Change detection and classification of land cover at Hustai National Park in Mongolia

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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, bordering the Russian Federation in the north and China in the south. Hustai National Park (HNP) is famous for the success story of the reintroduction and establishment of a viable population of the Przewalski horses (van Dierendonck and de Vries, 1996; King and Gurnell, 2007). 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 (Equus ferus przewalskii) in Mongolia (FPPPH, 2004).

In study area, several research projects have been performed to study the vegetation, plant species composition, and the effect of ungulates and forest pest species in connection with environmental changes (Wallis de Vries et al., 1996; Tsogtbaatar et al., 2003; Usukhjargal, 2006). However, all of these studies depend on the data obtained from several field surveys. Those surveys are of importance, but are limited in terms of the synoptic view of land cover. Instead, satellite data can make simultaneous, synoptic, and repetitive observations, which could enable us to understand the synoptic temporal change in land cover types over the study area. We also tried to conduct field surveys and collect ground truth data in accordance with the satellite data.

This paper aims to investigate spatial and temporal land cover changes in HNP and understand the possible causes of the changes. Our study is a case study of land cover changes, therefore we have employed popular and widespread methods such as maximum-likelihood classification, accuracy assessment, and change detection (Morgan and Morris-Jones, 1983; John and Xiuping, 1999; Jensen, 2000; Foody, 2002; Skidmore, 2002; Hagner and Reese, 2007, and many others).

To do this, we applied land classification schemes to classify the land cover types using high resolution satellite data for the first time in this region. Based on the previously developed methodology such as maximum-likelihood classification and change detection techniques, we assessed the accuracy of the land classification techniques by comparison with supervised classification based on numerous ground truth data and training field data. Land cover changes between 1994 and 2000 were quantitatively presented with the results of accuracy assessments. We also suggested potential processes for the landscape changes in HNP from a forested area to shrubland or grassland. Environmental

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factors affecting the land cover changes such as ungulates, insects and human activities were also considered.

2. Study area

The study area, Hustai National Park (HNP) as indicated in Fig. 1, is located at the Daurian forest steppe eco-region (about 100 km southwest of the capital city Ulaanbaatar), which is one of the undisturbed areas of the steppe ecosystem in temperate Eurasia (Hilbig, 1995; Gunin _et al._, 1999). Hustain mountain is situated at the southern boundary of the discontinuous permafrost (Sharkhuu, 2003; Ishikawa _et al._, 2005). At present, HNP is approximately 350,000 ha in area (including the buffer zone) with a small mountain and river valley, lying between the altitudes of 1400 m and 1842 m. The climate surrounding HNP consists of a mean annual temperature of about +0.2°C and yearly precipitation of about 270 mm. Forest covers only a small portion of the area, about 5%. The relatively dry conditions of HNP area mean that grassland and shrubland dominate, taking up a major (88%) portion of the area (Wallis de Vries _et al._, 1996).

3. Data

3.1. Satellite and digital elevation data

In order to investigate long-term variation in land cover type in the study area over several years, we selected the two representative years of 1994 and 2000. The month selected was September, since the vegetation reaches a maximum at that time of year and provides us with an opportunity to accurately discriminate between land cover types. For better spatial resolution of the land cover, a Landsat 5 TM image taken in September 1994 and a Landsat 7 ETM+ image taken in September 2000 were utilized. The acquired images cover the whole HNP area and its surrounding buffer zone, as indicated in Fig. 1b. The Landsat TM image data consists of seven spectral bands, with a spatial resolution of 30 m for bands 1–7, and a low resolution of 120 m for thermal infrared band 6. The Landsat ETM+ image data consists of eight spectral bands, with the same spatial resolution as the first five bands of the Landsat TM image.

Its 6th and 8th (panchromatic) bands have resolutions of 60 m and 15 m, respectively.

In order to construct a digital elevation model, we used SRTM DEM data with a resolution of approximately 90 m from the USGS (United States Geological Survey) site (http://srtm.csi.cgiar.org). The elevation data were fully utilized to improve the quality of the land type classification process and evaluate their application in the detection procedure of land cover changes. 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.

3.2. Vegetation and reference data

3.2.1. Ground/reference data

Reference data sets were obtained over 6 years: 1995, 1996, 1998, 2003, and 2004 and used for classifier training and accuracy assessment for this study (Table 1). In total, 1080 GPS points were used as reference data for analysis (Fig. 2). Also, essential ground truthing data for the earlier image were extracted from digitized maps of vegetation, pasture, forest and soil, which were produced by the HNP administration over 3 years from 1992 to 1994. The maps have a scale of 1:50,000. In order to classify the earlier 1994 Landsat image, 230 points were selected. These points consist of field and digitized data. A total of 280 points have been used to classify the Landsat image from 2000. These points were identified during vegetation studies in HNP between 2003 and 2004. In addition, a total of 780 vegetation surveys within the field work were sampled.

