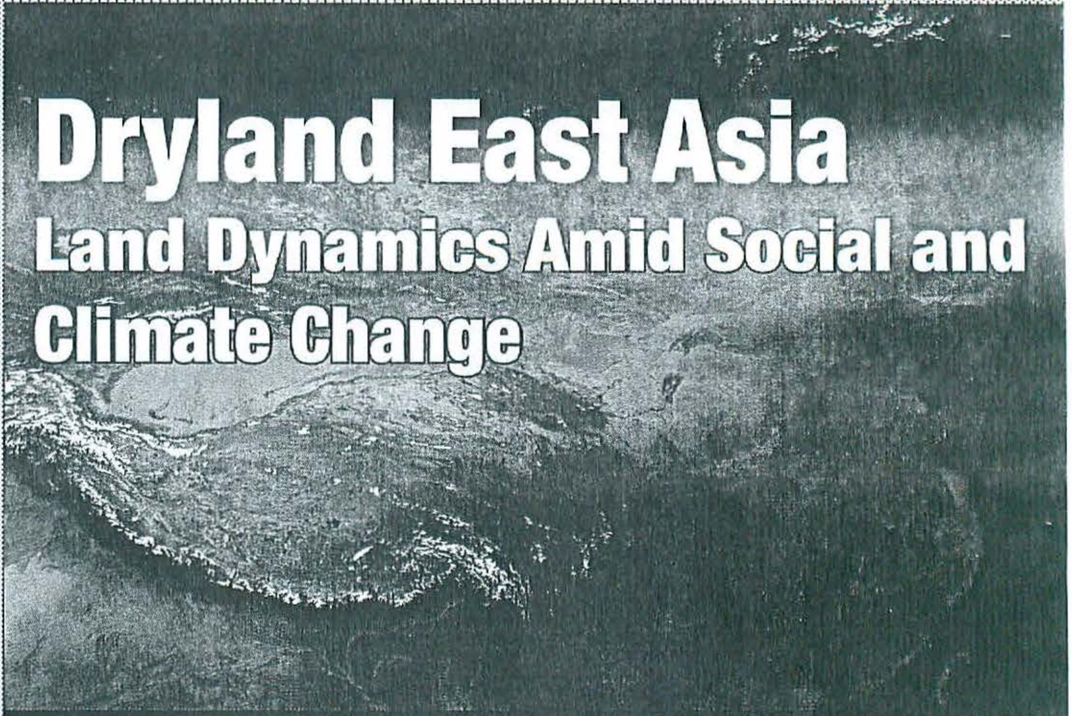
Ecosystem Science and Applications

Dryland East Asia

Land Dynamics Amid Social and Climate Change



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高等教育出版社
HIGHER EDUCATION PRESS

Chapter 1

State and Change of Dryland East Asia (DEA)

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Summary: Dryland East Asia (DEA) refers to a region with 4.81 million square kilometers (km^2) and includes Mongolia and four provinces/regions in Northern China (hereafter called "administrative units"): Inner Mongolia, Gansu, Ningxia, and Xinjiang. This introduction chapter provides an overview of the DEA region from three perspectives: 1) geography, demography, and economics, 2) climate and land use changes, and 3) ecosystem production and evapotranspiration. Development of a sound adaptation plan, therefore, is becoming a necessity for the sustainable future of a region such as DEA. We emphasize the spatial and temporal variations of the major variables associated with each of the three topic areas. Finally, we discuss the scientific and societal challenges for developing adaptation plans based on the concept of coupled natural and human (CNH) systems.

1.1 Geography, Demography and Economics in DEA

Dryland East Asia (DEA) is defined in this book as a region that includes Mongolia (MG) and four provinces/regions in Northwestern China (hereafter, called "administrative units"): Inner Mongolia Autonomous Region (IM), Gansu Province (GS), Ningxia Hui Autonomous Region (NX), and Xinjiang Uygur Autonomous Region (XJ). The 4.81 million square kilometer region (Fig. 1.1) is approximately the half size of China or the USA, with XJ as the largest province

(1.638×10^6 km^2) and NX as the smallest province (0.052×10^6 km^2) (Table 1.1). DEA borders Russia and Kazakhstan to the north and Kyrgyzstan, Tajikistan, Afghanistan, and Kashmir to the west (Fig. 1.1). The biogeographic units of DEA (i.e., ecoregions), classified by the World Wildlife Fund (WWF), include eight biomes within the Palearctic Realm (Olson et al., 2001) and are dominated by deserts and xeric shrublands (47.3%), temperate grasslands (23.4%), and temperate forests (11.1%). DEA has the Pamir Plateau and the Tibetan Plateau

Table 1.1 Composition (%) of land cover types in the Dryland East Asia (DEA) region that includes four provinces in China and Mongolia. The five dominant cover types are shown in bold.

