Chapter 17
Policy Impacts on Land Degradation: Evidence Revealed by Remote Sensing in Western Ordos, China

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Abstract This paper presents a multi-temporal monitoring and assessment of biomass dynamics in response to land cover change in Western Ordos, one of the most important dry areas in China, aiming to reveal the impacts of governmental land management policies on the biomass production of the rangeland ecosystem and on land degradation. Multi-temporal Landsat images (MSS 1978, 1979; TM 1987, 1989, 1991, 2006 and 2007; ETM+ 1999, 2001, 2002, 2004) were used in this research. An integrated processing algorithm, indicator differencing and-thresholding and post-classification differencing, was applied to reveal the land biophysical change and rangeland degradation, and a relevant biomass estimation model was developed for the rangeland ecosystem based on other researchers' work. Meteorological data since the 1960s were incorporated in the analysis to avoid false signals of degradation, as could arise from normal climatic variability. The results show that to some extent land management policies have been instrumental in the protection and recovery of grasslands biomass production. On the other hand, in the non-controlled and weakly monitored zones land degradation, in the form of biomass loss due to desert extension, vegetation degradation, salinisation and water-table decline has continued. This could be attributed to a combination of both natural and human factors, such as lack of protection against strong winds, collective grazing in the permitted rotation areas and previously controlled zones, and over-pumping for agricultural and sand control activities. From this case study, it seems that the effectiveness and rationality of land use policy depend on whether it can coincide with the interests of the local people while conserving the environment. Where there is a conflict between economic viability and environmental sustainability, land degradation is inevitable.

Keywords Biomass dynamics · Land use change and land degradation · Land use policy · Multi-temporal remote sensing · Ordos · China

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17.1 Introduction

Since they can directly and indirectly influence land resources exploitation, creation of market and economic opportunities and the impact of policies on the ecosystem degradation has been increasingly recognized as some of the main social drivers. Although a certain number of researches have dealt with human-environmental interaction by linking land use change revealed by remote sensing with human activity (Serneels and Lambin, 2001; Veldkamp et al., 2001; Verburg et al., 2002; Wu et al., 2002; Wu, 2003b; Xie et al., 2005), few analyses have focused specifically on the impacts of policies on land degradation. The objective of this paper is to conduct a study, taking the Western Ordos Region in China as an example, to monitor the biophysical response of ecosystems to the implementation of different land policies through remote sensing using vegetation indices trajectories and biomass dynamics.

As a part of the Ordos Plateau and bordering the Loess Plateau on the south, the Ordos region is administratively located in Inner Mongolia and adjacent with Shaanxi Province on the southeast and Ningxia Province on the southwest (Fig. 17.1). The region is mainly sandy rangeland interleaved with desert patches

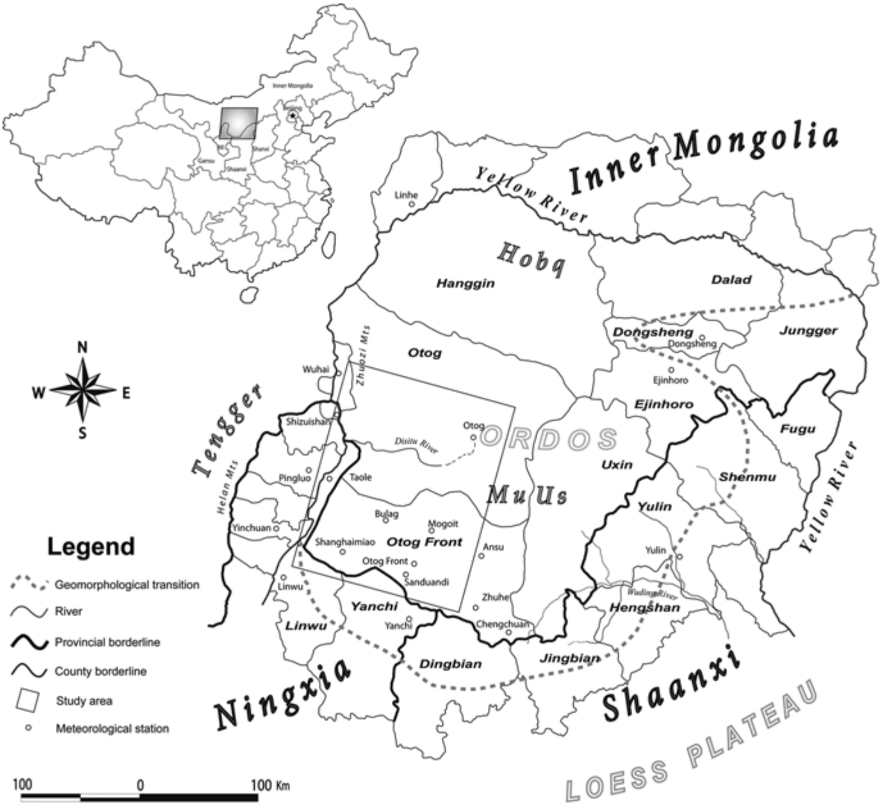

Fig. 17.1 Location of the Ordos Region and its administrative units. Note: The basic administrative unit shown in this figure in Inner Mongolia is Banner, which is equivalent to County in other provinces

and locally some pieces of cropland, and thus named the *Mu Us Sandy Land*. The field investigations by Huang and Zhang (2006) identified as the main herbaceous and shrub species in this sandy land *Artemisia ordosica, Stipa bungeana, Juniperus vulgaris, and Caragana intermedia*.

