Detection of Forest Free - South Slope Features from Land Cover Classification in Mongolia

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Abstract: Land cover types of Hustai National Park (HNP) in Mongolia, a hotspot area with rare species, were classified and their temporal changes were evaluated using Landsat MSS TM/ETM data between 1994 and 2000. Maximum likelihood classification analysis showed an overall accuracy of 88.0% and 85.0% for the 1994 and 2000 images, respectively. Kappa coefficients associated with the classification were resulted to 0.85 for 1994 and 0.82 for 2000 image. Land cover types revealed significant temporal changes in the classification maps between 1994 and 2000. The area has increased considerably by 166.5 km^2 for mountain steppe. By contrast, agricultural areas and degraded areas affected by human being activity were decreased by 46.1 km^2 and 194.8 km^2 over the six year span, respectively. These areas were replaced by mountain steppe area. Specifically, forest area was noticeably fragmented, accompanied by the decrease of ~400 ha. The forest area revealed a pattern with systematic gain and loss associated with the specific phenomenon called as 'forest free-south slope'. We discussed the potential environmental conditions responsible for the systematic pattern and addressed other biological impacts by outbreaks of forest pests and ungulates.

1. Introduction

Mongolia is one of the largest countries in the circumpolar boreal zone. It is located at the southernmost fringe of the Siberian taiga and the northernmost Central Asian deserts, including vast steppes. In 1992, Mt. Hustai was chosen as one of the most suitable areas for the reintroduction and establishment of a free-roaming population of Przewalski horses.

This paper aims to investigate spatial and temporal land cover changes in HNP and understand the possible causes of the changes. We suggested potential processes for the landscape changes in HNP from a forested area to shrub land or grassland. Environmental factors affecting the land cover changes such as ungulates, insects and human activities were also considered.

2. Study Area and Data

The study area, Hustai National Park (HNP) as indicated in Fig. 1, is located at the Daurian forest steppe eco-region, which is one of the undisturbed areas of the steppe ecosystem in temperate Eurasia. A Landsat 5 TM image taken in September 1994 and a Landsat 7 ETM+ image taken in September 2000 were utilized. we used SRTM DEM data with a resolution of approximately 90 meters from the USGS (United States Geological Survey). The other auxiliary data sets which include a soil, topographic, vegetation, and administration maps, as well as digital maps of HNP's core zone, were obtained from the HNP administration in Mongolia. Reference data sets were obtained over six years: 1995, 1996, 1998, 2003, and 2004 and used for

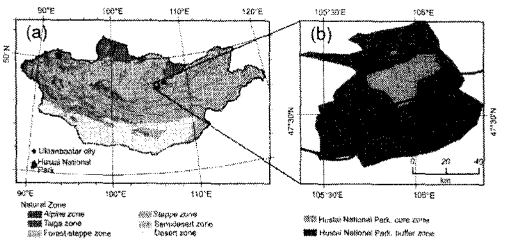

Fig. 1. Location of study area. (a) The distribution of natural zones in Mongolia, where HNP is located at the steppe zone in the central Mongolia and (b) the study area with the red and orange polygons stand for buffer zone and core zone, respectively.

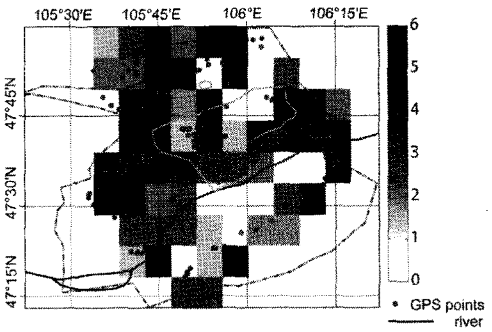

Fig. 2. Locations of ground truth points as training data sets during field surveys.A total of 520 plots with 1080 GPS points are displayed.

classifier training and accuracy assessment for this study (Fig. 2).