Cover Type	Regions					Overall
	IM	NX	GS	XJ	MG	
Region land area (million km^2)	1.152	0.052	0.405	1.638	1.566	4.814
Evergreen needleleaf forest	0.08	0.07	0.62	0.31	0.62	0.38
Evergreen broadleaf forest	0.02	0.00	0.01	0.00	0.01	0.01
Deciduous needleleaf forest	1.08	0.00	0.02	0.07	0.55	0.47
Deciduous broadleaf forest	0.45	0.23	1.07	0.01	0.08	0.23
Mixed forests	**6.16**	**0.27**	**3.70**	**0.25**	**1.68**	**2.42**
Closed shrublands	0.07	1.56	0.57	0.07	0.08	0.13
Open shrublands	**9.85**	**43.03**	**13.28**	**10.64**	**9.14**	**10.52**
Woody savannas	2.50	0.16	0.92	0.37	0.98	1.12
Savannas	0.82	0.51	1.27	0.09	0.34	0.45
Grasslands	**41.21**	**40.19**	**28.12**	**12.66**	**54.66**	**34.77**
Permanent wetlands	0.03	0.01	0.01	0.00	0.02	0.01
Croplands	**13.11**	**8.73**	**7.83**	**3.04**	**1.58**	**5.42**
Urban and built-up	0.19	1.02	0.40	0.15	0.00	0.14
Croplands	0.36	0.27	0.39	0.18	0.06	0.20
Permanent snow and ice	0.00	0.00	0.02	0.70	0.00	0.26
Barrens	**23.59**	**3.51**	**41.70**	**71.00**	**29.24**	**42.87**
Water	0.48	0.42	0.08	0.45	0.95	0.59
Total (5 dominants)	**93.92**	**95.74**	**94.63**	**97.59**	**96.30**	**96.01**

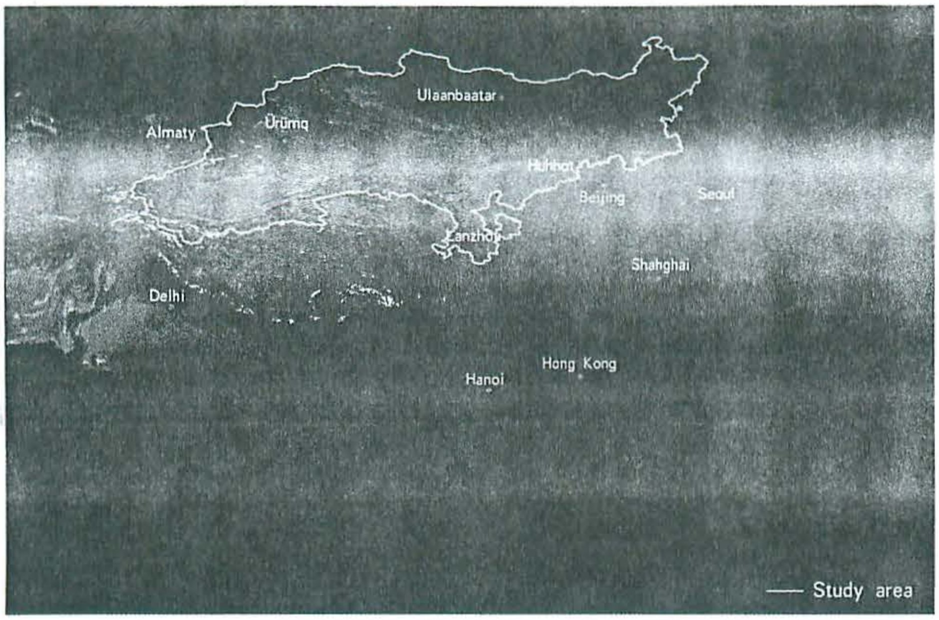

Fig. 1.1 The DEA region, with an elevation of −154 m–7,929 m asl, boarders the Tibetan Plateau in the southwest and is comprised of five administrative units, including four provinces/autonomous regions in China (Xinjiang, Gansu, Ningxia, and Inner Mongolia) and Mongolia. The Blue Marble Next Generation—a true-color earth dataset including seasonal dynamics from MODIS—is generated by combining MODIS NDVI with elevation derived from the three arc-second Shuttle Radar Topography Mission (SRTM) between 60°S and 60°N latitude (Stöckli et al., 2007).