3.2.2. Vegetation data

Almost all of the recent studies on Mongolian vegetation employ the Braun–Blanquet method (Cermak _et al._, 2005). A description of the vegetation was made for all different types of steppe and shrubland plant communities, which regularly occur in

<table>
<thead>
<tr>
<th>Time (year)</th>
<th>Points</th>
<th>Total points</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>13</td>
<td></td>
<td>Field research</td>
</tr>
<tr>
<td>1996</td>
<td>12</td>
<td></td>
<td>Field research</td>
</tr>
<tr>
<td>Image II (2000)</td>
<td>1998</td>
<td>27</td>
<td>Field research</td>
</tr>
<tr>
<td>2003</td>
<td>150</td>
<td></td>
<td>Field research</td>
</tr>
<tr>
<td>2004</td>
<td>130</td>
<td></td>
<td>Field research</td>
</tr>
</tbody>
</table>

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. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of the article.)
the study area. The number of points selected for each community type was variable, because some community types were spread over large areas, whereas others were in very restricted locations. The environmental data collected from each site consisted of coordinates, altitude in meters, slope, aspect, and geological substratum. Vegetation releves were based on the Braun–Blanquet method as described in Kent and Coker (1992). A plot size of 10 m² was chosen, with an increased plot size of 25 m² in the forest area. Vegetation description was made in each points; cover values of each plant species measured by the cover-abundance scale (Kent and Coker, 1992). Vegetation data were obtained from HNP’s administration, for the years 1995 and 1996. The training data in 1998 and 2003 were obtained from previous studies by Tsogtbaatar et al. (2003). They used the Braun–Blanquet method for grassland classification, and dendro-ecological methods in order to understand forest structure and species abundance. To describe forest ages they used the dendrochronological approach, with a plot size of 20 m². Landsat data is available at a spatial resolution of 30 m. It is adequate for detailed studies of HNP’s area. Ground truthing positional error is one of the important factors affecting the mis-registration of data sets. In order to reduce the ground truthing positional error, we took three GPS measurements at each point’s location. The precession of GPS measurements was ±7–9 m.

4. Methods

The maximum-likelihood classifier (MLC) has become popular and widespread in remote sensing because of its robustness (Strahler, 1980; Conese and Maselli, 1992; Ediriwickrema and Khorram, 1997; Zheng et al., 2005). Maximum-likelihood classifier assumes that the each class in each band can be described by a normal distribution. Each pixel is assigned to the class that has the highest probability. The probability \( p(o_i|x) \) gives the likelihood that the correct class is \( o_i \) for a pixel at position \( x \). Then the classification rule is performed according to:

\[
x \in o_i \quad \text{if} \quad p(o_j|x) > p(x|o_j) \quad \text{for all} \quad j \neq i.
\]

The final discriminant function for \( o_i \) can be stated as (Zheng et al., 2005; John and Xiuping, 1999):

\[
g_i(x) = \ln p(o_i) - \frac{1}{2} \ln \sum_i \frac{1}{t_i} -(x - m_i)^t \sum_i \frac{1}{t_i} (x - m_i),
\]

DCCA was performed in two steps. The first step is to summarize the main variation in the species data by ordination (Braak, 1986). The response model for the species is composed of a Gaussian distribution:

\[
E(y_{ik}) = c_k \exp \left( \frac{1}{2} \frac{(x_i - u_k)^2}{t_k} \right),
\]

where \( E(y_{ik}) \) denotes the expected value of \( y_{ik} \) at a site \( i \) that has a score \( x_i \) on the ordination axis. The second step is similar to an analysis, which relates an ordination axis to the environmental variables. Each site has a score which is the sum of the linear relations among all the potential environmental variables, as follows:

\[
x_i = b_0 + \sum_{j=1}^q b_j z_{ij},
\]

where \( b_0 \) is the intercept, \( b_i \) is the regression coefficient for the environmental variable \( j \), and \( z_{ij} \) is an \( n \times (q + 1) \) matrix containing the environmental data and a column of ones.

