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Characterization of land cover types in Xilin River Basin using multi-temporal Landsat images

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This study conducted computer-aided image analysis of land use and land cover in Xilin River Basin, Inner Mongolia, using 4 sets of Landsat TM/ETM+ images acquired on July 31, 1987, August 11, 1991, September 27, 1997 and May 23, 2000, respectively. Primarily, 17 sub-class land cover types were recognized, including nine grassland types at community level: F. sibiricum steppe, S. baicalensis steppe, A. chinensis + forbs steppe, A. chinensis + bunchgrass steppe, A. chinensis + Ar. frigida steppe, S. grandis + A. chinensis steppe, S. grandis + bunchgrass steppe, S. krylavii steppe, Ar. frigida steppe and eight non-grassland types: active cropland, harvested cropland, urban area, wetland, desertified land, saline and alkaline land, cloud, water body + cloud shadow. To eliminate the classification error existing among different sub-types of the same gross type, the 17 sub-class land cover types were grouped into five gross types: meadow grassland, temperate grassland, desert grassland, cropland and non-grassland. The overall classification accuracy of the five land cover types was 81.0% for 1987, 81.7% for 1991, 80.1% for 1997 and 78.2% for 2000.

Characterization of land cover types in Xilin River Basin using multi-temporal Landsat images CHEN Siqing1, LIU Jiyuan2, ZHUANG Dafang2, XIAO Xiangming2, 3 (1. Inst. of Remote Sensing Applications, CAS, Beijing 100101, China; 2. Inst. of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China; 3. Inst. for the Study of Earth, Oceans and Space, Univ. of New Hampshire, Durham, NH 03824, USA) 1 Introduction The growing concern over the impact of changes in land use and land cover on environmental conditions and the increasing human impact on the natural resources has captured worldwide attention of the political and scientific community (Ojima et al., 1991; Smith et al., 2001). It is expected that the changing land use/land cover pattern will be one of the driving forces of environmental changes superimposed on the natural changes at regional scale (Fu et al., 1993; Bonan, 1995). Arid and semi-arid lands at mid-latitudes of Northern Hemisphere are very sensitive to change in physical environment and land use. In Xilin River Basin, Inner Mongolia, which is right located at the mid-latitudes of Northern Hemisphere, grassland degradation and desertification have increased rapidly due to overgrazing and inappropriate crop cultivation under growing population pressure. To maintain the ecological balance and make sustainable use of the grassland resource, current information on land cover is in urgent need for both rangeland management and research on land use/land cover monitoring, biodiversity protection, global climate change and land surface-atmosphere interactions (IGBP, 1992; Brown et al., 1993; Townshend et al., 1991). Satellite remote sensing and geographical information systems (GIS) have been widely used in mapping grassland resources in arid and semi-arid regions of the world (Franklin, 1991; Khrustskiy et al., 1990; Vogelmann et al., 1998). Application of remote sensing to studies of Inner Mongolia grassland resources began in 1983. Vegetation, soil and land use types and spatial distribution patterns were visually interpreted based on Landsat MSS imageries at a scale of 1: 350,000 in combination with an extensive field survey (Inner Mongolia Grassland Resource Survey, 1987a; 1987b). A vegetation map (1:500,000) of Xilin River Basin was also generated (Li et al., 1988). The diverse and well-preserved grassland ecosystems in the Xilin River Basin basically represent all grassland types in Inner Mongolia area (Li et al., 1988). 2 Study area, material and method 2.1 Study area The Xilin River Basin is located in the eastern part of the Inner Mongolia Plateau (within latitudes of 43o26´N-44o39´N and longitudes of 115o32´E-117o12´E). The eastern boundary is demarcated by the low mountains and hills of the Da Hinggan Mountains, with height decreasing gradually from east (the highest elevation 1505.6 m) to west (the lowest elevation 902.0 m). The whole Xilin River Basin area falls within Landsat TM/ETM+ scenes WRS124-29, WRS124-30 (Figure 1). The Xilin River