in its southwest region and the Mongolian Plateau lies in the eastern portion of the region. The Tianshan and Kunlun Mountains lie at the western end of the DEA region, while the Qilian and Altay Mountains mark DEA's southern and northern boundaries, respectively. The Greater Xing'an Range runs from southwest to northeast in the northeastern part of DEA. The regional elevation varies from −154 m in the Lop Desert to 7,929 m in the Kunlun Mountains. These high-relief mountains are responsible for the existence of the 0.532×10^6 km^2 of temperate forest biomes and the relatively large amount of mountain grasslands and shrublands (17.1%). The Yellow River runs partially through the middle of the DEA region. Several major deserts (e.g., Gobi, Taklimakan, Junggar, Ordos, Lop, Badain Jaran and Maowusu) can be found within the region. The Taklimakan Desert is 337,000 km^2 with about 85% consisting of shifting sand dunes (i.e., the second-largest one next to the Sahara Desert) and is a major barrier along the Silk Road pathways. The Badain Jaran Desert, as another example, is home to the tallest stationary dunes on the earth (up to

500 m high). The increasing frequency and intensity of dust storms in East Asia have been attributed to these massive deserts and other degraded grasslands (Lu et al., 2009; Xuan et al., 2000).

In China, the region has special significance for national security and environmental concerns (e.g., the testing site for nuclear bombs in Lop Nur, the space flight center in Jiuquan, etc.). Mongolia itself is the 19th largest and most sparsely populated country in the world. It is also the world's second-largest landlocked country after Kazakhstan. The country contains very little arable land, as much of its area is covered by arid and unproductive steppes, with mountains to the north and west and the Gobi Desert to the southwest. Approximately 30% of the population is nomadic or semi-nomadic. For the Land Cover and Land Use Change (LCLUC) Program of the National Aeronautics and Space Administration (NASA), DEA is the continental extreme for the Monsoon Asia Integrated Regional Study (MAIRS) domain and the southern end of the Northern Eurasian Earth Science Partnership Initiative (NEESPI) domain (Groisman et al., 2009; Qi et al., 2012).

The population of all five administrative units has been steadily increasing, with an average annual rate of 2.19%, but varied from 1.14% in IM to 2.42% in NX (Fig. 1.2). The total population in DEA increased from 54.37 million in 1978 to 78.07 million in 2004. In 2008, the population density varied from 13.0/km^2 in XJ to 118.1/km^2 in NX, 21.3/km^2 in IM, and 65.0/km^2 in GS (Fig. 1.2a), which are all significantly lower than the Chinese national average of 139.6/km^2. Mongolia remains sparsely occupied, with a population density of 1.6/km^2 in 2004—an increase of 2.35%. Diverse ethnic groups such as Uygur, Mongol, Hui, Kazak, Man, and Zang (Tibetan) characterize all four administrative units in China. They are considered "Minority Regions" because of their diverse and numerous ethnic groups. Consequently, the region has been considered a focal area for government support (e.g., the Northwest Construction Program) since the early 1980s and for special policies set by the central governments such as college education, financial compensation, number of children per family, etc. However, the proportion of Han Chinese has been steadily increasing and becoming the majority in all four units. For example, Han Chinese comprises 79.1% of the population in IM, while Mongols account for 17.2%. In XJ, Uygur remains dominant (45%) over Han Chinese (41%). The major cities with large populations include Ürümqi (2.744 million) in XJ, Baotou (1.779 million) and Huhhot (2.867 million) in IM, Lanzhou (2.177 million) in GS, Yinchuan (1.290 million) in NX, and Ulaanbaatar (1.190 million) in MG (see Fan et al., this book). This accounts for 15.4% of the total population in the region. Further north, in Mongolia, 43.2% of its 2.6 million people can be found in its capital (Ulaanbaatar). Over the past decade, urbanization has continued to intensify due to the transition from a centralized economy to a market economy; this has resulted in an increase in urban population from 21.6% in 1956 to 63.3% in