The average annual precipitation is around 279 mm in the Banner Otog, of which 85% is concentrated in the period June–September. The wind blows mainly from the northwest (230 days) and its speed exceeds 17 ms^{-1} during more than 40 days per year. The highly concentrated rainfall and strong winds provoke soil erosion and water loss by runoff. Due to an abundant good-quality coal resource under the Plateau, as well as natural gas and oil reserves, Ordos has become in recent years one of the national energy bases under the mid-to-long term national strategy "To Develop the West". The fossil fuel exploitation driven by this development, combined with long-time human activities in grazing, deforestation and land reclamation for agriculture driven by a number of different local and national policies, together with medicinal herbs and fuel wood collection, have caused significant land use change and land degradation (Jiang et al., 1995; Zhang and Wang, 2001; Wu et al., 2005; Xu, 2006).

Among hundreds of national and local government policies, those related to, or having influenced land use and management in Western Ordos are listed in Table 17.1. Going back to their implementation dates, multi-temporal satellite images were acquired for revealing land cover change and land degradation and projecting biomass dynamics in time to understand the biophysical response of the rangeland ecosystem to the implementation of these policies. The images dated

Table 17.1 Multi-temporal satellite images used in this study

Captors	Scene	Acquisition dates	Spatial resolution	Mean haze	Policy implementation period
Landsat 5 TM	Path-Row:	2007 Aug 10	30 m	28.90	Period 3: 2000–2001,
Landsat 5 TM	129-33	2007 July 09	30 m	30.07	"Herbs collection
Landsat 5 TM		2006 Aug 07	30 m	35.28	forbidden" and
Landsat 7 ETM+		2004 Aug 25	30 m	13.18	"Grazing-forbidden
Landsat 7 ETM+		2002 Aug 20	30 m	13.78	and -rotation
Landsat 7 ETM+		1999 Aug 12	30 m	31.06	policy"
Landsat 5 TM		1991 Aug 30	30 m	27.87	Period 2: 1987–1988,
Landsat 5 TM		1989 Sep 17	30 m	38.11	Deng's "Open and
Landsat 5 TM		1987 Sep 20	30 m	28.24	reform" and
Landsat 3 MSS		1979 Oct 09	56 m		"Legalization of the
Landsat 3 MSS		1978 Aug 21	56 m	13.13	private economy"
					Period 1: 1979–1985, Nationwide implementation of Deng's "Household land tenure policy" and issues of the Decree of Grassland

Note: the haze values in digital count (DC) derived from the 4th Tasseled Cap feature are used for atmospheric correction.

1978, 1987, 1999 are considered to represent the initial state of the land at the beginning of each policy implementation period, and those of 2007 as representing the current state (see Table 17.1).

17.2 Data and Methods

17.2.1 Data

Multi-temporal Landsat images and the initial implementation dates of different policies concerning land use and management were compiled (Table 17.1) as well as meteorological data, especially monthly and annual rainfall from 1960 to 2007 (station locations shown in Fig. 17.1).

17.2.2 Method for Biophysical Change Extraction

Among a number of available change detection approaches, the post-classification differencing (Wu, 2008) and indicator differencing-and-thresholding algorithms were selected. Image pre-processing included image-to-image rectification (RMS error of 0.23–0.58 pixels), atmospheric correction using the COST model (Chavez, 1996; Wu, 2003b), transformation of the Enhanced Vegetation Index (EVI) developed by Huete et al. (1994) and the Normalized Difference Vegetation Index (NDVI) proposed by Rouse (1973) and Tucker (1979). After pre-processing a differencing and thresholding technique was applied to the EVI for the periods 1987–1999 and 1999–2007, and a post-classification differencing for the period 1978–1987 (overall classification accuracy >95%). For more details on this change detection technique is referred to (Wu et al., 2008). Here the emphasis is laid on the approaches for grassland biomass estimation.

17.2.3 Biomass Estimation Models

To project the biomass dynamics in response to land use change and land degradation in time, it is necessary to build up first biomass estimation models for the corresponding land use/cover type, in this case, rangeland interleaved with desert patches and croplands. In order to select an appropriate model, a comprehensive review was undertaken of the available estimation approaches, which is summarized in the following paragraphs.

Since 1980s a number of researchers have undertaken remote sensing-based biomass estimation for rangeland, grassland and savannah in different regions, such as Sahelian Africa (Tucker et al., 1983, 1985; Devineau et al., 1986; Justice and Hiernaux, 1986; Prince and Tucker, 1986, Diallo et al., 1991; Prince, 1991; Wylie et al., 1991 and 1995; Bénié et al., 2005), the grasslands in North America (Everitt et al., 1989; Merrill et al., 1993; Todd et al., 1998; Reeves, 2001; Reeves et al., 2001; Wylie et al., 2002; Butterfield and Malmstrom, 2004), in South America (Flombaum and Sala, 2007), in Inner Mongolia in China, and in Mongolia (Xiao et al., 1997, Kawamura et al., 2003; Akiyama et al., 2005; Kawamura et al., 2005; Akiyama and Kawamura, 2007; Ichiroku et al., 2008).

Tucker et al. (1985) found a strong correlation between the integrated satellite data (e.g.ΣNDVI) of the growing season and end-of-season aboveground herbaceous biomass for the Western Sahelian region where tree cover is less than 10%. Based on field measurements Devineau et al. (1986) obtained a non-linear relationship between herbaceous grassland biomass and NDVI, in the form B = 0.00216 $\text{NDVI}^{1.7}$ (t ha^{-1}, $R^2 = 0.927$), where NDVI is in fact NDVI $\times$ 100. Bénié et al. (2005) applied this equation to investigate the spatial-temporal dynamics of the herbaceous biomass in Burkina Faso. Buerkert et al. (1995) noticed that weed biomass is linearly correlated with NDVI in Niger in the form of B = 1.0417NDVI-0.2177 (t ha^{-1}, $R^2 = 0.777$).