The present method for change detection (Jensen, 2000; van Oort, 2007) used in this study 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. According to Liu et al. (2007) several accuracy indices derived from this error matrix are required to compare the change detection methods. Most of the common accuracy assessments include an overall accuracy, a user’s and producer’s accuracy and a Kappa coefficient (Cohen, 1960, 1968; Landis and Koch, 1977; Congalton, 1991; Stadelmann et al., 1994; Stehman and Czaplewski, 1998; Foody, 2002; Skidmore, 2002; Lu et al., 2004). The Kappa coefficient of accuracy equation used in this study is that described by Congalton (1991):

\[
K = \frac{N \sum_{i=1}^n x_i - \sum_{i=1}^n x_i x_i}{N^2 - \sum_{i=1}^n x_i x_i}.
\]

5. Results

5.1. Vegetation and environmental correlation

DCCA was performed with CANOCO 4.02 (Braak, 1988) and with transformed Braun–Blanquet scales (Kent and Coker, 1992). Transformation of the Braun–Blanquet scales was conducted as follows: cover type 1 for 1–5%, 2 for 6–25%, 3 for 26–50%, 4 for 51–75%, and 5 for 76–100%. A total number of 780 vegetation releves of samples and environmental variables were included in the DCCA. An environmental data matrix of eight factors was also made. The DCCA factors in all species and uses a detrending model based upon a second order polynomial with log-transformation and downweighted rare species. The first axis was defined by rocks and bare soil, the second axis by field and altitude. The first axis eigenvalue and correlation coefficient are highest with 0.071 and 0.47, respectively.

We classified the landscape area of HNP into six types with common species and environmental variables: (1) Betula platyphylla forest area, (2) shrubland, (3) mountain steppe, (4) meadow, (5) agriculture area, and (6) degraded area. Based on ground truth points we selected training sites for MLC analysis (Table 2).

5.2. Classification of land cover type and change detection

Based on the classification scheme (Table 2) 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 6 years, the mountain steppe area has increased by 166.5 km². In contrast, the degraded and agricultural areas have decreased by 194.8 km² and 46.1 km², respectively (Fig. 4).

The technique, known as post-classification change detection, was used to form the “from-to” matrix. Table 3 shows the resulting change detection matrix. The pixels without changes appear along

<table>
<thead>
<tr>
<th>Class name</th>
<th>Class code</th>
<th>Class definition</th>
<th>Training samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>Ag</td>
<td>Old tilling field</td>
<td>514 456</td>
</tr>
<tr>
<td>Forest</td>
<td>Ft</td>
<td>Birch forest area, dominated by Betula platyphylla</td>
<td>1132 848</td>
</tr>
<tr>
<td>River</td>
<td>Rv</td>
<td>Permanent open water, streams, river</td>
<td>350 290</td>
</tr>
<tr>
<td>Meadow</td>
<td>Mw</td>
<td>Geranium pratense and Iris lactea meadow, lower elevations</td>
<td>453 543</td>
</tr>
<tr>
<td>Degraded area</td>
<td>Ds</td>
<td>Settlement area, degraded pasture, bare soil</td>
<td>1422 1088</td>
</tr>
<tr>
<td>Shrubland</td>
<td>Sh</td>
<td>Shrubland dominated by Caryopteris mongolica–Amygdalus pedunculata, Spiraea aquilegiifolia</td>
<td>1224 1790</td>
</tr>
<tr>
<td>Sand</td>
<td>Sd</td>
<td>Sand dune</td>
<td>573 655</td>
</tr>
<tr>
<td>Mountain steppe</td>
<td>Ms</td>
<td>Stipa krylovii, Festuca lenensis dominated mountain steppe</td>
<td>2130 1548</td>
</tr>
</tbody>
</table>

Table 2
Classification scheme used for MLC and training samples using Landsat TM images for HNP.

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.
the diagonal of the matrix. The calculated Kappa coefficient of the error matrix in Table 3 was 0.63. This means that the change detection results may be used for further analysis.

5.3. Accuracy assessment of land classification

The accuracy of the classification was determined based upon ground truth region of interest (ROI). Ground truth ROIs were divided into two groups. The first group is for classification procedure and the second group is for accuracy assessment. Each class included a different number of ROIs, depending upon the albedo and contrast of class types. The forest, river and mountain steppe classes included the highest number of ROIs compared to those of the agricultural, meadow, and degraded area classes. The average number of pixels per ROI was 974.7 and 902.4 for the years 1994 and 2000, respectively.

Producer’s and user’s accuracy values were calculated for each classification scheme. The accuracy is estimated to be relatively high, showing the overall values of 88.0% in 1994 and 85.4% in 2000 (Table 4). The accuracy was highest for water bodies (Rv), with 98%, and sand dunes (Sd), with 97.91%, both in the year 1994. The minimum value of user’s accuracy was found to be 68.71% for shrubland in 1994.