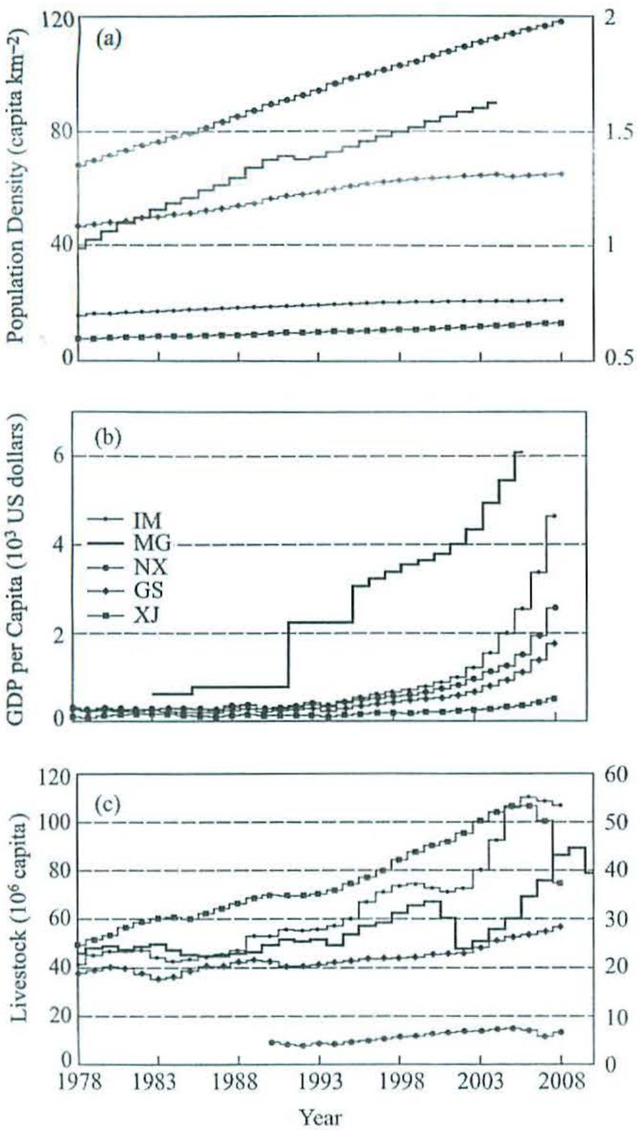

Fig. 1.2 Change in population density (a), gross domestic product (GDP) per capita (b), and livestock (c) in the five administrative units of the DEA region from 1978 through 2009. Note that the population density of Mongolia in (a) and livestock of MG, NX, GS, and XJ in (c) are marked by the second vertical axis on the right.

2006 (Ojima and Chuluun, 2008). The "Great Movement", started in 1990, will further aggregate land use in rural areas—a potential new land-use scenario for the future.

DEA has maintained a steady and high economic growth over the past three decades, with an earlier (since 1990) but slower takeoff in MG than those units in China (Fig. 1.2b). In MG, the transition from the centralized economy to the market economy started in 1990 after the collapse of former Soviet Union, with an average growth rate of about 2.8% in the 1990s and >6% in the recent decade.

The GDP per capita in MG was \$611 in 1983 but jumped to \$6,082 in 2006 — a tenfold increase over a 23-year period. In China, the "Open Economy Policy", implemented since 1979, promoted a miraculous growth of 9.7% between 1979 and 2006 at the national level. Interestingly, China was not affected by the global economic depression that began in 2008. However, because of its large population, the GDP per capita in the four DEA units of China was only \$233 in 1983 and \$1,373 in 2006, which were 38.1% and 22.8% of MG, respectively, for the two considered years, regardless of high GDP. Additionally, the economic growth was not evenly shared among the four units, with IM ranking first among China's 31 provinces, while XJ, GS, and NX had much smaller GDP growth. As a result, the GDP per capita in 2008 was \$4,639 and \$504 in IM and XJ, respectively. The lower-than-average economic growth and the significant differences among the units have been recognized by the government and are currently considered priority areas for development to address the regional disparity in upcoming years (i.e., China's 12th five-year plan, Qi et al., 2012).

Livestock has been widely used as a primary metric in dryland regions because of its importance in linking people, the economy and the environment. The livestock population in the DEA region doubled from 110.67×10^6 in 1978 to 222.38×10^6 in 2008 (Fig. 1.2c). An 88.7% increase was found in MG for the study period, while a 104.1% increase was found for the other four units within China. GS and XJ had the lowest increase, at ~50%, while IM and NX achieved 164.2% and 156.5% increases, respectively. The above differences in changes of livestock population among the four units in China may be partially due to the relatively high proportion of grasslands in IM (41.25) and NX (40.2%) and the low proportions in GS (28.2%) and XJ (12.7%) (Table 1.1). The large amount of livestock in IM (24.2% of DEA in 2008) made IM China's largest import base for dairy products (Sneath, 1998). Over time, the changes in livestock population seem to have had many more variables in IM and MG (i.e., on the Mongolian Plateau), but not in the other three units. We suspect that this may be related to the high sensitivity of the plateau to the changing climate because the Mongolian Plateau, with an elevation of 900–1,500 m, has been identified as one of the most sensitive regions in the world to the warming climate by IPCC (2007). For example, clear reductions in livestock population from 2000–2001 and 2008–2009 were recorded and both related to climate events such as low precipitation or drought (Fig. 1.3 and Fig. 1.4).