3. Methods

We used maximum-likelihood classifier (MLC) and DCCA. The present method for change detection (Jensen, 2000, van Oort, 2007) classifies adjusted images obtained at different times and then compares and analyzes these images using a change-detecting matrix for the construction of the final change map. The error matrix of changes was selected and analyzed for each map. The Kappa coefficient of accuracy equation used in this study is

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+}x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+}x_{+i})} \qquad (1)$$

4. Results

4.1 Classification of land cover type and change detection

Based on the classification scheme with an MLC classifier, we produced two classification maps of HNP. With appreciable accuracy, the HNP landscape was classified according to the eight land classes (Fig. 3). The number of classified pixels increased in the cases of mountain steppe (Ms), sand (Sd), river meadow (Mw) and water bodies (Rv), but decreased in the cases of shrubland (Sh), degraded area (Ds), forest (Fr) and agricultural(Ag) areas (Fig. 4). It is noteworthy that most of the maximum changes occurred in the mountain steppe area. During these six years, the mountain steppe area has increased by 166.5 km^2. In contrast, the degraded and agricultural areas have decreased by 194.8 km^2 and 46.1 km^2, respectively (Fig. 4).

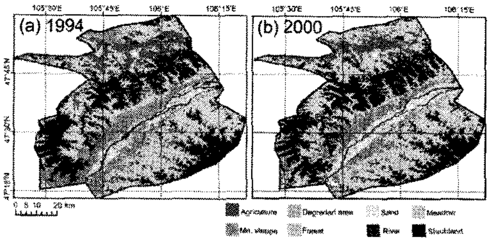

Fig. 3. Maps showing the distribution of the eight land classes in the study area: derived from (a) Landsat TM bands 1-5 and 7 in 1994 and derived from (b) Landsat ETM + bands 1-5 and 7 in 2000. Both images added to the SRTM DEM band for the supervised MLC classification process.

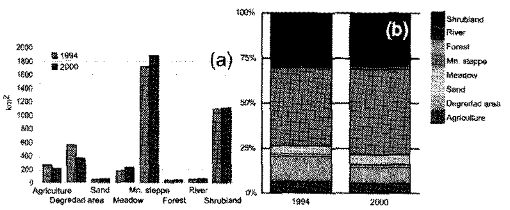

Fig. 4. Result of land classification, (a) histograms of land cover type areas in 1994 and 2000, and (b) their cumulative histogram by percentage.

4.2 Change Detection

Our result, from classification and change detection analysis, showed that the calculated area of agriculture decreased by 17.8% (or 46.1 km^2) from 1994 to 2000. Compared to the other land cover types, agricultural area (Ag) decreased most rapidly in HNP during the period from 1994 and 2000.Agricultural area underwent reduction every year since 1992 for social and economic reasons. Area that has been abandoned has increased continuously since then. This study shows clearly the series of incidents which led to this result.

Since the abandonment of land cover management, the cultivated area was covered over and dominated by various plant species. Some area was covered with species such as Artemisia macrocephala, A. scoparia, A. commutata, and A. pectinata. Some areas, where cultivation stopped earlier than this, were covered by the species; Agropyron repens, A. cristatum, Stipa Krylovii, Carex duriuscula, and Kochia prostrata. These fields are more similar to the natural background vegetation, namely the mountain steppe vegetation, in terms of plant species composition.

Our calculation of the forest area in the buffer zone reached 0.8% (~28.58 km^2) of the total area in 2000. This estimation is very close to the total area of the birch forest in HNP reported by the de Vries et al. (1996). In 2000, the forest area showed a decrease by 12% (~4 km^2) as compared with the forest area in 1994 as shown in Table 4. As the mentioned by Vries et al. (1996), birch forests were concentrated in two locations, especially occupying the north slopes of mountain upward from 1400 m with mountain steppes.

River and water area (Rv) covers 64.9

km^2. Except for quite a few mountain streams in the forested area of HNP valleys, there are no other surface water resources in the national park.

