Changes in rangeland cover associated with livestock grazing in Altun National Nature Reserve, northwest Qinghai-Tibetan Plateau

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Abstract. The Altun National Nature Reserve, located on the northern edge of the Qinghai-Tibetan Plateau of China, is one of 35 most important biodiversity sites worldwide. Land-use and cover change are affecting this alpine ecosystem. A supervised classification was used to classify types containing meadow, steppe, sparse rangeland, and non-rangeland environments based on Landsat Thematic Mapper (TM) imagery data. By conducting an aggregation analysis using a Geographic Information System an analysis of changes from 1990 to 2010 was conducted. The results demonstrated that sparse rangeland was the most widespread vegetation type and underwent significant changes over the period. The area of sparse rangeland increased by 64.4 km\textsuperscript{2} from 1990 to 1995 and by 49.3 km\textsuperscript{2} from 1995 to 2000. However, the area of sparse rangeland decreased by 99.2 km\textsuperscript{2} from 2000 to 2005 and by 247.4 km\textsuperscript{2} from 2005 to 2010. The major areas of change were primarily located in the vicinities of the Yishakipati central inspection station, the Kardun inspection station, and Ayakkum, Aqqikkol and Jingyu Lakes. There was a positive correlation between the change in area of sparse rangeland and the amount of livestock grazing. The change in non-rangeland was significantly negatively correlated with the amount of livestock grazing during the period in the grazing area. Appropriate livestock grazing may be essential for promoting the resilience of the predominant ecosystems and key habitats of wildlife in the Altun National Nature Reserve.

Additional keywords: alpine ecosystems, biodiversity, land-use and cover change, protected species, sparse rangeland.

Received 13 May 2014, accepted 26 August 2014, published online 27 January 2015

Introduction
A study of land-use and cover change was launched in 1994 as a core project of the International Geosphere Biosphere Program and the International Human Dimensions Program on Global Environmental Change to elucidate their relationship with global environmental change (Turner et al. 1995). Largely due to the large scale of the changes, studies on land-use and cover change have been identified as one of the top 10 research topics in landscape ecology in recent decades (Wu and Hobbs 2002; Zeledon and Kelly 2009). Land-use and cover change is a core research initiative of coupled human–natural systems, with important implications for both human and natural systems (Turner et al. 2007; López-Carr et al. 2012). Land-use and cover change is a complex process subject to interactions between the human and physical environments at different temporal and spatial scales (Hao and Ren 2009; Huang et al. 2012); it is a keystone for sustainable development and a major element of human responses to physical environments. Consequently, understanding such changes is key for regional and global development and the management and mitigation of many environmental problems (Turner et al. 1995; Yan et al. 2013).

Many regions worldwide have experienced massive land-use and cover changes over the past several decades (Baessler and Klotz 2006; Schirpke et al. 2012). Human activities affect land-use and cover change and ecological succession to various degrees (Temesgen et al. 2013), which has led to accelerated losses of primary ecosystems and biodiversity during the past few decades. As human activities significantly determine such changes, it is necessary to understand how land-use and cover change is likely to evolve (Rounsevell et al. 2006). To do so, researchers must analyse the underlying driving forces that motivate or constrain the associated human activities (Suzanchi and Kaur 2011). To mitigate or adapt the land to human activities, it is essential and efficient to identify
areas of high biodiversity, which can be given high priority for conservation. Previous work has identified 34 areas of high biodiversity throughout the five continents (Myers et al. 2000; Garcia 2006; Flamenco-Sandoval et al. 2007; Huang et al. 2011). However, identification of areas of high biodiversity alone is not enough to achieve their conservation. It is also necessary to assess the possibilities for conservation, considering that these areas are subject to rapidly growing human population and activities (Cincotta et al. 2000). Thus, analysis of changes in land-use and cover in protected areas (especially in nature reserves) becomes a fundamental tool for the adoption of conservation strategies (Turner et al. 1994). For analysing the changes in land-use and cover on protected areas, much attention has been given to the use of satellite remote-sensing imagery for mapping and monitoring large areas at regional or continental scales (van Lier et al. 2011). The use of Landsat Thematic Mapper (TM) data has become common practice in remote sensing from local to national scales (Woodcock et al. 2001).