Todd et al. (1998) used Tasseled Cap features (Greenness, Brightness and Wetness), NDVI and TM band 3 (Red) to investigate the above-ground biomass of the short-grass steppe of Eastern Colorado. They found that all of these indicators are well correlated to standing biomass ($R^2 = 0.62$–0.67) for grazed grassland but that the Red indicator is more responsive ($R^2 = 0.70$) than other indicators for ungrazed grassland. Frank and Karn (2003) obtained non-linear relationships between grassland biomass and NDVI in the Northern Great Plain in the form of $\text{B} = 2.698 + 3{,}709.449\ \text{NDVI}^3$ (kg ha^{-1}, $R^2 = 0.83$, $p \leq 0.05$) and found that NDVI has good potential for use in predicting biomass and canopy CO_2 flux rates for grassland. Butterfield and Malmstrom (2004) also reported that NDVI was strongly correlated with above-ground green biomass of grasslands in California throughout the growing season ($R^2 = 0.78$) and that a single NDVI-biomass function may be applied to the grasslands up to the period of peak greenness.

While quantifying herbaceous biomass in rangeland ecosystems in western North Dakota, Reeves (2001) worked out the relationship between biomass and NDVI, resulting into the equation $\text{B} = \text{NDVI}\,(65.0112) + \left(\sum \text{P}(0.9) - \left(\sum \text{Th}\right)^2 (0.0013)\right)$, where B is the estimated biomass within each Thiessen polygon, NDVI is the average NDVI for a given polygon, $\sum$P is the summation of precipitation from 1 January to the date of ground sampling, and $\sum$Th is the summation of thermal time (TAVGdaily – 0) from 1 January to the date of ground sampling where TAVGdaily is the daily average temperature. Reeves (2001) considered that the relationship between grassland biomass and LAI is strongest when the biomass is at its peak in July ($R^2 = 0.78$).

Yu et al. (2004) analysed the relationship between above-ground net primary production and annual rainfall in Inner Mongolia, China and found that peak above-ground biomass (PAB) is positively correlated with the annual rainfall (PAB = 0.5515Rainfall-25.631, $R^2 = 0.684$), in which the slope exceeds those obtained from other dry regions in Africa and South America implying a higher rain-use efficiency in Inner Mongolia. Kawamura et al. (2003) conducted biomass estimation in the same area employing AVHRR NDVI and later these authors (Kawamura et al., 2005) used MODIS vegetation indices to undertake a similar study by establishing both linear and exponential relationships. For the live and total biomass (including live and dead), these relationships are summarized in the regression equations of Table 17.2. It is clear from their study that for both live and total biomass MODIS NDVI and EVI are of higher predictive power than the same indices derived from AVHRR, and that NDVI gives a better result than EVI. Akiyama et al. (2005) obtained a similar level of correlation between the live biomass and MODIS EVI in the same region, with equation B = 18.722 exp (5.698EVI) ($R^2 = 0.744$).

Table 17.2 Regression analysis results between biomass and vegetation indices (After Kawamura et al., 2005)

Coefficient of determination	Explanatory variable	Function type	a	b	R^2	Average error ($g\ m^{-2}$)[a]
Total biomass (dry matter $g\ m^{-2}$) $n = 30$	AVHRR-NDVI	Linear	–58.23	571.37	0.53	± 54.24
		Exponential	11.13	6.07	0.64	± 36.65
	MODIS-NDVI	Linear	–160.02	628.08	0.75	± 40.08
		Exponential	16.31	4.26	0.83	± 33.16
	MODIS-EVI	Linear	–87.01	797.67	0.69	± 44.24
		Exponential	24.56	5.71	0.77	± 38.28
Live biomass (dry matter in $g\ m^{-2}$) $n = 30$	AVHRR-NDVI	Linear	–47.74	454.43	0.54	± 42.97
		Exponential	11.13	6.07	0.64	± 36.65
	MODIS-NDVI	Linear	–127.00	495.98	0.74	± 32.31
		Exponential	12.15	4.36	0.83	± 25.70
	MODIS-EVI	Linear	–73.39	644.10	0.71	± 33.75
		Exponential	18.35	5.86	0.80	± 28.48

Note: Linear-type: B = a + bX; Exponential-type: B = a∗Exp (bX); [a]Average error is calculated from the original "error sum of squares" by Kawamura et al. (2005).

Among the above mentioned models, the exponential one derived from MODIS NDVI for total biomass, by Kawamura et al. (2005) in Inner Mongolia, B = 16.31 exp(4.26*NDVI) ($R^2 = 0.83$) produced the best fit with the field biomass data measured in Ordos: (1) desert steppe for the period 2002–2005 (9.5–175.1 $g\ m^{-2}$ with a mean of 56.6 $g\ m^{-2}$) by Ma et al. (2008); (2) shrub-grassland within a range of 28–236 $g\ m^{-2}$ in Mu Us Sandy Land in 2006 by Cheng et al. (2007); (3) 50–100 $g\ m^{-2}$ in the Banners of Otog and Otog Front in the period July–August 2007 by the local government[1]; and 68–195 $g\ m^{-2}$ (mainly 124–140 $g\ m^{-2}$) in the enclosed grasslands in the north Yanchi near Sanduandi of Otog Front by Shen et al. (2007). In addition, Hu et al. (2007) investigated the spatio-temporal dynamics of aboveground net primary productivity (ANNP) in Inner Mongolia and reported the ANNP varying from 28.53 to 157.78 $g\ m^{-2}$ a in the western part of the Mu Us Sandy Land. Hence this model was selected for estimating the rangeland biomass for all other observation years.