Basin is dominated by continental moderate temperate semi-arid climate, where it is cold and dry in winter but warm and wet in summer (Chen, 1988). Annual precipitation varies from 400 mm in the east to 275 mm in the west; more than 70% of the annual precipitation occurs during May to August (Chen, 1988). The annual mean temperature and annual mean precipitation in the period of 1978-1998 were 0.4oC and 366.3 mm, respectively (Figure 2), while those in the 1950s-1960s were -0.4oC and 358.4 mm (Chen, 1988). Grass plants turn green at the end of April and senescence in early October. Plant growing season is from April to September, lasting about 150 days (Jiang, 1985). Dominant soil types are chernozem in the east, dark chestnut in the middle and light chestnut in the northwest of the Xilin River Basin (Wang et al., 1988). Main grassland vegetation includes three types: meadow grassland, typical grassland and desert grassland (Table 1), which can be divided into nine dominant grassland communities (Table 2). Wetland vegetation is well developed along the Xilin River, dominated by Ar. laciniata, Sanguisorba officinalis, Calamagrostis epigeios and Ac. splendens. Some 183 flowering species were recorded in wetland vegetation (Li et al., 1988). Within the sand area north of the Xilin River, there are small areas of Picea meyeri forests and Betula platyphylla + Populus davidiana deciduous forests, Ulmus pumila open forest, shrubs and meadow steppe (Li et al., 1988). 2.2 Landsat TM/ETM+ imagery and ancillary data Four sets of Landsat TM/ETM+ images acquired on July 31, 1987, August 11, 1991, September 27, 1997 and May 23, 2000, respectively (each set contains two half-scene images: the lower half of WRS124-29 and the upper half of WRS124-30) were analyzed by applying digital image processing techniques to the 6 visible/near-infrared bands. Image-to-image registration (MGE/Image Analyst Package) was conducted using "nearest neighbor" resampling procedure. The total standard error was less than 0.5 pixel (15 m). ERDAS/Imagine package was then used to mosaic the two registered images into a one-scene image, which was then clipped into a 5,000 pixels (column) × 4,800 pixels (row) image after deleting the areas that had many clouds or were extraneous to this study. It covers an area of 21,600 km2, including the whole Xilin River Basin (Figure 3). Atmospheric correction of the whole image was done by simple dark object subtraction. After the data preparation process, the image was ready for land use/land cover classification. The source data of 6 visible/near infrared bands (bands 1, 2, 3, 4, 5 and 7) were used for data analysis, and band 6, the thermal infrared band, had lower spatial resolution. Ancillary data include a vegetation map of the Baiyinxile Livestock Farm (1:100,000), a soil map of the Xilin River Basin (1:300,000), topography maps, field biomass sampling data, field pictures taken with a GPS recording the latitude and longitude of the sample sites and literature. Abundant data have been accumulated on the spatial distribution of plants, vegetation, soil, land use and wildlife of the Xilin River Basin. 2.3 Methods Based on the main characteristics of the grassland vegetation in the Xilin River Basin, the following classification system (information classes or land cover types) was established before the images were classified (Table 3). Taking the image of 1987 as an example, 48 spectral classes were generated with an unsupervised classification procedure ISODATA (ERDAS/Imagine 8.4 package), using the six atmospherically-corrected bands as input. However, roads, cropland and wetland were not separated out as unique spectral classes. Thus, supervised training was used to define training samples of fallow cropland (class 49), cropland with crops (class 50), wetland (class 51), abandoned croplands (class 52) and roads (class 53). The five supervised training samples and 48 unsupervised signatures were combined together, and the whole image was classified again, using the maximum likelihood classification procedure (ERDAS/Imagine 8.4 package). Images of 1991, 1997 and 2000 were also classified following the same procedure. 3 Results 3.1 Land cover classification Using the ancillary data as reference, visual interpretation of land cover image of 1987 was done through image display of various band combinations. (e.g. 5-4-1 combination, 5-4-3 combination, 7-4-3 combination, 4-3-2 combination). The bands 5-4-1, 5-4-3 and 7-4-3 composites were much better than the band 5-4-3 composite in separating various land cover types of the Xilin River Basin. Based on spatial correspondence of spectral classes and information classes, the relationships between spectral classes and information classes (land cover types) were determined (Table 4). Roads (class 53) were not taken as a unique class, but assigned to several classes. This is possible as roads in the study area were usually not over 10 m wide, thus vegetation along roads might contribute more to spectral values. Abandoned croplands (class 52) were also not classified as a unique class, but mostly assigned into the category of A. chinensis + Ar. frigid steppe. In abandoned croplands, dominant plants were Ar. frigida and weeds initially, but A. chinensis increased after several years of recovery. Dense forests and open forests were not separated out because their areas were so small that they were not able to form a distinct spectral class, but fell within the edge of different meadow steppes (Figure 4a). Similarly, land cover of 1991, 1997 and 2000 were also interpreted (Figures 4b, 4c and 4d). 3.2 Classification accuracy analysis To make the time series land cover classification data applicable for later land use/land cover change analysis, the cloud, water body and cloud shadow features were extracted from each of the master land cover maps and overlaid as a subset map. Then the area corresponding to the subset in each land cover classification map was eliminated. After this procedure, each of the final land cover classifi

