desertification on different scales have been investigated using field surveys and remote sensing imagery in several previous studies (Wu, 2003; Xu, 2003). Using a change detection method to examine desertification, Zhan et al. (2006) showed environmental improvement over the last 30–50 years. The ecological and environmental restoration projects have revealed preliminary success.

Desertification in the region has vacillated between degradation and improvement (Han et al., 2009). At present, the general trend is towards decreased desertification. Zhao et al. (2007) have shown that the desertification area in Horqin decreased from 5163 km<sup>2</sup> in 1987 to 4674 km<sup>2</sup> in 2000 after a large-scale restoration project. Since 2000, the trend of desertification exacerbation has been controlled and desertification area has gradually reduced, according to several studies based on moderate resolution remote sensing data (Li et al., 2006; Du et al., 2009). Despite these improvements, desertification is still a wide-spread problem resulting in non-deserted land turning to sand dune; in some regions, land reclamation still takes place and these areas will require continual monitoring.

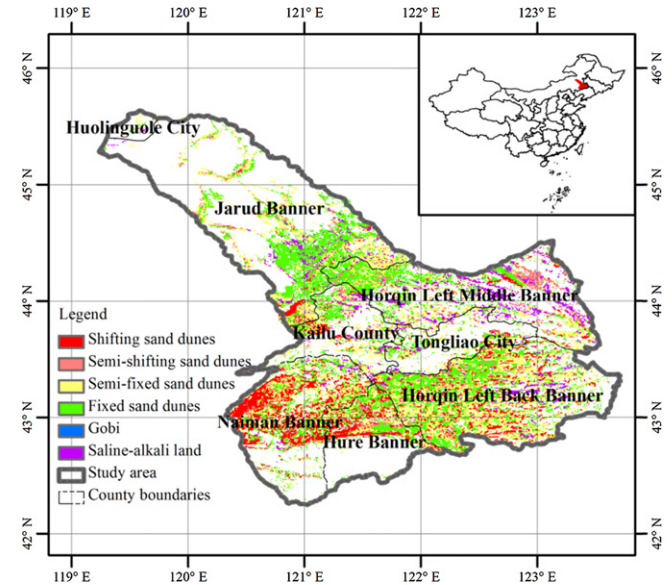
NDVI is an effective indicator of above-ground biomass and land cover changes (Stow et al., 2007), and the slope of NDVI has been used to monitor climate and vegetation cover changes (Stow et al., 2003, 2007; Ma et al., 2007; Du and Li, 2008; Olthof et al., 2008). In this study, we use NDVI to estimate vegetation cover change for assessing the ecological restoration effectiveness.

This paper aimed to investigate the effectiveness of ecological restoration projects on desertification process in Horqin Sandy Land. The effectiveness in different sand dune types was assessed separately. We sought to answer several questions, including: What were the effects of the ecological restoration projects over last ten years? Were the effects of desertification treatment in various sand dune types consistent? Did the restoration projects have similar effects on different regions? These questions have important implications for decision makers in future ecological restoration work.

## 2. Materials and methods

### 2.1. Study area

Tongliao is located in the transitional region between the Inner Mongolia Plateau and the Northeast Plain in China, and in the middle and lower Plain of West Liaohe River. It has an area of  $5.95 \times 10^4$  km<sup>2</sup> located between 119°14′–123°43′E, and 42°15′–45°59′N (Fig. 1), and contains Huolinguole City, Jarud Banner, Kailu County, Tongliao City, Horqin Left Middle Banner, Horqin Left Back Banner, Hure Banner, and Naiman Banner (Fig. 1). In China, a banner is a small administrative region similar with county. The terrain is high in the southern and northern parts, low-lying and saddle-shaped in the central part. The West Liaohe River Basin is a sandy alluvial plain located in the central portion, covering 70.7% of the total area. It belongs to a typical semi-arid continental monsoon climate. Annual mean temperature is between 0 and 6 °C, and annual average precipitation is 350–400 mm.



**Fig. 1.** The location of study area in China, and the spatial distribution of sandy land types according to the sand-covered desert classification map of China in 2000 with a scale of 1:100,000. There are six types of sandy lands existed there including shifting sand dunes, semi-shifting sand dunes, semi-fixed sand dunes, fixed sand dunes, gobi and saline-alkali land. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

Tongliao City is the main body of Horqin Sandy Land, and almost half of the area is covered by sand dunes. Sand-covered land is mainly distributed in the north-central and south-central regions of Tongliao City, and partly in the northern regions (Fig. 1).

The main sand-covered land types include the fixed and semi-fixed sand dunes, which accounted for 35.71% and 33.40% of the entire sand dune area, respectively (see Table 1). Shifting dunes, had an area of 14.62%; the area covered by semi-shifting dunes and saline-alkali land was small. There were hardly Gobi desert areas.

### 2.2. Data

#### 2.2.1. SPOT VGT NDVI

SPOT VEGETATION 10-day Synthesis Archive (SPOT VGT-S10) products with a spatial resolution (1 km × 1 km) from 1999 to 2007 were used in the study. These data were compiled by merging 10-day segments (data strips) with a Maximum Value Compositing (MVC) method (Holben, 1986) for reducing some errors from cloud cover and large solar zenith angles (Stow et al., 2007). The data has been pre-processed by VEGETATION processing Centre of Flemish Institute for Technological Research, Vito of Belgium (Maisongrande et al., 2004). A series of processes such as atmospheric correction, radiometric correction, and geometric correction have been done to ensure data quality. SPOT VEGETATION data has been evaluated and widely used in many studies (Fraser and Li, 2002; Xiao et al., 2002; Stibig et al., 2007; Song et al., 2010).