[1]Ordos Weather Bureau, 2008: http://www.imwb.gov.cn/qxinfo/stinfo/200803/773.html

17.3 Results

The land degradation detection and multi-temporal biomass estimation results are shown in Figs. 17.2 and 17.3. Several types of degradation were observed. The first one is the southeasterly expansion of desert patches, especially in the non-controlled zones, at a rate of 11–21 m year^{-1}. In more detail, deserts and small patches of sand dunes expanded depending on location by 120–240 m, 90–180 m, and 60–150 m, or 240–570 m in total, in the periods 1978–1987, 1987–1999 and 1999–2007 (Fig. 17.2) and swallowed the grassland on their southeast margins where there were not enough shrubs (e.g., *Caragana Korshinskii Kom* and *Salix gracilior*) to block sand movement. This extension is a result of wind blowing from northwest, which occurs about 230 days per year. The second type is vegetation

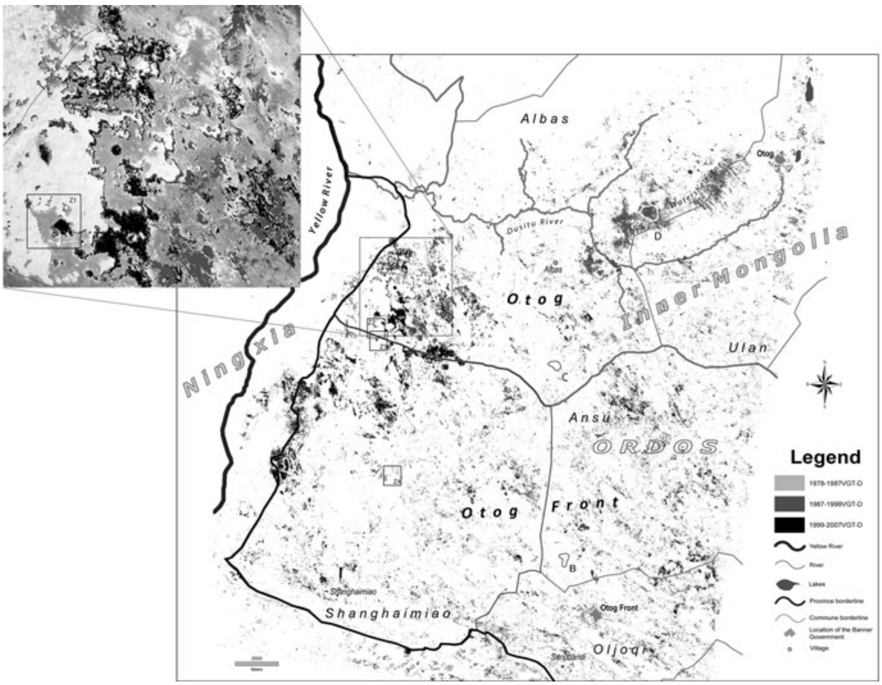

Fig. 17.2 Land degradation in the Western Ordos (modified from Wu et al., 2008). Note: this Figure shows (1) desert patches extending to the southeast (see the *up-left* zoom) along the dominant wind direction from NW to SE and (2) grassland in degradation in the observed periods 1978–1987, 1987–1999 and 1999–2007. Sites A, B, C and D were selected to check and calibrate the relationship between the biophysical feature changes (e.g., NDVI and biomass) and the annual rainfall variation. According to our previous work (Wu et al., 2008), Site A experienced degradation in 1978–1989 but controlled in 1991–1999 and again degradation after 2002; Sites B and C are protected or enclosed areas from grazing, no evident degradation was observed; site D suffered degradation in 1987–1999 but recovered after 2002. Zooms Z1, Z2 and Z3 are examples showing vegetation cover degradation around water points/settlements and Z4 a recovery (see Wu et al., 2008 for detail)

Fig. 17.3 Multi-temporal biomass dynamics in the Western Ordos

degradation around water ponds/settlements (with patch diameter varying from 300 to 1,600 m) and in some permitted rotation grassland, of which a part had previously been controlled. This kind of degradation is not stationary: in one period it was observed in one place, and in another period in another place.

While discerning vegetation degradation in some places, we also observed significant increase in vegetation vigor and cover (see Wu et al., 2008), especially in the recent decade. This greening trend is attributed to the conversion from grassland to agricultural land (including farmland, plantations of economic plants such as ephedra, licorice, etc.), and from natural grassland into pasture/forage land irrigated with underground water. Sand control in the sandy land and desert patches, by planting grasses, shrubs and trees in a grid pattern, has also increased the greenness of land cover. This practice has to some extent restored a number of degraded patches around water ponds/settlements, although the greenness in these patches has not yet reached the same level as the surrounding grassland after 20–30 years recovery.

In order to uncover the spatio-temporal variability of the biophysical features related to these land cover changes, and to understand the importance of human intervention in provoking land degradation, four typical sites, marked A, B, C and D (see Figs. 17.2 and 17.3 for locations), were extracted for checking biomass dynamics against annual rainfall (Fig. 17.4). Of these, sites A and D suffered degradation, whereas B and C experienced no significant change (see note of Fig. 17.2).