Alpine regions are affected by land abandonment of agriculture, mining and livestock grazing (Zimmermann et al. 2010). The Altun National Nature Reserve is one of three refuges for protecting three endemic, endangered wild ungulates – the wild yak (Bos mutus), the wild Tibetan ass (Equus kiang) and the chiru (Pantholops hodgsonii) – and their alpine ecosystem habitats on the Qinghai-Tibetan Plateau (QTP) of China, which is well known as the world’s ‘third pole’. Due to its unique ecosystem and rich biodiversity, the Altun National Nature Reserve is also recognised as 1 of 34 areas of high biodiversity in the world. Although the reserve is considered rich in biodiversity and natural resources, in recent decades, it has been threatened by changes in land-use and cover that may affect these key species and their habitats. The fragile alpine desert ecosystem in the reserve is vulnerable to human activities. For the sustainable protection and the development of habitats of wild ungulates, it is necessary to assess the changes in land-use and cover that have taken place in the reserve. In particular, livestock grazing, the major human activity in the reserve, may lead to changes in land-use and cover at multiple temporal and spatial scales, which may in turn affect the resilience of these alpine ecosystems. Within this context, we conducted this study to examine the changes in land-use and cover of the rangelands associated with changes in livestock grazing in an effort to provide a sound basis for planning the sustainable conservation management of alpine ecosystems in the Altun National Nature Reserve and similar environments.

Materials and methods

Study area

The Altun National Nature Reserve was established as an inland nature reserve of China in May 1983. It is situated at the northern edge of the QTP (36°00′N–37°49′N, 87°10′E–91°18′E), bordered by the Altun Mountains to the north and the Kunlun Mountains to the south (Fig. 1). The reserve is on the south-east border of the Xinjiang Uyghur Autonomous Region and is located at the junction of three provinces in Western China: the Xinjiang Uygur Autonomous Region, Qinghai Province and the Tibet Autonomous Region (Bleisch et al. 2009). The reserve covers an area of 46 000 km² and is 3748 to 6948 m above sea level. The reserve has no absolute frost-free period and a highly seasonal variation in temperature throughout the year. The annual precipitation is ~300 mm and the mean annual temperature is below 0°C. Dominated by the alpine desert ecosystem, the reserve is rich in natural resources such as minerals and wildlife, due to its geographic location.

Data collection

Data on change in land-use and cover

Satellite imagery has been popular and well utilised in measurements of qualitative and quantitative terrestrial changes in land-use and cover (Seto et al. 2002). The data used in this study can be classified into three groups. Group 1 was used for interpreting and acquiring land-use and cover change information. We selected Landsat TM imagery as the basic data for this research. We downloaded Landsat TM imagery from between 1990 and 2010 at 5-yearly intervals from the United State Geological Survey. All five images were captured in July and August, during the warm season. The spatial reference is path 139–141 and row 034–035 in the Landsat World Reference System 2. Group 2 was used for evaluating the accuracy of the basic data. We obtained reference data such as a topographic map (scale 1 : 100 000) and a district map of the study area. We transferred all data to vectors for convenient managing of attributes. We used the supervised classification in ERDAS IMAGING 9.2 software to classify them into meadow, steppe, sparse rangeland and non-rangeland types (Fig. 2a–e). Our definitions were as follows. Meadow is dominated by Kobresia myosuroides and Carex sutschanensis. Steppe is dominated by Stipapopurea. Sparse rangeland is dominated by Androsace onet. Non-rangeland contains water, desert, snow cover and bare land. To represent the accuracy of the classification, we also obtained ground reference data from land surveys using handheld Global Positioning System units (Fig. 2f). The land survey routes ran from Kardun inspection station to Yishakipati central inspection station, from Yishakipati central inspection station to Tuzihu inspection station, and from Tuzihu inspection station to Jingyu Lake. We recorded a total of 257 reference points that were used for the assessment (40–55 points per type). The overall accuracy was 85.3%. Group 3 is other social-economic statistics data collected mainly from the yearbooks of Bayingolin Mongol Autonomous Prefecture Statistical Bureau and Altun National Nature Reserve Administration Bureau, published over the years 1985–2010. To clearly understand the locations of change in land-use and cover and their driving forces, we divided the reserve into eastern and western parts based on elevation and the basin of the Yishakipati River (Fig. 2f). The eastern part has long been used as grazing pastures by local pastoralists and that use has continued even after the establishment of the reserve in 1985. The western region, however, has not been historically influenced by livestock grazing.