The yearly mean normalized difference vegetation index (YMNDVI) was calculated through averaging monthly NDVI, which provides information about the vegetation condition on the land surface and the effectiveness of ecological restoration. The formula was calculated as follows,

$$YMNDVI = \frac{\sum_{i=1}^{12} MNDVI_i}{12} \quad (1)$$

where *MNDVI* means monthly maximum NDVI, which is calculated using MVC method by maximizing the three stages of data,  $MNDVI = \max(NDVI_1, NDVI_2, NDVI_3)$ .  $NDVI_1$ ,  $NDVI_2$ , and  $NDVI_3$  are

**Table 1**

The sand dune types of Horqin Sandy Land and their relevant criteria, according to the Chinese desert classification criteria.

Dune types	Sand content (1–0.05 mm) (%)	Organic matter content (%)	Roughness	Vegetation coverage (%)	Area (10 <sup>4</sup> × km <sup>2</sup> )
Shifting sand dunes	98–99	0.065	1.1 × 10 <sup>−3</sup>	<5	0.43
Semi-shifting sand dunes	93–98	0.267	2.85 × 10 <sup>−1</sup>	5–20	0.24
Semi-fixed sand dunes	91–93	0.359	1.6	21–50	0.95
Fixed sand dunes	79–89	0.975	2.33	>50	1.11

the maximum NDVI in the first ten days, second ten days, and third ten days of every month, respectively.

### 2.2.2. The sand dune classification map

The sand-covered desert classification map of China (2000) with a scale of 1:100,000 was completed based on the vector data of national land use classification and Landsat TM images in 2000. The dataset was derived from Environmental and Ecological Science Data Center of Western China (<http://westdc.westgis.ac.cn>). The dataset was processed by using the artificial visual interpretation method. There were mainly four types of sand dunes (as shown in Table 1): shifting sand dunes, semi-shifting sand dunes, semi-fixed sand dunes and fixed sand dunes. We extracted the classification data within the Tongliao boundary (Han et al., 2009). The dataset provided geographical distribution, size, sand land types and other information.

## 2.3. Methods

### 2.3.1. Ecological restoration effectiveness analysis based on vegetation trend analysis and significance test

Vegetation restoration can be reflected by the change trend of NDVI values and a metric called the greenness rate of change (GRC), which is defined as the slope of the linear regression line with least squares fitting of the inter-annual NDVI values (Stow et al., 2003). Here we take GRC as an indicator for the trend of YMNDVI images from 1999 to 2007. Moreover, the GRC image showed spatiotemporal variation patterns. It was generated with the following formula,

$$GRC = \frac{n \times \sum_{i=1}^n (i \times YMNDVI_i) - \sum_{i=1}^n i \times \sum_{i=1}^n YMNDVI_i}{n \times \sum_{i=1}^n i^2 - \left( \sum_{i=1}^n i \right)^2} \quad (2)$$

where  $i$  is the order of year from 1 to 9, and  $n$  is equal to 9.  $YMNDVI_i$  is the mean NDVI of year  $i$ . GRC is the vegetation change rate. If  $GRC > 0$ , then the vegetation improved, otherwise the vegetation showed degradation.

To assess the ecological restoration levels of sand dunes qualitatively, we divided the GRC values into six levels: moderate degradation, light degradation, unchanged, mild improvement, moderate improvement and strong improvement by referring to frequency histogram of pixel numbers with different GRC values (Table 2).

### 2.3.2. Vegetation Coefficient of Variation

The variability of the YMNDVIs from 1999 to 2007 can be evaluated by the Coefficient of Variation (CV), calculated by the following formula,

$$CV = \frac{S}{\bar{x}} \times 100\% \quad (3)$$

$$S = \sqrt{\frac{\sum x^2 - ((\sum x)^2/n)}{n-1}} \quad (4)$$

where  $S$  is the Standard Deviation (SD) of YMNDVIs from 1999 to 2007, and  $\bar{x}$  is the mean of YMNDVI,  $x$  is the YMNDVI in a given year. The larger the CV values, the greater the change in vegetation.

### 2.3.3. Spatial statistical analysis of different sand dunes

The sand dune composition of Horqin Sandy Land was analyzed; YMNDVIs, GRC and CV of different sand dunes during 1999–2007 were extracted using the zonal statistics function in ArcGIS; different levels of degradation or improvement areas were calculated and compared in different sand dunes.

## 3. Results

### 3.1. The spatial pattern of multi-year mean vegetation state in the study area

#### 3.1.1. Spatial differences of various regions

Multi-year mean YMNDVI (MYNDVI) can represent the regional vegetation cover characteristics spatially. Fig. 2a shows the spatial distribution of MYNDVI in the desert region during 1999–2007. Vegetation cover of desert land was better in Horqin Left Back Banner in the southeastern Tongliao, followed by the northern region of the study area. Vegetation cover was relatively poor in Naiman Banner, Hure Banner, the central of Horqin Left Middle Banner and the southwest of Jarud Banner where MYNDVI values are less than 0.22.