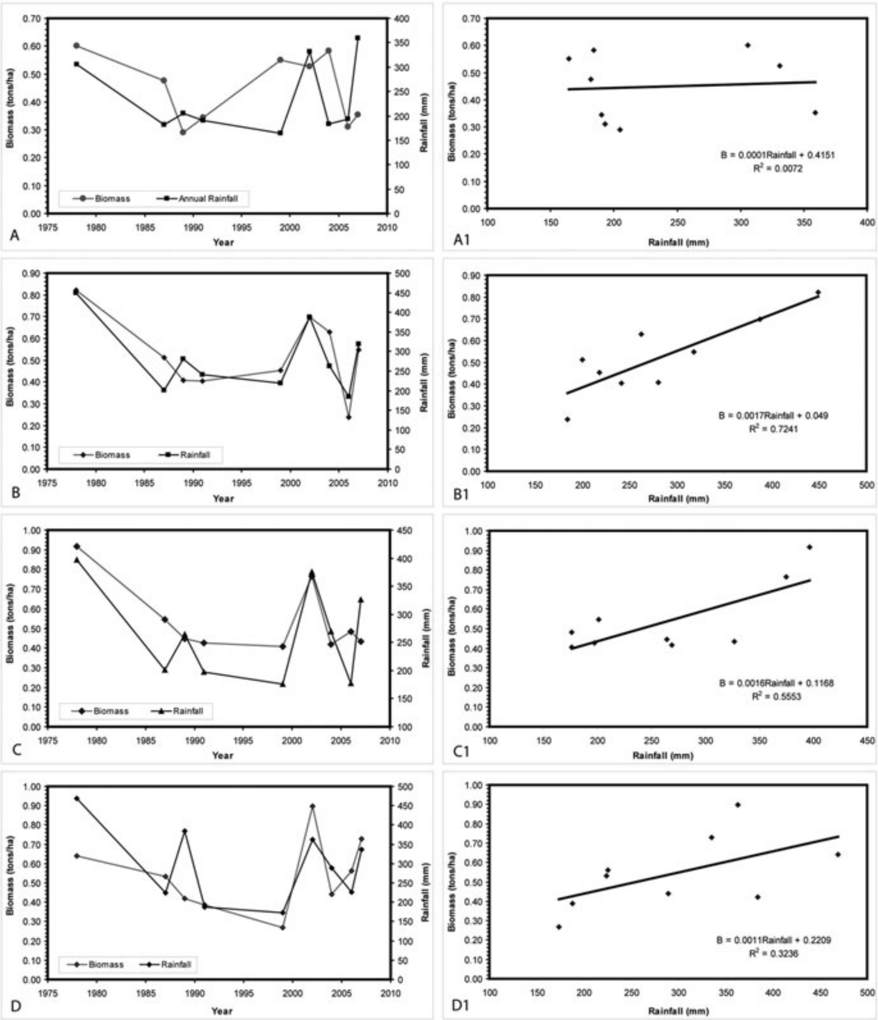

Fig. 17.4 Temporal biomass dynamics in the observed sites. Note: *Left side* graphs show biomass dynamics against annual rainfall in the Sites A, B, C and D, *right side* ones reveal their relationships

It was found that the average biomass production sensed by satellites in the sites A and D is not well correlated to their annual rainfall (A1 and D1 in Fig. 17.4, $R^2 =$ 0.007–0.324). However, in the enclosed or protected sites B and C a strong positive relationship exists between biomass density and the annual rainfall (B1 and C1 in Fig. 17.4) with R^2 values of 0.555–0.724, which are close to the correlation ($R^2 =$ 0.684) obtained by Yu et al. (2004) in Inner Mongolia.

17.4 Discussion and Conclusions

Land degradation as influenced by unfavourable land cover changes, is a complicated phenomenon related to both natural and human factors. After weighing the importance of the two groups of factors, Zhu and Liu (1989) concluded that the anthropogenic factors account for 94.5% of the responsibility in provoking desertification in China. It is thus essential to analyse the impacts of human activities on the environmental change and land degradation.

Heretofore, recognized human factors include overgrazing, population growth, land reclamation, institutional weaknesses, irrational policies, land tenure, market economy, water overuse, over-collection of fuelwood, over-excavation of wild medicinal and edible herbs, exploitation of fossil fuel (coal, oil and gas), overhunting, culture and lack of education (Jiang et al., 1995; Erdunzhav, 2002; Enkhee, 2003; Wu, 2003a; Gai, 2007). However, not all of these socio-economic and cultural factors had the same importance in effecting land degradation in history. Policies are the underlying forces driving other kinds of socio-economic activities (proximate causes) which directly lead to land use change, development of market economy and new enterprises, and exploitation of natural resources in Ordos (Wu et al., 2008).

In the past centuries, land reclamation from grassland for agriculture was, despite unsuccessful outcomes, undertaken again and again, driven by different national policies such as “Consolidating the frontier with immigrants from the interior of the country for reclamation” in Dynasty Qing and “Giving prominence to agricultural food production” in the period 1956–1974. Of little productivity under the semi-arid and arid climate conditions, rainfed cropland was, after 2–3 years of use (Enkhee, 2003; Wu, 2003a), often abandoned and exposed to soil erosion and desertification. New land reclamation was conducted elsewhere for food production. These practices constituted a vicious cycle “Reclamation-Cultivation-Abandonment-Reclamation” leading to land degradation in the rangelands (Wu, 2003a). As Enkhee (2003) analysed, land reclamation, regardless of natural conditions, might have been the major cause producing the initial state of the Hobq Desert in the north and the desert patches in the Mu Us Sandy Land (see the up-left zoom in Fig. 17.2 and the patches with biomass density < 0.3 t ha^{-1} in Fig. 17.4) in the south in Ordos since the Dynasty Tang (A.D. 618–907). Unfortunately, neither remote sensing images nor maps are available to back up this kind of historical land degradation analysis.

In the recent decades the impacts of policies can be analysed in a more tangible way. In the period 1979–1984, Deng's policy "Household responsibility for agricultural production" and the promulgation of the "Decree of Grassland" in 1985 had greatly aroused the enthusiasm of peasants and raised the agricultural production, but left the grassland in a situation "collective grassland and private cattle" which lasts up to today. To gain more personal profits and income, each herdsman had an incentive to raise as many animals as possible on the public land, inevitably leading to a Chinese variant of "the Tragedy of the Commons" (Hardin, 1968) and the "institutional defect" (Erdunzhav, 2002), which is the direct consequence of "indefinite land property" (Gai, 2007). During this period, land degradation, despite its localized character, occurred throughout the study area (1978–1987 VGT-D in Fig. 17.2).