Data on livestock grazing

We collected data on livestock grazing at 5-year intervals from 1985 to 2010 from the Altun National Nature Reserve...
Administration Bureau (Table 1). In 1985, 26 pastoral households grazed 20,400 sheep in the eastern part of the reserve. By 1995, 24 pastoral households grazed 14,000 sheep there. The implementation of the ‘Program of Retiring Livestock, Restoring Grassland’ policy in 2001 and the ‘National Management Measures on Grassland and Livestock’ program in 2005 caused the local government to gradually move herders and livestock out of the reserve in 2000. Thus, livestock grazing decreased sharply from 2000 to 2010. According to the Plan of Ecological Emigration, the local government will move all herders and livestock out of the reserve over time. In 2010, only eight pastoral households were grazing 5,200 sheep in the reserve. The sites of livestock grazing in the eastern Altun National Nature Reserve (ANNR) were located mainly near Yishakipati central inspection station, Karchuka inspection station, and Kardun inspection station.

Aggregation analysis

We used Environmental Systems Research Institute (ESRI) ArcGIS 9.3 software to calculate and manage all the land-use and cover data. We opened the attributes of all the data and added a new field for each of the four types (meadow, steppe, sparse rangeland, and non-rangeland). For example, we added a field for the land-use and cover data in 1990. If the polygon belonged to meadow, the value of the new field named MeadowID was 100. Otherwise, MeadowID was 0. Therefore, the value of MeadowID was 100 or 0. The three other land-use and cover change (LUCC) types were named in the same way steppe had a new field named, SteppeID whose value was 100 or 0; sparse rangeland had a new field named SparseID whose value was 100 or 0; and non-rangeland had a new field name, Non-rangelandID, whose value was 100 or 0. The values of the new fields (MeadowID, SteppeID, SparseID, and Non-rangelandID) held basic values; we converted all vector land-use and cover change (LUCC) types were named in the same way steppe had a new field named, SteppeID whose value was 100 or 0; sparse rangeland had a new field named SparseID whose value was 100 or 0; and non-rangeland had a new field name, Non-rangelandID, whose value was 100 or 0. The values of the new fields (MeadowID, SteppeID, SparseID, and Non-rangelandID) held basic values; we converted all vector land-use and cover data to raster data with a spatial resolution of 30 m × 30 m. We separated the four types as four raster datasets (Meadow, Steppe, Sparse rangeland and Non-rangeland) in each period. We obtained five datasets of each type from 1990 to 2010. By using the ‘Aggregate’ spatial analyst tool, we aggregated 10,000 cells in all raster datasets as a cell in a new raster dataset with a 3 km × 3 km spatial resolution. We averaged the values of 10,000 cells as the value of the new raster data;

Fig. 1. Location of the study area.
ranged from 0 to 100. We subtracted the former and latter data of every type. Thus, we could obtain datasets of the four types over four time intervals (1990–1995, 1995–2000, 2000–2005, and 2005–2010). The values ranged from –100 to 100. Positive values indicate that the type increased in this cell while negative values indicate that the type decreased.

Table 1. Livestock grazing from 1985 to 2010

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of pastoral households</th>
<th>Number of livestock</th>
<th>Summer pasture</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>26</td>
<td>20,400</td>
<td>From 30 km east to 16 km west of Yishakipati central inspection station. The vicinity of Karchuka inspection station. The vicinity of the Kardun inspection station</td>
<td>From 30 km east to 16 km west of Yishakipati central inspection station</td>
</tr>
<tr>
<td>1990</td>
<td>24</td>
<td>16,700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>24</td>
<td>14,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>15</td>
<td>8,400</td>
<td>From 30 km east to 16 km west of Yishakipati central inspection station</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>13</td>
<td>7,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>8</td>
<td>5,200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. (a–e) Land-use cover change in the Altun National Nature Reserve in (a) 1990, (b) 1995, (c) 2000, (d) 2005 and (e) 2010; (f) grazed and non-grazed areas in 2012.
decreased in this cell. Zero values indicate that the type did not change.

Statistical analysis

We compared the changes in area of the rangeland types from 1990 to 2010 between grazed and non-grazed areas. We conducted a correlation analysis between the land-use and cover change of all rangeland types and the amount of livestock grazing from 1990 to 2010. All the data were processed in Excel 2007.