The spatial distribution of MYNDVI in 2007 is shown in Fig. 2b, we can find that vegetation cover of the southern region in 2007 was generally better than the average vegetation cover in 1999–2007 except for the southern Jarud Banner and western Horqin Left Middle Banner, where vegetation was worse than the average for 1999–2007.

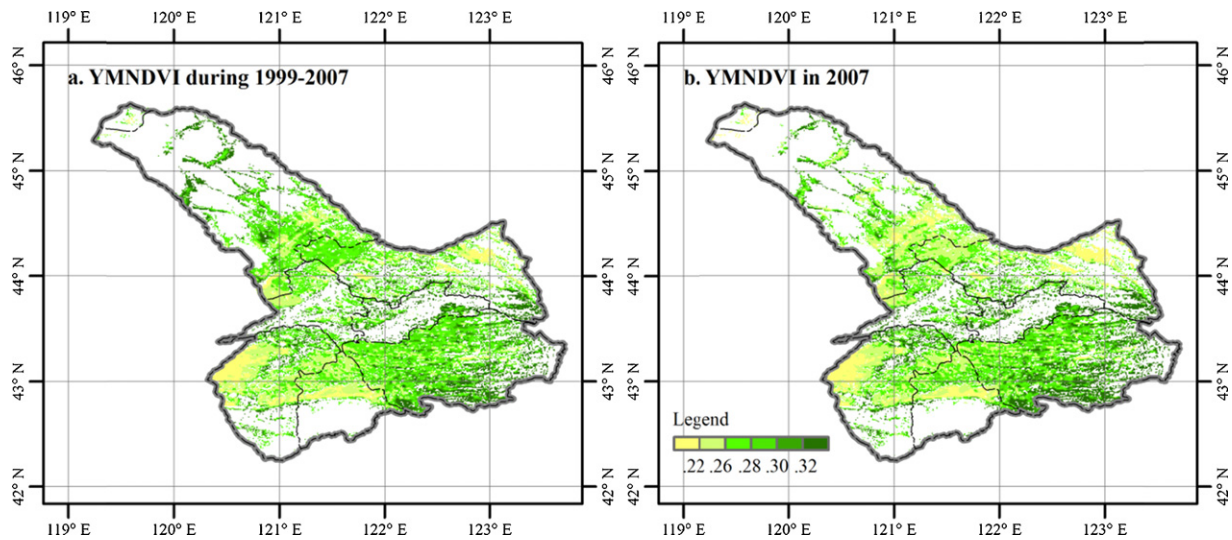
#### 3.1.2. Preliminary analysis of different sand dunes

Across the different sand-covered land types in the study area, vegetation cover varied greatly (Table 3). The MYNDVI value of the shifting sand dunes was lowest at 0.25. The semi-shifting sand dunes had more vegetation cover than the shifting sand dunes, with a mean value of 0.27. The values of fixed sand dunes and semi-fixed sand dunes were relatively higher than the shifting types. Both fixed and semi-fixed sand dunes had almost equal values ( $\sim 0.28$ ); however, the semi-fixed sand dunes were very scattered (Fig. 1)

**Table 2**

Vegetation change trend levels reflecting the effectiveness of ecological restoration projects.

Range	Change levels
$GRC < -0.004$	Moderate degradation
$-0.004 \leq GRC < -0.001$	Light degradation
$-0.001 \leq GRC < 0.001$	Unchanged
$0.001 \leq GRC < 0.004$	Mild improvement
$0.004 \leq GRC < 0.008$	Moderate improvement
$GRC \geq 0.008$	Strong improvement



**Fig. 2.** Spatial distribution of multi-year YMNDVI during 1999–2007 (a) and YMNDVI in 2007 (b) of Tongliao. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

**Table 3**

Annual YMNDVIs, the nine-years' mean, standard deviation (SD), and coefficient of variation (CV) for various sand dunes in Horqin Sandy Land. The entire study area included both sand dunes and un-sandy land areas.

Year	Shifting sand dunes	Semi-shifting sand dunes	Semi-fixed sand dunes	Fixed sand dunes	Saline-alkali land	Entire study area
1999	0.252	0.272	0.291	0.293	0.268	0.307
2000	0.228	0.239	0.257	0.259	0.234	0.272
2001	0.231	0.246	0.263	0.265	0.241	0.278
2002	0.242	0.255	0.272	0.273	0.251	0.286
2003	0.266	0.283	0.299	0.301	0.283	0.314
2004	0.271	0.285	0.304	0.303	0.284	0.320
2005	0.271	0.288	0.302	0.303	0.284	0.320
2006	0.263	0.272	0.291	0.287	0.271	0.306
2007	0.261	0.264	0.285	0.279	0.261	0.297
9-years' mean	0.254	0.267	0.285	0.285	0.264	0.300
SD	0.017	0.018	0.017	0.017	0.019	0.018
CV %	6.55	6.55	5.99	5.84	7.14	5.94

with small area which may have resulted in weak representation in the analysis.