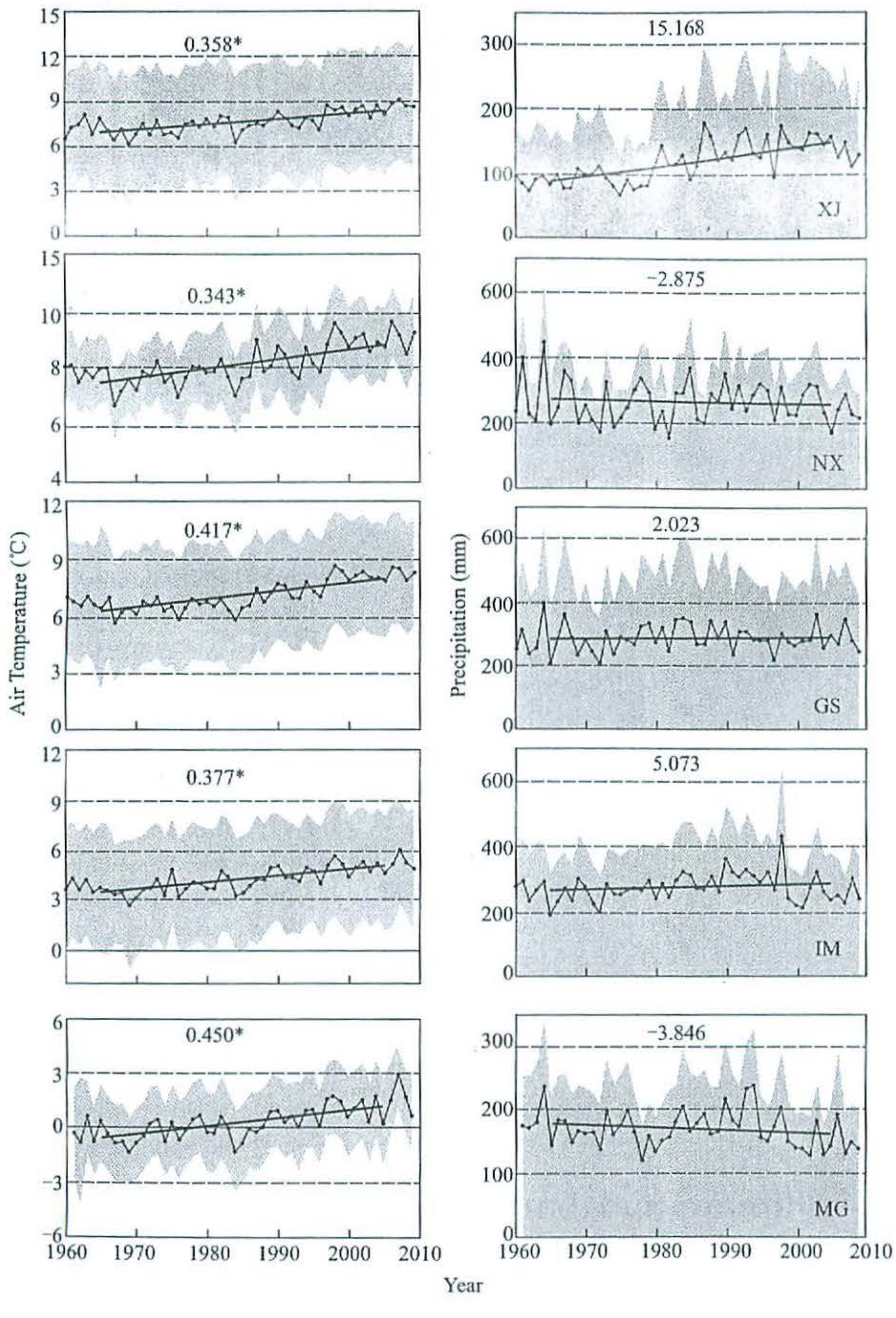

Fig. 1.3 Long-term changes of annual mean air temperature and precipitation between 1960 and 2009 in the five administrative units of DEA, showing a consistent warming trend in all five units but a variable precipitation trend. The number in each panel indicates the decadal change of temperature (°C) or precipitation (mm) and the * indicates a significant level at 0.05.