Results

Land-use and cover changes of the rangeland types in the reserve

A slight change in the cover of meadows was observed across the reserve from 1990 to 2010 mainly near Yishakipati and Kardun central inspection stations in the eastern part of the reserve [Fig. 3(a1–a4)]. Similarly, slight changes in cover in the steppe were found across the reserve from 1990 to 2010 with the greatest changes occurring near Yishakipati and Kardun central inspection stations and in the middle of the reserve [Fig. 3(b1–b4)]. Significant cover changes were observed for sparse rangelands during the study period. The cover of sparse grasslands occurred mainly in the vicinities of the Yishakipati and Kardun central inspection stations and in the west and south-east of the reserve [Fig. 3(c1–c4)]. Slight changes in non-rangelands were observed occurring mainly in the vicinities of the three lakes (Ayakkum, Aqqikkol, and Jingyu Lakes) and in the western part of the reserve [Fig. 3(d1–d4)].

Land-use and cover change in the rangelands in grazed and non-grazed areas

The area of meadows did not change significantly in the non-grazed area (western part of the reserve) during the study period (Fig. 4a). The area of meadow showed no change from 1990 to 1995, increased by 6.93 km² from 1995 to 2000, and decreased by 4.54 km² from 2000 to 2010 in the grazed area (eastern part of the reserve). The area of the steppe increased by 32 km² from 1990 to 2005, but decreased by 10 km² from 2005 to 2010 in the grazed area (Fig. 4b). The area of the steppe in the non-grazed area decreased by 3.54 km² continuously from 1990 to 2010. The area of the sparse rangeland in the grazing area increased by 33 km² from 1990 to 1995 and by 48 km² from 1995 to 2000, but it decreased by 24 km² from 2000 to 2005 and by 100 km² from 2005 to 2010 (Fig. 4c). The area of the sparse rangeland in the non-grazing area increased by 24 km² from 1990 to 1995 and decreased by 207 km² from 1995 to 2010. The area of non-rangeland in the grazed area decreased by 37.8 km² from 1990 to 1995, by 72 km² from 1995 to 2000, but it increased by 20 km² from 2000 to 2005 and by 111 km² from 2005 to 2010 (Fig. 4d). The area of non-rangeland in the non-grazed area decreased by 24 km² from 1990 to 1995 and increased by 208 km² from 1995 to 2010.

Relationship between land-use and cover change of rangelands and numbers of grazing livestock

The relationship between the land-use and cover change of all rangelands and the amount of livestock grazing in the grazed area are described in Fig. 5. The change in the cover of meadows and steppe at the four time periods was not significantly related to the amount of livestock grazing (Fig. 5a, b), whereas the change in area of sparse rangelands was significantly related with the amount of livestock grazing in the grazed area. In contrast, the change in area of non-rangeland was negatively related to livestock grazing in the grazed area, indicating that the area of non-rangeland increased when livestock grazing was forbidden (Fig. 5d).

Discussion

Land-use changes and the consequent impacts on vegetation cover is one of the most profound human-induced alterations of the Earth system (Vitousek et al. 1997). Knowledge of land-use and cover changes and the driving forces is a fundamental tool for landscape planning and management, especially in protected areas (Álvarez-Martínez et al. 2011). Human activities can also be a major threat to biodiversity as a result of the destruction of natural vegetation and the fragmentation or isolation of natural areas across different scales (Terra et al. 2014). Protected areas or parks are established to limit the effects of changes within delineated areas that are often located in areas of high biodiversity; these areas are assumed to be large enough to effectively protect endangered species (Verburg et al. 2006). Hence, research on land-use and cover changes in nature reserves (protected areas) is a critical issue and an understanding of the driving forces of land-use change is needed for their preservation in face of pressures from local and/or global socioeconomic development (Xie et al. 2012). The area needs to be preserved as natural habitats for conservation and recreation through optimal allocation (Zhang et al. 2014). A key challenge in the Altun National Nature Reserve and elsewhere around the globe is to achieve sustainable ecosystems while considering environmental changes along with the requirements and desires of local and global societies (Baehre et al. 2011). The ecological integrity of nature reserves needs to be preserved and managed sustainably and not exploited for their natural resources to meet the demand of people’s daily lives. Thus, land-use and cover changes, the driving forces, adjustment schemes, and land-use policy changes should be investigated together. The Altun National Nature Reserve, which is one of 34 areas of high biodiversity in the world and has a fragile alpine desert ecosystem, has undergone dramatic changes from 1990 to 2010. Under harsh natural conditions, livestock grazing is the primary source of income for local people on the QTP. Because the reserve is also one of three refuges for protecting three wild ungulates, the human–livestock impact on natural wildlife habitats has been the main causes of deteriorating wildlife populations and habitats. Generally speaking, natural reserves face pressures from the external environment and require stricter protection, especially in buffer and core zones. Thus, a powerful suite of policy and management tools for the recovery and protection of natural reserves becomes crucial for the preservation of biodiversity (Dobson et al. 1997; Hameed et al. 2012).