As for the discrepancy of vegetation changes of dunes, the CVs of shifting and semi-shifting sand dunes were larger than fixed and semi-fixed sand dunes (Table 3), which indicated that the vegetation restoration in the environments that were most degraded at the beginning of the study period tended to be unstable because of more vulnerable growth conditions. The semi-shifting sand dune had higher standard deviation than shifting and fixed dunes. The CV and SD saline-alkali land were both greater than that of the other types. This indicates the vegetation was more fragile in saline-alkali land.

The whole study area including both dunes and other land-cover types had a larger MYNDVI value of 0.30 (Table 3), as the vegetation of dunes had a smaller MYNDVI value than vegetation in other land types. In addition, we can find poor vegetation tends to be located in shifting sand dunes while better vegetation appears in fixed and semi-fixed sand dunes.

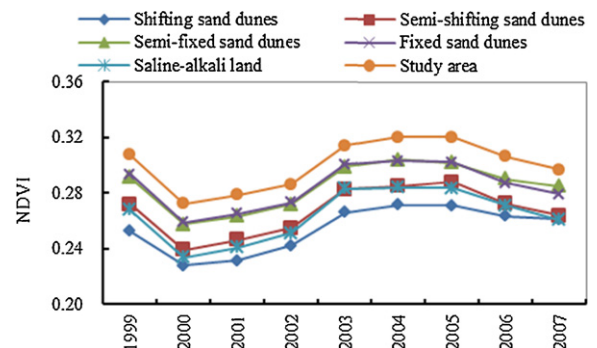
### 3.2. Spatial and temporal changes of the vegetation in different sandy types

#### 3.2.1. Inter-annual variation of the vegetation of different sand dunes

The interannual variation of YMNDVI in different sand dunes from 1999 to 2007 is shown in Fig. 3. The sand dunes had

similar variability, specifically, the YMNDVI values decreased in 2000, increased from 2001 to 2004/2005, and then decreased once again from 2005 to 2007. There were almost equal intervals among the curves of various dunes in different years. The YMNDVI values for the whole study area included that in not only sand dunes but also other land cover regions and thus showed the highest values in the five curves in Fig. 3. Shifting sand dunes showed the lowest YMNDVI values of all the curves.

Fixed sand dunes and semi-fixed dunes had overlapping YMNDVI curves, but fixed sand dunes decreased more in 2006 and



**Fig. 3.** The inter-annual vegetation variations of different sand dunes.

2007. The shifting sand dunes did not decrease in 2007 but all other types did.

### 3.2.2. Vegetation restoration effectiveness of different sand dunes

YMNDVI trend analysis over a banner scale can reflect the overall vegetation changes for one specific administrative region; however, some details in small-scale areas may be ignored. In view of this, the spatial differences of the vegetation trend of different sand dune types over nine years can be reflected in the spatial GRC raster. Figs. 4 and 5 show the spatial distributions of vegetation cover trends and their significance levels from 1999 to 2007, respectively.

#### (1) Vegetation restoration in the shifting sand dunes

The shifting sand dunes are mainly distributed in southern Tongliao (Fig. 4a), especially in the central portion of Naiman Banner, and are scattered in Hure Banner and Horqin Left Back Banner. The area that showed improvement over the study period covered more than 90% of the total area of shifting sand dunes (Table 4), especially in the central part of Naiman Banner, where vegetation cover improved significantly (Fig. 5a).

#### (2) Vegetation restoration in the semi-shifting sand dunes

Semi-shifting sand dunes had the smallest area of all sand dune types. It was scattered over the study area (Fig. 4b). More than 75% of vegetation in the semi-shifting sand dunes significantly improved into better condition, and a small degree of vegetation degradation occurred dispersedly in the northern region and was not significant.

#### (3) Vegetation restoration in the semi-fixed sand dunes

The semi-fixed sand dunes are an important component type in Tongliao, and are widely distributed in the study area (Fig. 4c). The vegetation in the central and southern semi-fixed sand dunes gradually improved and the improvement trend was evident (Fig. 5c), accounting for 80% of the area of the semi-fixed dunes (Table 4).

However, the southeastern part of Jarud Banner and the western part of Horqin Left Middle Banner had an insignificant trend of degradation; the area of moderate degradation and mild degradation accounted for 0.49% and 2.32% of the total sand dune area, respectively (Table 4).

#### (4) Vegetation restoration in the fixed sand dunes

The area of the fixed sand dunes is the largest among all dune types, and is widely distributed in the central and southern parts of study area. It was more concentrated in the central part, and showed a dispersed distribution in the southern part (Fig. 4d). In addition, the spatial distribution of its vegetation change trend was similar to the semi-fixed sand dunes with some minor differences. The area of vegetation degradation of the fixed sand dunes was larger than that of semi-fixed sand dunes; furthermore, the moderate degradation located in the central and southern Horqin Left Middle Banner was more significant.

The vegetation degradation area of the fixed sand dunes was the largest among all dunes, accounting for more than 16% of the fixed dune area and 5.82% of total area. The percentages of moderate degradation and mild degradation in fixed sand dunes were 1.15% and 4.67% of total sand dune area, respectively (Table 4).

