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Monitoring and analysis of grassland desertification dynamics using Landsat images in Ningxia, China

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ABSTRACT

State and local governments in China have implemented a series of grassland protection policies to address the problem of grassland degradation. In 2003, Ningxia was the first province to implement a province-wide grazing ban. The effect of this ban is contentious at all levels of government and has become a topic of public concern. Grassland desertification is the most direct indicator of the effect of the grazing ban. We selected 14 counties and cities in north-central Ningxia as the study area. A desertification classification and grading system for Ningxia's grassland was then designed based on fieldwork and expert review. Using the Spectral Mixture Analysis (SMA) and decision-tree methods, we interpreted Landsat TM/ETM+ images of the study area during four years: 1993, 2000, 2006 and 2011. The following results were obtained: from 1993 to 2011, the area of desertified grassland in north-central Ningxia decreased gradually from 8702 km^2 in 1993 to 7485 km^2 in 2011, a decrease of 13.98%; the degree of desertification gradually decreased from 3573 km^2 of severely desertified grassland in 1993 to 1450 km^2 in 2011, a decrease of 59.41%; desertified grassland vegetation was restored rapidly during 2000–2006 and 2006–2011, reducing the total area of desertified grassland annually by 1.87 and 0.61%, respectively; finally, the area of severely desertified grassland decreased annually by 5.78 and 6.28% during 2000–2006 and 2006–2011, respectively. These results show that the region-wide grazing ban, together with other ecological engineering measures, has helped reverse desertification and promote the restoration of grassland vegetation.

1. Introduction

Grassland desertification, the primary form of grassland degradation, is defined as the degradation of grasslands in arid, semi-arid and dry sub-humid areas. Non-desert grasslands in these areas typically include aeolian sand, similar to desert landscapes, and desertified grasslands (DGs) are grasslands where the action of sand is further exacerbated due to climate variation and/or human activity. China has nearly 400 million ha of natural grasslands, representing 41.7% of its territory. However, 90% of China's available natural grasslands exhibit varying degrees of degradation, half of which is manifested as reduced vegetative coverage, desertification, salinization, and other characteristics of moderate or severe degradation (Development Planning Department of Agriculture, 2002). In the face of increasingly serious grassland desertification, accurate, timely and effective monitoring of grassland desertification is essential to understanding the grassland desertification process and to establishing early warning measures for the prevention of desertification (Reynolds et al., 2007). Because a field measurement is expensive, labor-intensive and often limited with regard to its temporal and spatial scale, remote-sensing data (which yield multi-temporal data covering a wide spatial extent that are periodically repeated) allow for the monitoring of changes in grassland desertification (Rogan, Franklin, & Roberts, 2002; Yang & Liu, 2005).

The Ningxia Hui Autonomous Region, which has a total area of 51,800 km^2, is located primarily in arid and semi-arid zones and is surrounded by the Tengger Desert, the Ulan Buh Desert and the Mu Us Sandland in the west, north and east, respectively. This region is also one of the most desertified provinces in China. Some studies have indicated that the desertified area in Ningxia has been significantly reduced due to the implementation of the Three-North Shelterbelt Forest Program, the Grain for Green Project and the region-wide grazing ban, among other ecological engineering measures. These measures were implemented over the last few years after Ningxia was chosen as a sand prevention and control demonstration region. These studies also indicate that the desertification process has been reversed, showing that the sand prevention and control work has achieved significant results (Huang et al., 2011; Yan, Wang, Feng, & Wang, 2003; Yang,

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Wu, & Shen, 2013). However, other studies have indicated that the harsh natural environment and underdeveloped economic conditions in Ningxia have caused the ecology of the sandy area to become extremely fragile. The trend of desertification, officially described as “overall reversal but partial deterioration,” still exists. Further development of the anti-desertification work and stabilization of the desertification reversal zone, among other measures, remain necessary (Yu, Wang, Jiang, Ren, & Li, 2011). Currently, little monitoring of Ningxia's desertification is conducted. Most of the monitoring consists of ground-survey methods, which are time-consuming and limited in their assessment of the overall spatial distribution and trend of desertification in Ningxia; other monitoring efforts involve the visual interpretation of remote-sensing images to determine the extent of Ningxia's desertification (Jia & Zhang, 2011), a process that is more subjective.

In the present study, we selected 14 counties and cities in the north-central part of Ningxia as the study area. A Ningxia grassland desertification classification and grading system was constructed based on Landsat TM/ETM+ remote-sensing images, field observations and expert review, and remote-sensing interpretation symbols representing different grassland desertification levels were established. Spectral Mixture Analysis (SMA) and decision-tree methods were then selected to interpret the data from the four periods (1993, 2000, 2006 and 2011).