In 1987–1988, under the development strategy "Invigorating the domestic economy and opening to the outside world", Deng's "Open and reform" policy, and the decree on "Legalization of the private economy", hundreds of rural enterprises and companies were established in Ordos, based on the region's agricultural and pastoral products like food, wool and natural resources (coal, oil, gas, medicinal and edible wild herbs). Widespread collection of herbs for providing materials to these enterprises and for increasing family income induced local people to overturn the fragile sandy soils in search for licorice roots (*Glycyrrhiza uralensis*) and *Nostoc commune* var. *Flagelliforme,* leading to a large reduction in biomass production in some areas and land degradation (e.g., see 1987–1999VGT-D and Site D in Fig. 17.2 and Fig. 17.4d). One bright spot during this period was the spontaneous establishment of an ecological construction enterprise – a non-governmental sand-control team – composed of the local peasants and shepherds. The objective of this team was to combat desertification by planting ephedra, licorice, *Hedysarumleave*, *Caragana korshinski*, *Artemisia sphaerocephala* and *Artemisia ordosica*, sea-buckthorn, etc., in a grid pattern to restore the degraded land and protect the sandy land from degeneration, and simultaneously bring economic benefits for the local people. No doubt this activity has greatly produced positive impacts on the environment, as evidenced by the biomass increase in the period of 1989–1999 in Site A (Fig. 17.4a).

After 1999, with the inauguration of the national middle-to-long term strategy "To Develop the West" in 1999, Ordos has become one of the National Energy Bases, thanks to its abundant fossil fuel resources. With the exploitation of coal, oil and natural gas and overuse of water in mining and agriculture, new forms of land degradation took place, particularly oil pollution, cropland destruction, water-table decline.[2] Aware of this serious land degradation, the central government promulgated a national order to "Forbid collection of herbs in grasslands" in 2000. Complementing this national policy, the local governments of Otog and Otog Front implemented a "Grazing-forbidden and -rotation policy with a subsidy system" in 2001 to treat grazing differently in different zones. The policies were implemented by closure of large pieces of grassland for recovery and by conversion of parts of

[2]http://yudefu186.bokee.com/viewdiary.15081810.html

highly productive grassland into pastures, cultivated with some aridity- and cold-resistant forage grasses such as alfalfa (*Medicago sativa*) and *Astragalus adsurgens* for animal breeding. As a result the previously open grazing became indoor dry-lot feeding. With the added boost of favourable rains biomass has since increased (e.g., Fig. 17.4). An interesting fact is that with the implementation of these policies, not only the vegetation vigour and biomass but also the cattle numbers have increased. This has led to an improvement of household income of the local peoples and their livelihood. The average per capita income of the rural people has increased by 60.9 and 119.1% respectively in the Banners Otog and Otog Front from 2000 to 2005 (Wu et al., 2008). However in areas where communal grazing was permitted or in the protected zones where surveillance was less effective, the grasslands have suffered even more grave destruction due to overgrazing (1999–2007 VGT-D in Fig. 17.2 and Fig. 17.4a), although the annual rainfall was normal in 2007.

In summary, the impacts of policy are complex and often entail positive and negative aspects, in terms of whether the policy can bring profits to the herdsmen and farmers while protecting grassland from degradation. The evidence from Ordos suggests that if there is a contradiction, land degeneration is unavoidable. The impact assessment should be dialectically conducted from multiple dimensions, although it is difficult to unravel the effects of overlapping policies.

This study attempted to assess the impacts of policy from a viewpoint of biophysical change, as revealed by remote sensing in the Western Ordos rangeland. Despite its immaturity this technology provides interesting possibilities to look into the interaction between changes in socio-economic activities, especially those that are policy-driven, and the ecological system. In the absence of human intervention, biomass productivity is completely associated with the natural conditions, such as rainfall, temperature and radiation. When there is human intervention, this productivity is not any more related only to natural conditions but also to land use practices and exploitation of land resources. This difference makes it possible to discern the contribution of human impact on the rangeland productivity. This is one of the advantages that remote sensing technology has brought us. Another fact revealed in this case study is that it is possible for decision-makers to work out sustainable grazing and rangeland use policy by controlling grazing intensity through carrying capacity analysis based on biomass productivity estimation.

Land degradation is not an irreversible biophysical degeneration. It is produced by implementation of unwise policies (e.g., land reclamation in the early of 1970s Zhang and Wang, 2001; Enkhee, 2003; Wu, 2003a) or by exploitative activities under rational policies (e.g., overgrazing in the permitted areas under the "grazing forbidden and rotation" policy; overuse of underground water for planting trees on the sand dunes to combat desertification). At the same time land degradation can also be mitigated and reversed by reasonable execution of rational policies. For example, the legalization of the private economy in 1988 not only promoted land degradation but also gave rise to the sand control enterprise in the region, which contributed significantly to the ecological recovery of the region. Similarly the "grazing forbidden" policy implemented with subsidies to herdsmen has truly restored and protected some grassland.

References

Akiyama, T. and Kawamura, K. (2007). Grassland degradation in China: Methods of monitoring, management and restoration. Grassland Science 53:1–17.

Akiyama, T., Kawamura, K., Yokota, H. and Chen, Z. (2005). Real-time monitoring of grass and animal for steppe management in Inner Mongolia, China. Proceedings of the AARS (Asian Association of Remote Sensing) 2005 Conference. Mongolia, China. Available at: http://www.aars-acrs.org/acrs/proceeding/ACRS2005/Papers/EEC-1.pdf.