#### (5) Vegetation restoration in the saline-alkali land

The saline-alkali land area is the smallest of all sand dune types and is mainly scattered in the middle and eastern parts of the study area (Fig. 4e). In most saline-alkali lands, vegetation improved, but light degradation occurred in the northern region, accounting for 7.14% of saline-alkali land. In

addition, 1.02% of the saline-alkali land was moderately degraded (Table 4).

#### (6) Vegetation restoration for all sand dune lands

Overall, vegetation cover for sand dunes improved, accounting for more than 76% of the sand dune area. This improved area was mainly distributed in the southern parts of study area (Fig. 4f). The vegetation improved significantly in Naiman Banner, Hure Banner and the southern part of Horqin Left Back Banner. Mild improvement occurred in the central part of study area but was not significant (Fig. 5f).

## 4. Discussion

### 4.1. Comparison of the effectiveness of restoration projects among different sand types

The results of this vegetation restoration analysis demonstrated that improvement occurred throughout almost the entire study area. However, the effectiveness of ecological restoration projects for different dune types varied. The vegetation trends of different sand types are shown in Fig. 6.

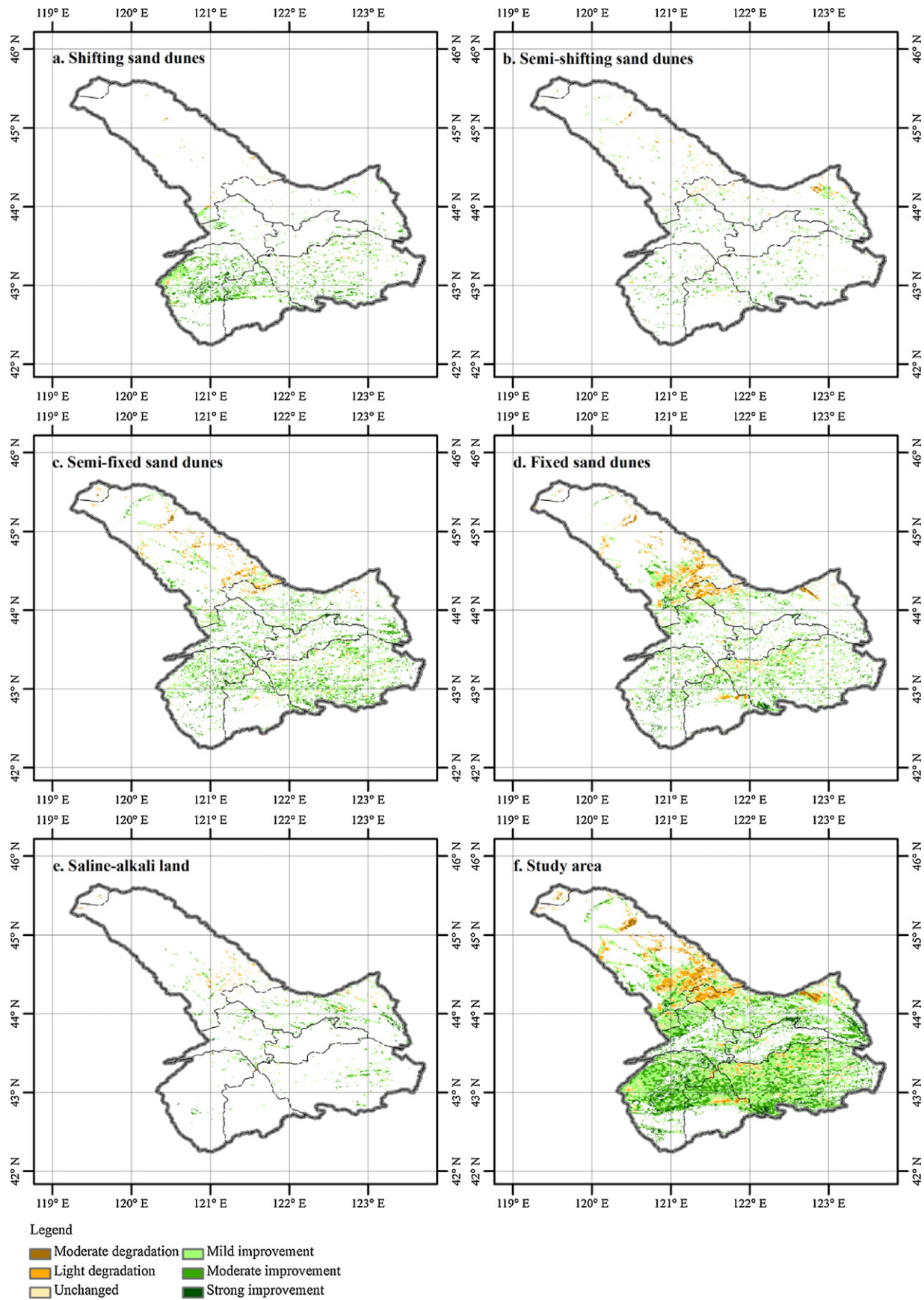
By comparing the vegetation response of different dunes, we find that the treatment and restoration of the shifting dunes were most effective. Of the total area of shifting dunes, 47.38% showed moderate improvement (Table 4). This improvement may be in part due to restoration projects that planted sand scrubs on shifting dunes. Previous studies showed that sand scrubs can decrease soil degradation and improve soil effectively by reducing wind speed and improving regional climate in shifting sand dunes regions (Okin et al., 2001; Zhao et al., 2007). Semi-shifting and semi-fixed dunes also demonstrated obvious improvement. 39.06% and 33.91% of semi-shifting sand area were respectively in the mild and moderate improvement levels (Table 4), which covered almost 70% of the semi-shifting dune area. The semi-fixed sand dunes showed mild and moderate improvement as well; there were respectively 41.04% and 35.06% of areas in mild and moderate improvement levels. However, the fixed dunes showed no obvious improvement, and more than 33% of area was degraded or unchanged.