Meadow area (Mw) occurs along the Tuul River banks and the mountain valleys with streams (Fig. 3). The area of Mw was 218.2 km^2, covering 6.3% of HNP in 2000. Most classified pixel changes have occurred in the areas between meadow (Mw) and degraded areas(Ds). Degraded areas (Ds) were found along the Tuul River banks. This area was 360.5 km^2 in 2000, a considerable decrease of 35.1% as compared to 1994 (Fig. 5). Land degradation is thought to be caused by overgrazing of domestic livestock near surface water resources. During summertime, herders face a serious problem of limited water sources and all local herder families move and settle along the riverbanks. After the designation of HNP as a national park, several families moved out of the area. Also, the limited number of pasture land resources has forced herders to either reduce their livestock numbersor find other sites outside the national park. These circumstances led to the increase of Mw area from 1994 to 2000.

Shrubland area (Sh) covered 27.8% (1,111.50 km^2) of HNP. The shrub-dominated community (Betula fusca, Spiraea media, Caryopteris mongolica, Amygdalus pedunculata, Spiraea aquilegifolia) was found in a peaty valley. Shrubland area (Sh) mostly occurs at forest edges, rocky mountain ridges, and alpine vegetation sites. Over the six years, shrubland area (Sh) increased by 1.4%.

Sand dunes (Sd) are located in the northern part of HNP, with a total area of 56.5 km^2. Compared to 1996, the sand dune area has increased by 10.2%.

Mountain steppe (Ms) area is the main landscape type in HNP. The total area of Ms is 1,878.8 km^2, which is about 50% of the total area of HNP. Between 1996 and 2000, this area increased by 9.7%. The net contribution to mountain steppe came from degraded (Ds) and agricultural (Ag) areas (Fig. 5).

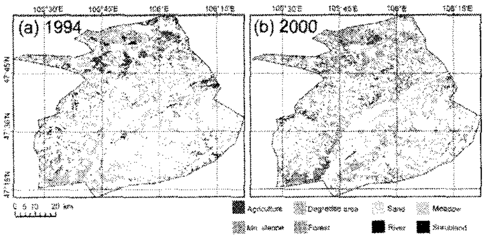

Fig. 5. "From-to"changes map, (a) changed area, (b) net contribution area and white areas indicating unchanged area (persistence).

4.3. Forest free-south slope features

The presence of mixed pixels is a major problem in the use of classification techniques for thematic mapping. Recent effort on representing the spatial distribution of classification quality has been direct at the visualization of classification uncertainty with maximum likelihood classification. Figure 6 shows change detection analysis of birch forest and sand dune area. The forest area shows the systematic pattern of gain and loss along its edge, which may be understood to be mis-registration errors as mentioned by Foody(2002). However, our detailed analysis and field surveys confirmed that the systematic pattern was resulted from not the misregistration errors but real

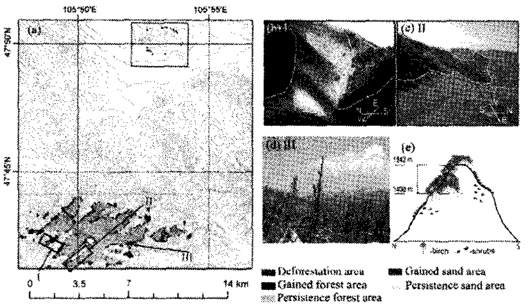

Fig. 6. Distribution of birch forest (dominated with Betula platyphylla and Populus tremula) in HNP and the change detection maps, derived from Landsat TM in 1994, and Landsat ETM+, in 2000. (a) One of the birch forest concentrated areas with changes between 1994 and 2000. Red pixels indicated deforested area and black pixels represent newly gained forest area. Brown box indicates sand dune area, which the green pixels represent gained area. Photos (b), (c), and (d) were taken at the site I, II, III respectively. Photo (d) shows deforestation area and dead fallen trees marked as the red dots. (e) A diagram of mountain birch forest distribution along the altitude.

temporal changes of the forest region. If the pattern was generated from the mis-registration error, the sand dune area in the upper portion of Fig. 6a should also reveal the pattern similar to the forest area, but not shown at all. Several literatures have mentioned about the systematic changes associated with 'forest free-south slope' phenomena around the study area, which focused at the transition zones of Siberian taiga and Central Asian steppe based on extensive in-situ measurements of vegetation ecology and permafrost.