2. Materials and methods

2.1. Study area

The Ningxia Hui Autonomous Region is located at 104°17′E–107°39′E, 35°14′N–39°23′N along the upper reaches of the Yellow River. The region is approximately 456 km long from north to south and 250 km wide from east to west. The entire territory from north to south is divided into six geomorphic regions: the Helan Mountains, the Yinchuan Plain, the Lingyan Mesa, the mountainous region and inter-mountainous plain, the loess hills and the Liupanshan mountains. The annual precipitation in the region ranges from 180 to 350 mm, the annual evaporation ranges from 2100 to 2300 mm, and the region has an aridity of 3.3 to 4.7 (Guo, Xin, & Cao, 1995).

The study area, located in north-central Ningxia, includes 14 administrative counties and cities (Fig. 1), which cover 67.5% of the total area of Ningxia. The study area includes the following three main desert zones: the Mu Us sandy land area, the Tengger sandy area and the Yellow River Plain sandy irrigation area.

2.2. Data acquisition and pre-processing

Landsat TM/ETM+ scenes obtained in 1993, 2000 and 2006 were selected because they have similar precipitation and high data quality. The TM images acquired in 2011 were selected to interpret the recent grassland desertification status, whereas the former three years were used to analyze the effect before and after the implementation of the region-wide grazing ban in 2003. These time-series Landsat images, with a spatial resolution of 30 m, were obtained during summer and autumn (July–August), when vegetation typically reaches its maximum growth during the region's growing season. The images were downloaded from the United States Geological Survey (USGS) (http://glovis.usgs.gov) at no cost or were purchased from the Center for Earth Observation and Digital Earth (CEODE) at the Chinese Academy of Sciences. In addition, we purchased one Spot-5 HRVIR image (September 13, 2011) with spatial resolutions of 2.5 m (panchromatic band) and 10 m (multi-spectral band) covering the central part of the study area, which aided in the establishment of Landsat TM/ETM+ interpretation keys. Geometric correction (to reduce the error to less than 0.5 pixels), atmospheric correction and other image processing were performed for the 12-scene Landsat TM/ETM+ images. Ortho-rectification, geometric correction, true-color conversion and band fusion (positioning accuracy after fusion at 5 m) were performed for the Spot-5 HRVIR images.

The basic study-area data, including the annual land-use map, the meteorological data (rainfall, temperature, etc.), the grassland-type map and the soil-type map, were collected and collated.

2.3. Grassland desertification evaluation system and indicators

In the 1980s, the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP) developed a provisional methodology for the assessment and mapping of desertification. The methodology consists of 22 indicators, many of which can only be obtained from field measurements, which are difficult to obtain, and from a wide range of monitoring techniques that are even more difficult (Symeonakis & Drake, 2004). Formulating a system of universal grassland desertification monitoring indicators is a challenging task (Sommer et al., 2011) due to the regional differences in the type of grassland desertification, the evaluation criteria and the conceptual understanding of grassland desertification. However, because grassland desertification monitoring is based on specific aspects of the study area, the interpretation of grassland desertification indicators is simplified as

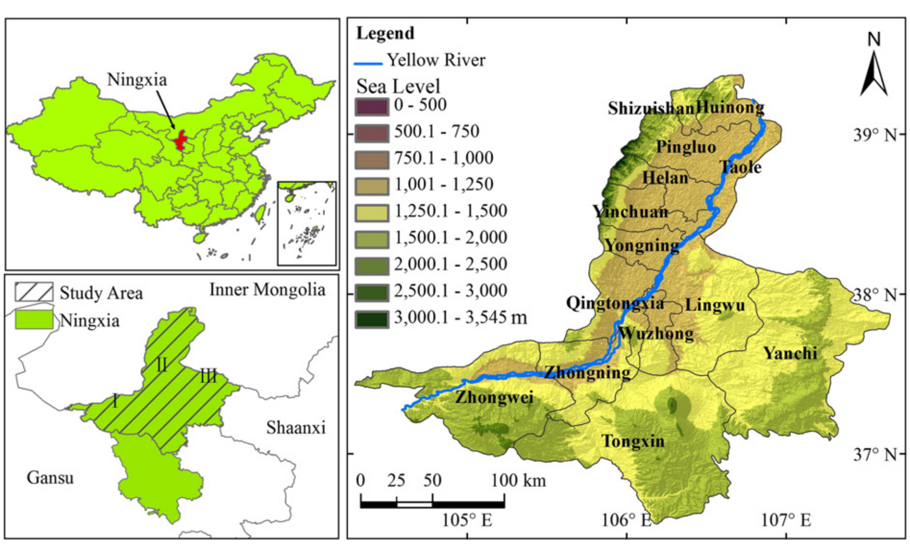

Fig. 1. Location of the Ningxia Hui Autonomous Region and the study area. I is the Tengger sandy area, II is the Yellow River Plain sandy irrigation area, and III is the Mu Us sandy land area.