The mean GRC in shifting dunes was 0.004, while 0.003 in semi-shifting dunes, 0.003 in semi-fixed dunes and 0.002 in fixed dunes. This indicates that along with the increase of dune fixity, the vegetation shows a decreased response to restoration efforts. Ecological restoration projects were potentially the main driving factors for the vegetation improvement. Overgrazing was likely to be the main factor contributing to new degradation in sand dune regions, according to a 5-year grazing experiment in the Horqin region (Zhao et al., 2004).

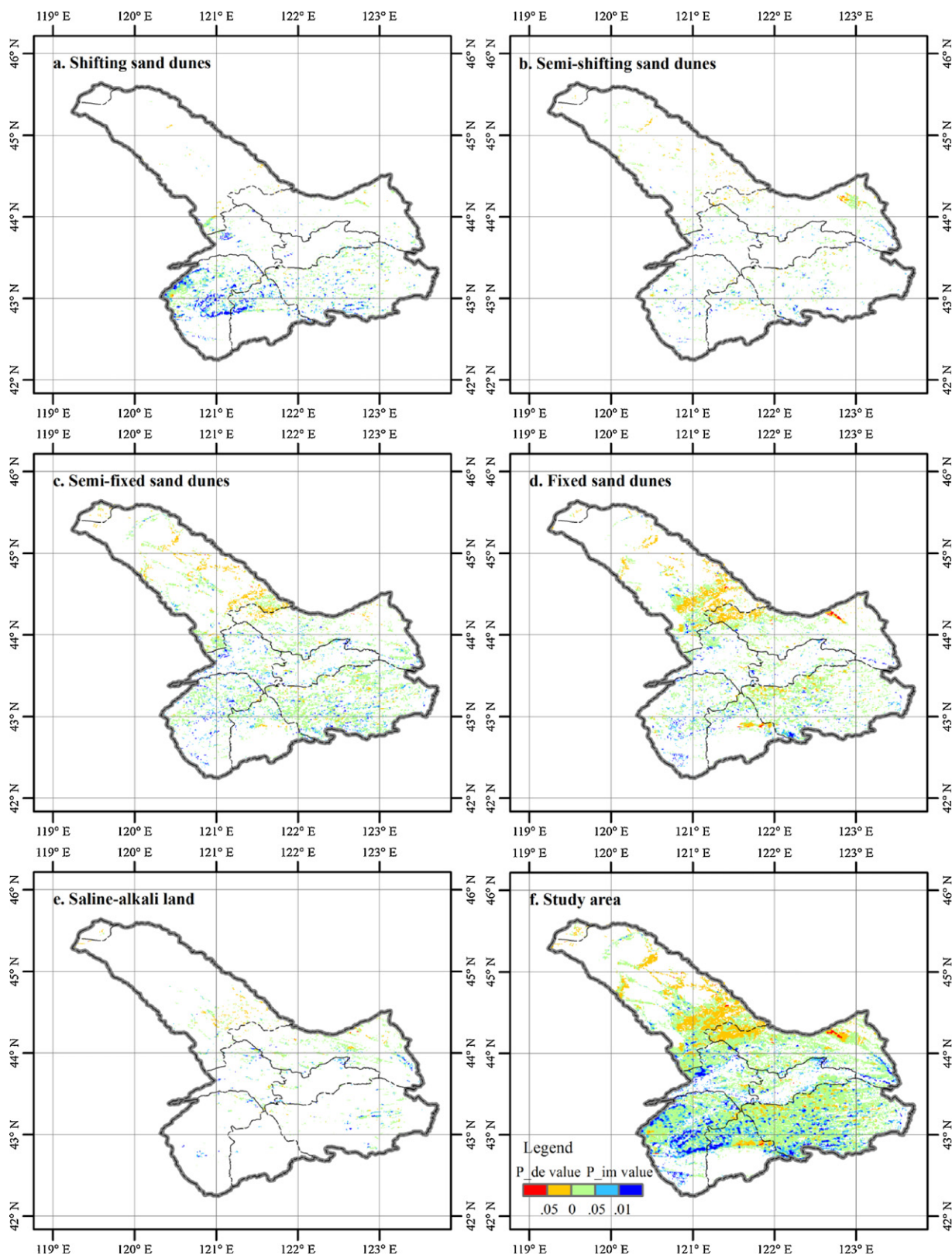
We can deduce that the ecological restoration projects emphasized shifting sand dunes more than fixed dunes, and overgrazing was avoided there. Furthermore, there could be fewer restoration treatments for fixed dunes due to its better original conditions.