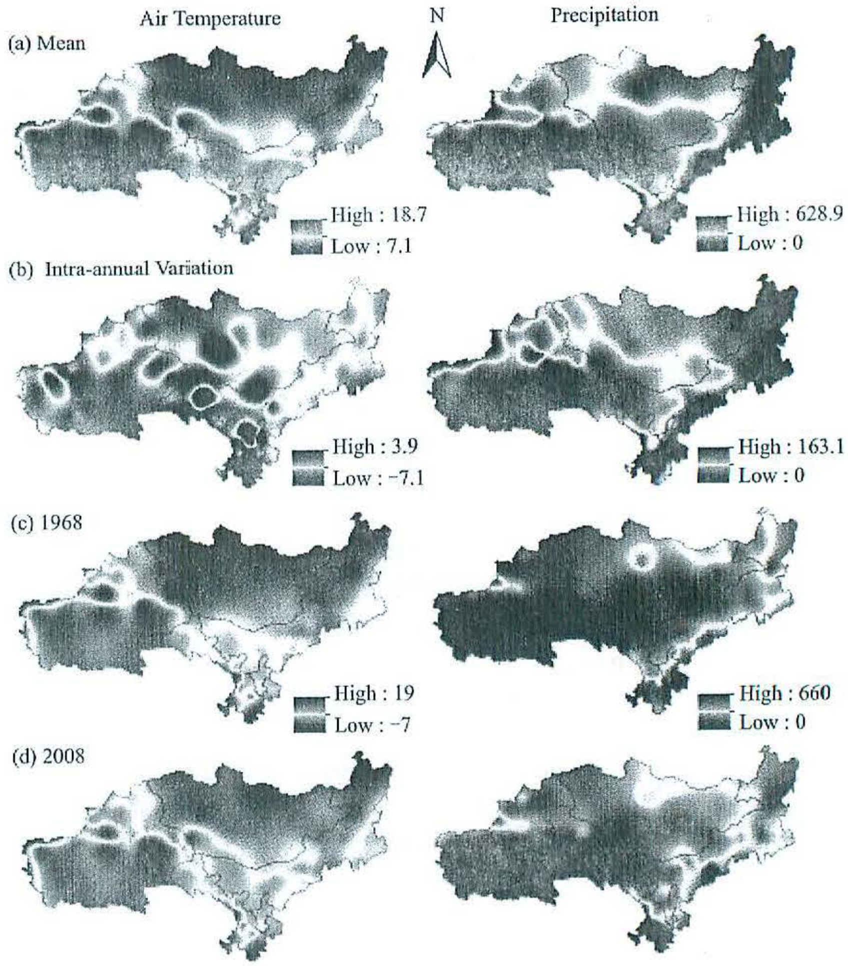

Fig. 1.4 Changes in long-term mean (1960–2009), standard deviation (i.e., intra-annual variation), and annual mean in 1996 and 2008 across the DEA region. These spatially continuous trend maps were created using the tension spline method based on 166 national climatic stations in China and Mongolia.

1.2 Climate and Land-Use Changes

Long-term *in situ* records of temperature and precipitation were used to quantify changes over time and across DEA landscapes (Lu et al., 2009). The daily meteorological data (1961–2009) from 149 weather stations was acquired from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/), while monthly mean temperature and precipitation at 17 national meteorological stations in Mongolia were provided by the Hydro-Meteorological Agency of

Mongolia for the same time period. The latitude, longitude, and elevation for each of the 166 stations were also included in the data, allowing us to analyze the spatial variation. We spatially interpolated the annual mean temperature and precipitation using a tension spline method (Franke, 1982; Mitas et al., 1988). The tension spline creates a less-smooth surface as compared to a regular spline, with values constrained closer to the sample range. This is especially true for the interpolated extreme values for annual temperature and precipitation. The tension spline was projected on a 5,600 m (i.e., 0.05 degree) to match the Climate Modeling Grid (CMG), with an Albers equal area projection.