Buerkert, A., Lawrence, P.R., Williams, J.H. and Marschner, H. (1995). Non-destructive measurements of biomass in millet, cowpea, groundnut, weeds and grass swards using reflectance, and their application for growth analysis. Experimental Agriculture 31:1–11.

Butterfield, H. and Malmstrom, C. (2004). Phenological changes in the relationship between NDVI and aboveground biomass in California annual grasslands. Proceedings of Ecological Society of America (ESA) 2004 Annual Meeting. Portland, Oregon, USA (abstract available at: http://abstracts.co.allenpress.com/pweb/esa2004/document/37735).

Bénié, G.B., Kaboré, S.S., Goïta, K. and Courel, M-F. (2005). Remote sensing-based spatio-temporal modeling to predict biomass in Sahelian grazing ecosystem. Ecological Modelling 184:341–354.

Chavez, P.S., Jr. (1996). Image-based atmospheric correction – revisited and improved. Photogrammetric Engineering and Remote Sensing 62:1025–1036.

Cheng, X., An, S., Chen, J., Li, B., Liu, Y. and Liu, S. (2007). Spatial relationships among species, above-ground biomass, N, and P in degraded grasslands in Ordos Plateau, north-western China. Journal of Arid Environments 68:652–667.

Devineau, J.L., Fournier, A. and Lamachere, J.M. (1986). Programme d'évaluation préliminaire SPOT. PEPS No. 149 – SPOT Oursi. Centre ORSTOM de Ouagadougou, 52 pp.

Diallo, O., Diouf, A., Hanan, N.P., Ndiaye, A. and Prevost, Y. (1991). AVHRR monitoring of savanna primary productivity in Senegal, West Africa: 1987–1988. International Journal of Remote Sensing 12:1259–1279.

Enkhee, J., (2003). A historical rethink about the grassland desertification: The cultural dimension of development, Friends of Nature, No.7 (in Chinese, available at: http://old.fon.org.cn/enl/content.php?id=64).

Erdunzhav. (2002). Reflections on institutional deficiency that account for grassland desertification. Journal of Inner Mongolia University (Humanities and Social Sciences) 34:8–12.

Everitt, J.H., Escobar, D.E. and Richardson, A.J. (1989). Estimating grassland phytomass production with near-infrared and mid-infrared spectral variables. Remote Sensing of Environment 30:257–261.

Flombaum, P. and Sala, O.E. (2007). A non-destructive and rapid method to estimate biomass and aboveground net primary production in arid environments. Journal of Arid Environments 69:352–358.

Frank, A.B. and Karn, J.F. (2003). Carbon dioxide flux, biomass, and radiometric reflectance of northern Great Plains Grasslands. Journal of Range Management 56:382–387.

Gai, Z. (2007). Grassland property right and its eco-environmental protection, Globalization Forum (in Chinese, available at: http://www.china-review.com/gath.asp?id=18883).

Hardin, G. (1968). The tragedy of the commons. Science 162:1243–1248.

Hu, Z., Fan, J., Zhong, H. and Yu, G. (2007). Spatiotemporal dynamics of aboveground primary productivity along a precipitation gradient in Chinese temperate grassland, Science in China, Series D. Earth Sciences 50:754–764.

Huang, Y. and Zhang, M. (2006). Temporal and spatial changes of plant community diversity on the Ordos Plateau. Biodiversity Science 14:13–20.

Huete, A.R., Justice, C. and Liu, H.Q. (1994). Development of vegetation and soil indices for MODIS-EOS. Remote Sensing of Environment 49:224–234.

Ichiroku, H., Kawada, K., Kurosu, M., Batjargal, A., Tsundeekhuu, T. and Nakamura, T. (2008). Grazing effects on Floristic composition and above ground plant biomass of the grasslands in the Northeastern Mongolian Steppes. Journal of Ecology and Field Biology 31:pp. 115–123.

Jiang, H., Zhang, P., Zheng, D. and Wang, F., (1995). The Ordos plateau of China. In: J.X. Kasperson, R. E.Kasperson and B. L. Turner II (eds.), Regions at Risk: Comparisons of Threatened Environments. United Nations University Press, Tokyo (available at: http://www.unu.edu/unupress/unupbooks/uu14re/uu14re11.htm).

Justice, C.O. and Hiernaux, P.H.Y. (1986). Monitoring the grasslands of the Sahel using NOAA AVHRR data: Niger 1983. International Journal of Remote Sensing 7:1475–1497.

Kawamura, K., Akiyama, T., Watanabe, O., Hasegawa, H., Zhang, F.P., Yokota, H. and Wang, S. (2003). Estimation of aboveground biomass in Xilingol Steppe, Inner Mongolia using NOAA/NDVI. Grassland Science 49:1–9.

Kawamura, K., Akiyama, T., Yokota, H., Tsutsumi, M., Yasuda, T., Watanabe, O. and Wang, S. (2005). Comparing MODIS vegetation indices with AVHRR NDVI for monitoring the forage quantity and quality in Inner Mongolia grassland, China. Grassland Science 51:33–44.

Ma, W., Yang, Y., He, J., Zeng, H. and Fang, J. (2008). Temperate grassland biomass and its relation with environmental factors in Inner Mongolia (in Chinese), Chinese Science (C). Life Science 38:84–92.

Merrill, E.H., Bramble-Brodahl, M.K., Marrs, R.W. and Boyce, M.S. (1993). Estimation of green herbaceous phytomass from Landsat MSS data in Yellowstone National Park. Journal of Range Management 46:151–157.

Prince, S.D. (1991). Satellite remote sensing of primary production: Comparison of results for Sahelian grasslands 1981–1988. International Journal of Remote Sensing 12:1301–1311.