### 4.2. Challenges of ecological restoration projects

The results show that generally the restoration projects reduced degradation in Tongliao. As for the desertification of Horqin Sandy Land, previous studies mainly focused on spatial and temporal dynamics of desertification (Han et al., 2009; Bagan et al., 2010); comparison of measurements (Zhang et al., 2004; Hao et al., 2005a,b); the drivers of land use change and desertification (Wang et al., 2004; Tang et al., 2008) and policy implications (Shen et al., 2006; Zeng and Jiang, 2006; Zhao et al., 2006b). Qu et al. (2009) pointed out that the conversion of cropland into forest or grass had significant ecological effects. The biological diversity and



**Fig. 4.** Spatial distribution of the change trend of annual average NDVI in different sandy land types of Tongliao from 1999 to 2007. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

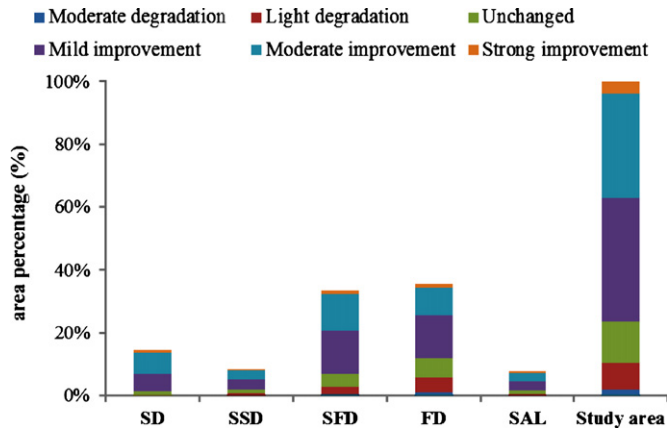


**Fig. 5.** Spatial distribution of significance levels of annual average NDVI change trend in different sandy land types of Tongliao from 1999 to 2007. *P.de* value means *P* value of vegetation degradation, and *P.im* value means *P* value of vegetation improvement. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

**Table 4**

Area statistics of different ecological restoration levels in different sand types (%). A is the percentages in this type of sandy land; B is the percentages in the total sandy land area.

	Shifting sand dunes		Semi-shifting sand dunes		Semi-fixed sand dunes		Fixed sand dunes		Saline-alkali Land		All sand dunes	
	A	B	A	B	A	B	A	B	A	B	A	B
Moderate degradation	0.32	0.05	1.83	0.16	1.48	0.49	3.22	1.15	1.02	0.08	1.92	1.92
Light degradation	1.63	0.24	7.10	0.60	6.95	2.32	13.08	4.67	7.14	0.56	8.39	8.39
Unchanged	6.73	0.98	14.01	1.19	12.30	4.11	16.89	6.03	11.78	0.92	13.23	13.23
Mild improvement	38.43	5.61	39.06	3.32	41.04	13.72	38.40	13.71	39.10	3.04	39.40	39.40
Moderate improvement	47.38	6.92	33.91	2.88	35.06	11.72	24.92	8.90	35.15	2.73	33.15	33.15
Strong improvement	5.52	0.81	4.09	0.35	3.18	1.06	3.49	1.25	5.79	0.45	3.91	3.91
Sum	100.00	14.60	100.00	8.51	100.00	33.43	100.00	35.70	100.00	7.77	100.00	100.00



**Fig. 6.** Area compositions of vegetation change situations for different dune types. SD, SSD, SFD, FD, and SAL respectively means shifting sand dunes, semi-shifting sand dunes, semi-fixed sand dunes, fixed sand dunes, saline-alkali land, and the entire study area. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

ecosystem stability improved. The habitats of many species also improved due to the ecological restoration projects (Xiao and Yan, 2009).

This study found that degradation happened in the southeast part of Jarud Banner and the western part of Horqin Left Middle Banner, which could be related to the land reclamation in that region (Wang and Tian, 2010), although land reclamation was

forbidden by law. In addition, the standard deviation and coefficients of variation of YMNDVI were high in these regions (Fig. 7).

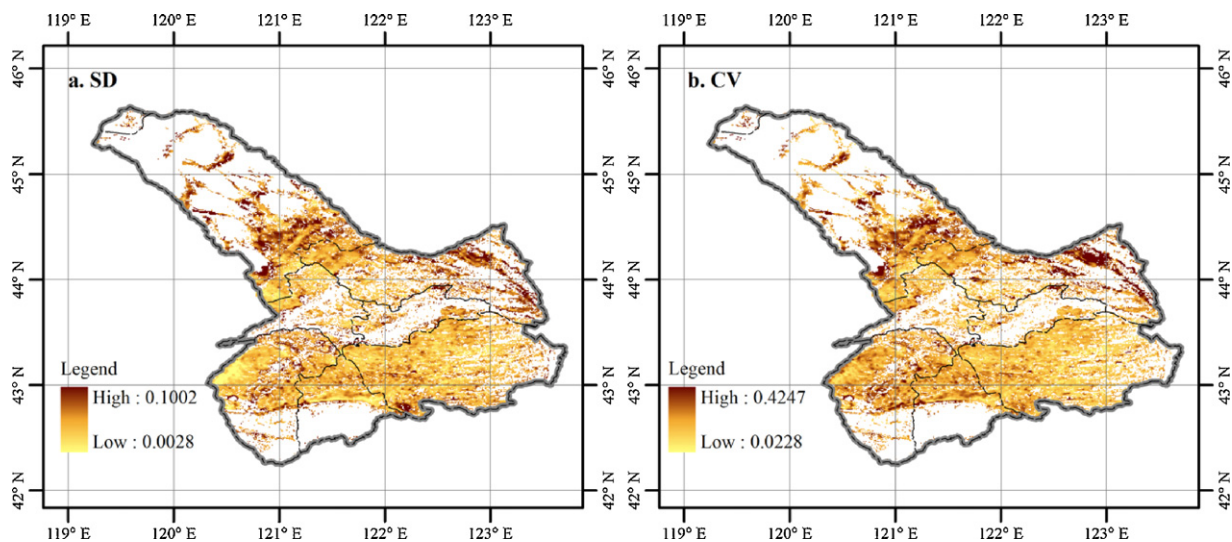
#### 4.3. Implications for ecological restoration projects