There has been a significant increase in annual mean temperature, but variable, insignificant changes in precipitation for the study period from 1960–2009 (Fig. 1.3). The long-term changes in both temperature and precipitation are complicated by the high intra-annual variations as well as the complex topography (Fig. 1.1a). The decadal increase in annual temperature was higher in MG and GS (0.450 and 0.417 °C/10 yr, respectively) than in the three remaining units, with the lowest warming (0.343 °C/10 yr) in NX. As a result, the annual mean temperature in XJ, NX and IM has not been below zero since 1985. These increasing trends were previously reported for different biomes and spatial scales. Lu et al. (2009) reported that the warming is more affected by daily minimum temperature than daily maximum values (see also Zhai & Pan, 2003), suggesting that the warming trends reported here are likely less pronounced than when minimum daily temperature is used. They also reported that the grassland biome (+0.41 °C/10 yr) and desert biome (+0.39 °C/10 yr) experienced more increases in air temperature per decade than forest biomes (0.27 °C/10 yr). Precipitation at low elevations has been increasing; however, at high elevations, it has been decreasing. On a seasonal basis, the trend of temperature increases was higher in winter (0.42 °C/10 yr) than fall (0.34 °C/10 yr), spring (0.30 °C/10 yr), or summer (0.27 °C/10 yr). As for precipitation, we did not find a significant change for any unit from a linear regression analysis. However, NX and MG had an overall decreasing trend over the 50-year study period, compared to the increasing trends in the other three units (Fig. 1.3). XJ has the largest portion of deserts (71.0%, Table 1.1) and experienced the highest increase (15.2 mm/10 yr) in precipitation (Piao et al., 2005). The fact that arid biomes get more rain in DEA is different from other arid regions (e.g., North Africa and Australia), where a marked decrease in Sahelian rainfall and increased precipitation variability in arid Australia have been reported (Dai et al., 2004; Morton et al., 2011).

From the southwest to northeast, annual mean temperature decreases while precipitation increases (Fig. 1.4a). Warmer anomalies were found around the Lop and Taklimakan Deserts in XJ, while cold anomalies were found in Tianshan, the Greater Xing'an Range, and northern Mongolia. This spatial pattern of the surface air temperature in DEA does not match as well with the spatial distribution of precipitation in southeastern DEA as it does in southern GS, NX, and IM, where high annual means coincide with high precipitation. More importantly, there seem to be contrasting spatial patterns for the intra-annual variations (i.e., measured by the standard deviation of the climatic data from 1960 to 2009) for both variables (Fig. 1.4b). High intra-annual variations in temperature were found in southwest Tianshan, Yumen of GS (a.k.a., the west end of the Great Wall of China), Qilianshan, and the northern Gobi Desert. Precipitation variability, on the other hand, matches well with its spatial means—the higher mean values correspond to higher precipitation variances. To demonstrate the intra-annual variability of temperature and precipitation, we include the spatially interpolated distributions in an extreme cold and dry year (1968, Fig. 1.4c) and a warm and wet year (2008, Fig. 1.4d).

Current land cover types (MODIS-IGBP LC) following the IGBP classification system (Olson et al., 2001) in DEA are predominated by barrens and sparsely vegetated land (2.06×10^6 km^2, 42.9%), temperate grasslands (1.67×10^6 km^2, 34.8%), (0.51×10^6 km^2, 10.5%), and croplands (0.26×10^6 km^2, 5.42%) (Table 1.1, Fig. 1.5a). Croplands, open shrubland, and mixed coniferous forest account for >96% of the DEA region; urban land use occupies only 6.8×10^3 km^2 (0.2%), despite the high population in the region. From 1992 to 2004, there were significant increases in cropland, barren land, urban land, and grassland in IM, while MG had the smallest amount of croplands in the region. The average composition of land cover types is deviated for every unit, including ~84% of MG as grasslands and barrens, 71.0% of XJ as barrens, and 43.0% NX as shrublands (Table 1.1).

DEA landscapes have also been undergoing dramatic changes. The grasslands fluctuated between 33.7% and 42.0% between 2001 and 2009, while barrens fluctuated between 43% and 47%. Urban growth, desertification and land conversion to agricultural systems are the three major land-use changes in recent decades. John et al. (2009) reported that the urban, crop, and barren lands in IM increased by 249%, 47%, and 151%, respectively, resulting in significant changes in species distribution (John et al., 2008) and increased water stress (Shao et al., 2008; Miao et al., 2009). Desertification normally results in an increase in both shrublands in semi-arid areas and deserts near the grassland-desert transitional zones (Figs. 1.5b and c). Herbaceous grass species native to the region are being replaced by deep-rooted invasive shrubs, which have less-efficient water use (Cheng et al., 2007). Based on the MODIS LU database, it seems that intensified land use changes are mostly within or around the transitional zones between the biomes (Figs. 1.5a and b). From a statistical point of view, however, the total land area for grasslands has increased (Fig. 1.5c). A careful study of the land-use changes (Fig. 1.5b) reveals that this is due to the large loss of forests in northern MG and northwest XJ. A surprising phenomenon is that the total cropland area has also been decreasing, which is likely related to the