5.4. Change detection

Our result, from classification and change detection analysis, showed that the calculated area of agriculture decreased by 17.8% (or 46.1 km²) from 1994 to 2000. Compared to the other land cover types, agricultural area (Ag) decreased most rapidly in HNP during the period from 1994 to 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 km²) of the total area in 2000. This estimation is very close to the total area of the birch forest in HNP reported by the Wallis de Vries et al. (1996). In 2000, the forest area showed a decrease by 12% (~4 km²) as compared with the forest area in 1994 as shown in Table 4. As the mentioned by Wallis de 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 km². 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 km², 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 km² 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 numbers or 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% (1111.50 km²) of HNP. The shrub-dominated community (Betula fusca, Spraera media, Car- yopteris mongolica, Amygdalus pedunculata, Spiraea aquilegifolia) was found in a peaty valley. Shrubland area (Sh) mostly occurs at

Table 3
From-to matrix, result of change detection analysis (by percent).

<table>
<thead>
<tr>
<th>Final state (2000)</th>
<th>Agriculture</th>
<th>Forest</th>
<th>River</th>
<th>Meadow</th>
<th>Degraded area</th>
<th>Shrubland</th>
<th>Sand</th>
<th>Mountain steppe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>62</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>River</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Meadow</td>
<td>0</td>
<td>0</td>
<td>39</td>
<td>86</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Degraded area</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>51</td>
<td>0</td>
<td>24</td>
<td>3</td>
</tr>
<tr>
<td>Shrubland</td>
<td>6</td>
<td>38</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>78</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Sand</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>44</td>
<td>0</td>
</tr>
<tr>
<td>Mountain steppe</td>
<td>54</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>34</td>
<td>19</td>
<td>18</td>
<td>82</td>
</tr>
</tbody>
</table>

Table 4
Comparison of the producer’s and user’s accuracies in 1994 and 2000 (by percent).
forest edges, rocky mountain ridges, and alpine vegetation sites. Over the 6 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 km². 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 1878.8 km², 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).

5.5. Potential causes of land cover changes

5.5.1. Forest free-south slope

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 (Congalton, 1991; Foody, 2002). Fig. 6 shows change detection analysis of birch forest and sand dune area. The forest area shows the systematic pattern of

![Image](https://example.com/image.png)

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

![Image](https://example.com/image2.png)

**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 sites I, II and 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. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of the article.)
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 mis-registration errors but real
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 (Hilbig, 1995; Wallis de Vries et al., 1996; Gunin et al.,
1999; Sugimoto et al., 2002; Boehner and Lehmkuhl, 2005;
Dulamsuren et al., 2005).

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 (Hilbig, 1995;
Dulamsuren et al., 2005), as shown in the photos of Fig. 6b and c.
The areas of red pixels in Fig. 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 (Sugimoto et al.,
2002; Boehner and Lehmkuhl, 2005). However, the permafrost layer
has been increasingly disappearing 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 able to grow properly at level higher than 1400 m and die
eventually as shown in Fig. 6d and e (Dulamsuren et al., 2005; Wallis
de Vries et al., 1996).

Fig. 7 designates the conversion of birch forest area to other
categories. The forest area of 32 km² in 1994 was reduced to
~28 km² in 2000. Net area of ~4 km² was transferred to shrubland.
Except the mountain steppe area and shrubland, the other
categories did not present any change.

5.5.2. Biotic factors

In addition one of the key factors in forest fragmentation is the
outbreak of forest pest insects. In 1999, 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 (Tsogbaatar et al., 2003).

Most of the young generation of birches have died or grown
under heavy stresses due to red deer feeding (Usukhjargal, 2006).
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 1994–1996,
reaching as many as 437 individuals (Usukhjargal, 2006). These
estimates show that the number of red deer has dramatically
increased, reaching eight times the original population size in only
the first few years of state protection.

6. 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.
The ecological characteristics of dominant plant species of the
mountain steppe area were defined by their preference for light,
warm temperature, and their ability to grow in open spaces under
dry atmospheric conditions. Expansion of the mountain steppe area
is important to explain the connection between global warming and
deforestation processes in Mongolia. A meteorological data analysis suggested that in 1990 annual precipitation dropped to a 50-year minimum (Gunin et al., 1999).

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 expan-
sion. 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 free-south
slope” phenomenon, which play an important role in land type
changes (Sharkhuu, 2003; Dulamsuren et al., 2005; Ishikawa et al.,
2005).

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 of the implementation of these activities, that the area of
degraded land has decreased.

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References

Braak, C.J.F.T., 1986. Canonical correspondence analysis: a new eigenvector tech-