Our study revealed that the dunes with higher fixity show the least improvement in response to restoration projects. Restoration projects should concern more about revegetating fixed dunes. Furthermore, our study implies that continuous treatments are necessary for sustainable and permanent improvement. This is necessary for the sustainability of ecological restoration projects.

Ecological restoration is a comprehensive issue with many mechanisms and these vegetation restoration mechanisms need consideration for successful project management. To prevent land degradation the grazing intensity must stay at a reasonable level by considering its self-repairing mechanism (Zhao et al., 2006a).

#### 4.4. Possible effects of climate change and land use change

Climate change may be another important factor in ecological restoration, the variation of annual mean temperature and precipitation (the data was acquired by means of averaging the seven meteorological stations in Tongliao) is shown in Fig. 8. We can find that there was a significant change in both temperature and precipitation. Precipitation was perhaps an important factor in vegetation change, the correlation coefficients between YMNDVI and annual precipitation were higher than that between YMNDVI and annual average temperature (Table 5). However the precipitation variation characteristics from several stations were similar, also, it was



**Fig. 7.** Standard deviation (a) and coefficients of variation (b) of annual average NDVI in sandy land of Tongliao from 1999 to 2007. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

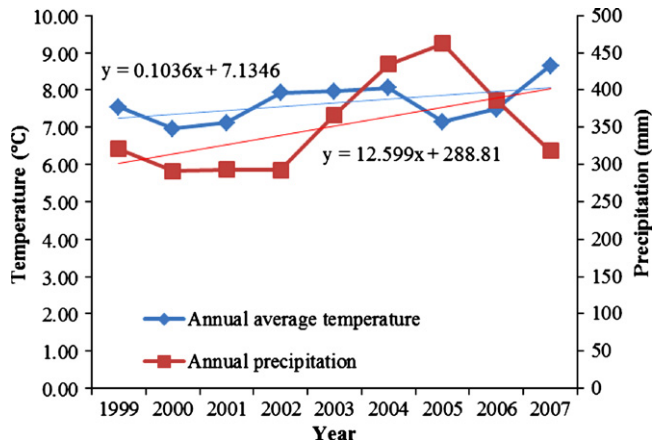


Fig. 8. The interannual variations of annual mean temperature and precipitation in study area during 1999 and 2007.

Table 5

The correlation coefficients between YMNDVI and annual average temperature, and between YNDVI and annual precipitation.

	Annual mean temperature	Annual precipitation
Shifting sand dunes	0.478	0.845
Semi-shifting sand dunes	0.314	0.869
Semi-fixed sand dunes	0.386	0.842
Fixed sand dunes	0.296	0.834
Saline-alkali land	0.353	0.853
Study area	0.314	0.867

difficult to distinguish its effects in the crossing distribution region of different sand dunes. Therefore, this paper mainly focused on human contribution to ecological restoration, and a quantitative analysis about effects from climate change will be further considered in future studies to reduce the uncertainty in assessing ecological restoration effectiveness.

The sand dune category (e.g. fixed dune, shifting dune) in this study did not change during the study period of 1999–2007. This was a reasonable assumption, as some studies showed little changes in sand dune types (Han et al., 2009). The whole magnitude of deserted land decreased slightly from 22,423.1 km<sup>2</sup> in 2000 to 22,422.4 km<sup>2</sup> in 2005 with a decrease rate of more than 0.1 km<sup>2</sup> per year (Han et al., 2009).

## 5. Conclusions

This paper assessed the effectiveness of ecological restoration projects by means of vegetation cover change; the responses of different dunes types were explored. The results of this analysis provide decision-making support for future project implementation.

The results demonstrated that the ecological restoration effectiveness was significant in Horqin Sand Land; the overall vegetation cover improved in the study area. The treatment effectiveness varied depending on the category of sand dune to which it was applied, and was more effective in increasing order for: fixed, semi-fixed, semi-shifting, and shifting sand dunes.

This paper provided a preliminary assessment method to evaluate the effectiveness of ecological restoration projects. However, the factors affecting ecological restoration are complicated and may include climate change, human population, and grazing mode. Therefore, a comprehensive evaluation including all factors should be studied in future work.

## Acknowledgements

This study was supported by a research grant from the Open Project Program of Key Laboratory of Resources Remote Sensing and Digital Agriculture, Ministry of Agriculture (RDA0903), and the NASA Earth Observing System (EOS) Data Analysis Program (NNX09AE93G).

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