In Mongolia, forests occupy both the northern and eastern slopes of mountains, whereas grasslands are commonly observed in the more sun-exposed southern and western sides, as shown in the photos of figure 6b and 6c. The areas of red pixels in figure 6 represent deforested areas. These areas can be explained by the "forest free-south slope" phenomenon. Previous researchers have demonstrated that the northern and eastern mountain slopes are covered by birch forests (Hilbig, 1995; Wallis de Vries et al., 1996). The "Forest free-south slope" has been reported to be caused by less soil moisture which became an important factor to the growth of forests in Mongolia. Most of the water resources depend upon the permafrost layer. However, the permafrost layer has increasingly disappeared due to climate change and global warming (Sugimoto et al. 2002, Boehner and Lehmkuhl 2005). This environment of low soil moisture made poor condition for young trees not to be able to grow properly at level higher than 1400 m and die eventually as shown in fig. 6d and 6e (Dulamsuren, et al., 2005 Wallis de Vries et al., 1996).

Figure 7 designates the conversion of birch forest area to other categories. The forest area of 32 km^2 in 1994 was reduced to ~28 km^2 in 2000. Net area of ~4 km^2 was transferred to shrubland. Except the

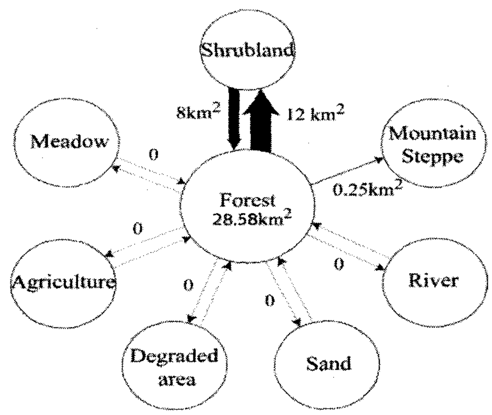

Fig. 7. A diagram shows of the transitions among the forest area and other categories. Arrows indicated direction of gains and losses.

Mountain steppe area and shrubland, the other categories did not present any change.

4.4. Biotic factors

In addition one of the key factors in forest fragmentation is the outbreak of forest pest insects. In1999, there was a severe outbreak of a gypsy moth species (Lymantria dispar) over the forested area in HNP. In total, a wide area of 550 ha was affected by this pest species. Previous research on the forest changes revealed that 31.0% of forest area was heavily defoliated, 26.6% of forest area moderately defoliated, and 39.4% of forest area-lightly defoliated by the gypsy moth outbreak (Tsogtbaatar et al., 2003).

Most of the young generation of birches have died or grown under heavy stresses due to red deer feeding. Red deer feed well at the edge of the forest near the southern slope in winter, since all the grassland area is fully covered with snow. In 1993, there was a total of 54 red deer in HNP. Since then, the number of red deer has increased over the years 1994, 1995 and 1996, reaching as many as 437 individuals. These estimates show that the number of red deer has dramatically increased, reaching 8 times the original population size in only the first year of state protection.

5. Summary and Conclusion

In this study we used remote sensing classification and change detection methods to investigate land covers and their temporal changes in HNP. Classification analysis showed that the accuracy of MLC with DCCA in 1994 and 2000 was 88.0% and 87.4%, respectively. In DCCA, the relationships between vegetation and environment are important to integrated land cover classification.

A post-classification change analysis from 1994 to 2000 reveals that forest and shrubland types of different small tree and shrub species compositions were particularly vulnerable to steppe expansion. The greatest amount of change detected in the forest occurred around the edges. The potential cause may lie in changes in the permafrost and limited water resources with "forest freesouth slope" phenomenon, which play an important role in land type changes.

Anthropogenic factors (such as protected area management, and shifting land use status from pasture to protected area) have also contributed to these land cover changes in HNP. Over the decades, HNP administration has made a lot of effort to move local herders from the protected area. Change detection results showed, in spite ofthe implementation of these activities, that the area of degraded land has decreased.

6. Acknowledgements

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