cation map of the Xilin River Basin contained 14 identical classes: F. sibiricum steppe, S. baicalensis steppe, A. chinensis + bunchgrass steppe, A. chinensis + forbs steppe, A. chinensis + Ar. Frigida steppe, S. grandis + A. chinensis steppe, S. grandis + bunchgrass steppe, S. krylavii steppe, Ar. Frigida steppe, cropland, urban and residential area, wetlands, desertified land and saline and alkaline land. In this way, all the land cover classification maps were optimized and were ready for land use /land cover change detection and classification accuracy analysis. Taking the classification map of 1987 as an example, the classification accuracy matrix was generated by comparing pixels in land cover map with randomly selected reference sites from ancillary data (Table 5). Table 5 indicates that the classification accuracy of most of the land cover classes was below 70%, some even below 50%. S. grandis + A. chinensis steppe (class 24) had the lowest classification accuracy, which could be possibly ascribed to its spatial distribution pattern. S. grandis + A. chinensis steppe was generally distributed in the transition and mixed-up area between S. grandis steppe and A. chinensis steppe, and it was easily classified as both the former class and the latter class in the process of classification. However, the cropland (class 41) had the satisfactory classification accuracy, which was also the highest. This could be attributed to the cropland´s unique shape and sharp spectral contrast to the background area (Figure 5). The classification accuracy at grassland community level was greatly discounted because of the mix-up of grassland subtypes under one gross type, e.g. F. sibiricum steppe and S. baicalensis steppe were both meadow grassland subtypes, but they could be mixed up at the community level classification thus enhanced the classification error. The following process was used to improve classification accuracy: except for the cropland class, which already had good classification accuracy, all the other grassland subtypes under one gross type were grouped to one land cover class, e.g. F. sibiricum steppe and S. baicalensis steppe were grouped to "meadow grassland" class. In this way, the classification accuracy matrixes of 1987, 1991, 1997 and 2000 were generated again. Actually this method has greatly improved the classification accuracy. The overall accuracy of the five land cover types was 81.0% for 1987, 81.7% for 1991, 80.1% for 1997 and 78.2% for 2000 (Table 6). 4 Conclusions and discussion Based on Landsat TM/ETM+ imagery and ancillary data, grassland vegetation and land use types were successfully classified both at formation level (grassland ecosystem level) and at sub-formation (grassland community level) level, but the former has higher classification accuracy, since it eliminated the errors aroused by the mix-up of different sub-formations of one formation. This land use/land cover classification method is applicable to land use mapping only using the six bands of raw visible/near infrared reflectance of Landsat TM/ETM+ sensor. From the time series land cover classification maps, it is easy to notice that both the spatial extent of grassland degradation and fragmentation of grassland ecosystems in the Xilin River Basin have been increasing due to quickening human settlement and intensified livestock grazing. It is also obvious that the area of cropland, urban and residential area and desertified land has been increasing for the last two decades in the Xilin River Basin, Inner Mongolia. A detailed comparison of the four land use/land cover classification maps is needed to quantitatively address the land use/land cover changes in the Xilin River Basin over the past two decades. Land-use/land-cover change forms one of the most substantial aspects of global climate change and global carbon budget studies (Ciais et al., 1995; Bousquet et al., 2000). However, the land use/land cover classification work is the basis of any land use/land cover change analysis. Meanwhile, conservation of species and ecosystems of the Xilin River Basin requires better and updated information of land cover types. Therefore, it is necessary to conduct temporal analysis of Landsat TM/ETM+ images so that we will be able to monitor the dynamics of grassland resources, to assess changes in grazing patterns and to evaluate the grazing effect on natural grassland ecosystems. Computer-aided Landsat TM/ETM+ image analysis could extract information of grassland resources in a fast and efficient way, and it will not only fulfill the information requirements of governmental decision-making in sustainable use of grassland resources but also support the global climate change studies. Acknowledgement The authors thank the following people for their many contributions throughout the course of this study: Steve Boles, Michael Routhier, Stanley Glidden, Tim Carmell, and Qingyuan Zhang.

关键词： land-use/land cover classification; multi-temporal Landsat images; Xilin River Basin