Prince, S.D. and Tucker, C.J. (1986). Satellite remote sensing of rangelands in Botswana II: NOAA AVHRR and herbaceous vegetation. International Journal of Remote Sensing 7:1555–1570.

Reeves, M.C., (2001). Quantifying Herbaceous Biomass in a Rangeland Ecosystem Using MODIS Land Products (available at: http://www.ntsg.umt.edu/projects/rangeland).

Reeves, M.C., Winslow, J.C. and Running, S.W. (2001). Mapping weekly rangeland vegetation productivity using MODIS algorithms. Journal of Range Management 54:A90–A105.

Rouse, J.W., Haas, R.H., Schell, J.A. and Deering, D.W. (1973). Monitoring vegetation systems in the Great Plains with ERTS', Third ERTS Symposium, NASA SP-351 I, pp. 309–317.

Serneels, S. and Lambin, E.F. (2001). Proximate cause of land-use change in Narok District, Kenya: A spatial statistical model. Agriculture, Ecosystem and Environment 85:65–81.

Shen, Y., Zhang, K., Du, L. and Qiao, F. (2007). Impacts of exclusion region on vegetation feature and diversity in Yanchi County, Ningxia. Ecology and Environment 16:1481–1484.

Todd, S.W., Hoffer, R.M. and Milchunas, D.G. (1998). Biomass estimation on grazed and ungrazed rangelands using spectral indices. International Journal of Remote Sensing 19:427–438.

Tucker, C.J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 8:127–150.

Tucker, C.J., Vanparet, C.L., Boerwinkel, E. and Gaston, A. (1983). Satellite remote sensing of total dry matter production in the Senegalese Sahel. Remote Sensing of Environment 13:461–474.

Tucker, C.J., Vanpraet, C.L., Sharman, M.J. and Van Ittersum, G. (1985). Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel: 1980–1984. Remote Sensing of Environment 17:232–249.

Veldkamp, A., Verburg, P.H., Kok, K., De Koning, G.H.J., Priess, J. and Bergsma, A.R. (2001). The need for scale sensitive approaches in spatially explicit land use change modeling. Environmental Modeling and Assessment 6:111–121.

Verburg, P.H., Veldkamp, W.S.A. et al. (2002). Modelling the spatial dynamics of regional land use: The CLUE-S model. Environmental Management 30:391–405.

Wu, W. (2003a). Evaluation on land use and land cover changes in north Shaanxi, China. Photo-Interpretation 36:15–29.

Wu, W. (2003b). Application de la géomatique au suivi de la dynamique de l'environnement en zones arides, PhD dissertation, Université de Paris 1, France, p. 217.

Wu, W. (2008). Monitoring land degradation in drylands by remote sensing. In: A. Marini and M. Talbi (eds.), Desertification and Risk Analysis Using High and Medium Resolution Satellite Data. Springer, Berlin, pp. 157–169.

Wu, W., De Pauw, E. and Zucca, C. (2008). Land degradation monitoring in the West Mu Us, China. Proceedings of ISPRS 2008, Part B 8:847–858.

Wu, W., Lambin, E.F. and Courel, M-F. (2002). Land use and cover change detection and modeling for North Ningxia, China. Proceedings of Map Asia 2002, Bangkok, Thailand, Aug.6–9, 2002 (available at: http://www.gisdevelopment.net/application/environment/overview/envo0008.htm).

Wu, W., Zucca, C. and Enne, G. (2005). Land degradation monitoring in the Ordos region, China. Proceedings of the International Conference on Remote Sensing and Geoinformation Processing in the Assessment and Monitoring of Land Degradation and Desertification (RGLDD), Trier, Germany, pp. 618–625.

Wylie, B.K., Dendra, I., Piper, R.D., Harrington, J.A., Reed, B.C. and Southward, G.M. (1995). Satellite-Based herbaceous biomass estimates in the pastoral zone of Niger. Journal of Range Management 48:159–164.

Wylie, B.K., Harrington, J.A., Jr., Prince, S.D. and Denda, I. (1991). Satellite and ground-based pasture production assessment in Niger: 1986–1988. International Journal of Remote Sensing 12:1281–1300.

Wylie, B.K., Meyer, D.J., Tieszen, L.L. and Mannel, S. (2002). Satellite mapping of surface biophysical parameters at the biome scale over the North American grasslands, A case study. Remote Sensing of Environment 79:266–278.

Xiao, X., Ojima, D.S., Ennis, C.A., Schimel, D.S. and Chen, Z.Z. (1997). Estimation of above-ground biomass of the Xilin River Basin, Inner Mongolia using Landsat TM imagery. In: Inner Mongolia Grassland Ecosystem Research Station, Chinese Academy of Sciences (ed.), Research on Grassland Ecosystem 5, Science Press, Beijing, pp. 130–138.

Xie, Y., Mei, Y., Tian, G. and Xing, X. (2005). Socio-economic driving forces of arable land conversion: A case study of Wuxian City, China. Global Environmental Change (Part A) 15:238–252.

Xu, J. (2006). Sand-dust storms in and around the Ordos Plateau of China as influenced by land use change and desertification. CATENA 65:279–284.

Yu, M., Ellis, J.E. and Epstein, H.E. (2004). Regional analysis of climate, primary production, and livestock density in inner Mongolia. Journal of Environmental Quality 33:1675–1681.

Zhang, F. and Wang, L. (2001). Analysis on land use situation in the Banner Ejinhoro, Research Report of UNDP Project: Construction of the capacity to implement the UNCCD in China (available at: http://nic6.forestry.ac.cn/sts/tdly/tdly.html).

Zhu, Z. and Liu, S. (1989). Desertification and Its Control in China (in Chinese). Science Press, Beijing, China.