In this study, remote-sensing, Geographic Information System and Global Positioning Systems were applied in the extraction, monitoring and allocation of land cover types (Gao
Fig. 3. Locations land-use and cover change of the four types of rangelands: (a) meadow, (b) steppe, (c) sparse rangeland, and (d) non-rangeland in the Altun National Nature Reserve during four periods (1, from 1990 to 1995; 2, from 1995 to 2000; 3, from 2000 to 2005; and 4, from 2005 to 2010).
The cover of meadows and steppe were found to be stable; that is, these ecosystems showed nearly no changes from 1990 to 2010. In contrast, dramatic decreases in the cover of sparse rangelands and increases in the cover of non-rangelands (mostly bare land) occurred over the same time period. For the sustainable development of rangeland in alpine regions, the

\[
y = 4.4173 \ln(x) - 39.819 \\
R^2 = 0.1574
\]

\[
y = 17.1541 \ln(x) - 151.5 \\
R^2 = 0.3025
\]

\[
y = -167.31 \ln(x) - 1537.2 \\
R^2 = 0.7259
\]

Fig. 4. Land-use and cover change of four types of rangelands: (a) meadow, (b) steppe, (c) sparse rangeland, and (d) non-rangeland in grazed and non-grazed areas.

Fig. 5. Relationship between land-use and cover change of rangelands: (a) meadow, (b) steppe, (c) sparse rangeland, and (d) non-rangeland and the amount of livestock grazing in the grazed area.
central government has implemented a policy called ‘Retiring Livestock, Returning Grassland’.

According to this compulsory policy, the local government of Ruoqing County gradually moved herders and livestock out of the reserve in 2000. However, the area of sparse rangelands decreased sharply from 2000 to 2010, after this policy was implemented. The decrease of area of sparse rangelands and increase of the area of non-rangelands with a sharp decrease in livestock grazing from 2000 to 2010 indicates that removing grazing livestock may increase the degradation of sparse rangelands into bare lands. This implies that livestock grazing may help maintain the stability of sparse rangelands, which are key habitats for the wild ungulates (wild yak, Tibetan antelope and Tibetan donkey) (Su et al. 2014). Therefore, appropriate livestock grazing may be essential for promoting the resilience of the dominant ecosystems and key wildlife habitats in the reserve. However, the policies promulgated by the government may be having negative impacts on protected areas in China such as the Altun National Nature Reserve. Indeed, large areas of land collectively owned by the government have been included within nature reserves, which have led to increased management conflicts (Li et al. 2013).

A more effective land management system would allow the nature reserve to hold the ownership of all the land within the reserve, ending disputes with the local government about land ownership and land acquisition (Xie et al. 2012). If nature reserve managers had ownership of the reserve land, they could develop land-use approaches such as using a system of ecological compensation for people who contributed to conservation and protection efforts. Collective ownership restricts the decision-making process and provokes conflicts between local herders and conservation managers. Our analysis showed that government policies that restrict land-use are negatively impacting on biodiversity conservation and potential natural resource development. It is thus important to adjust land-use strategies in the reserve by handing land ownership to the nature reserves managers in order to implement appropriate livestock grazing regimes to promote the sustainable conservation and protection of these important alpine ecosystems.

Conclusions

In this study, we have presented a temporal-spatial analysis of land-use and cover change and the driving forces of change over the last 20 years in the reserve. Our analysis of the changes indicates that the area of sparse rangelands, the key habitat for endangered populations of wild ungulates, has deteriorated over the past decade concurrent with policies that restrict livestock grazing in the reserve. Livestock grazing may be beneficial to the protection and sustainable use of the sparse rangeland. Future research should aim to further quantify grazing impacts, including changes to wildlife habitats, and changes in biodiversity, and, lastly, update protection policies and management.

Acknowledgements

This study was financially supported by grants from the Ministry of Environmental Protection, China (2012090033) and the Ministry of Science and Technology, China (2012BAC01B02). The authors wish to express their great thanks to the reviewers and the editors for their efforts and time.

References


Rangeland cover change