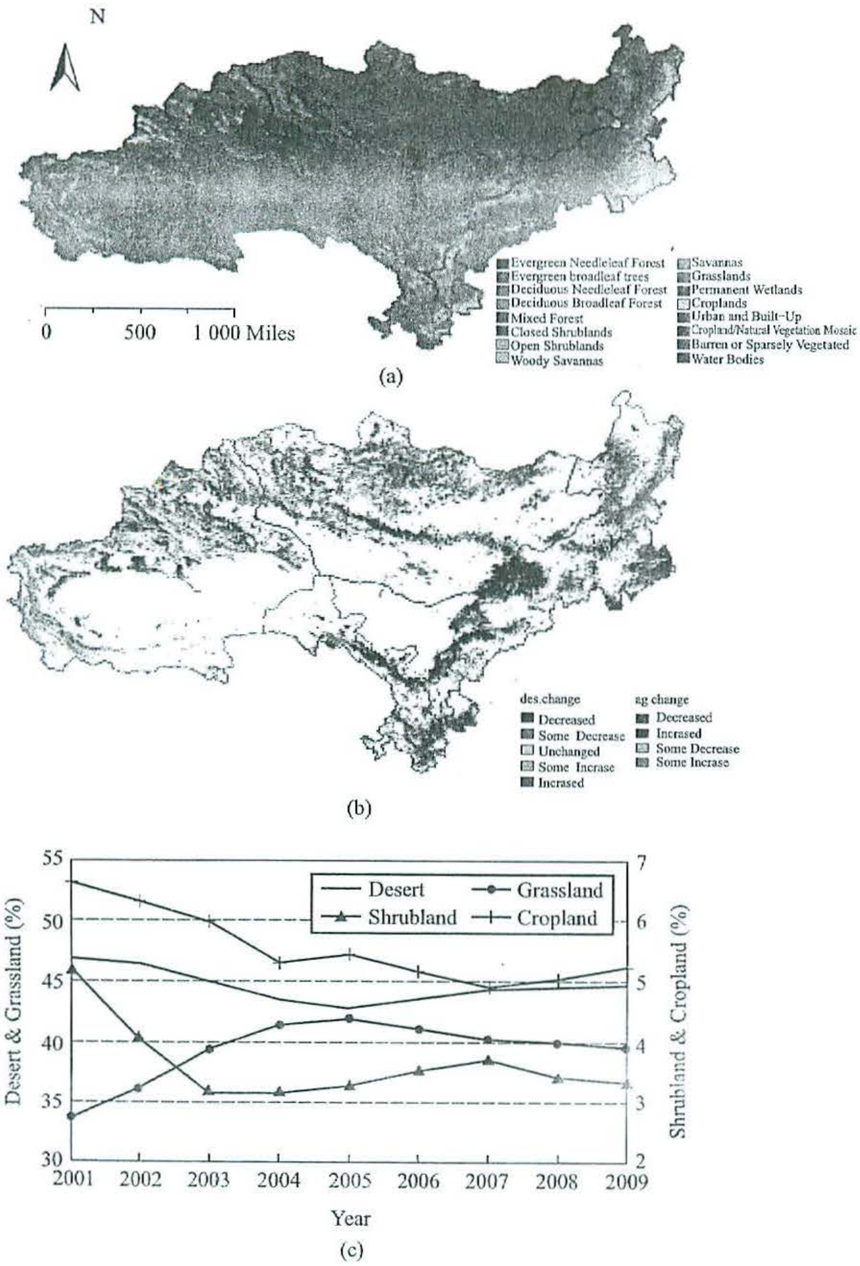

Fig. 1.5 Land use (a), land use changes between 2004 and 2009 (b), and the gradual changes of major land use types (c) in the DEA region. Data and maps are based on the MOD12Q1 land cover type (https://lpdaac.usgs.gov/products/modis_products_table).

major policy of "Restorations of Grasslands from Croplands", set by the Chinese Government for China's northwest region in the late 1990s.

1.3 Ecosystem Production and Evapotranspiration

Ecosystem production, evapotranspiration (ET), and their changes in time and space are among the most important functional variables to characterize ecosystem functions. Gross primary production (GPP) is used here for ecosystem production. Both GPP and ET are directly affected by changes in land use and climate. In this chapter, we used the 500 m resolution MODIS GPP (MOD17A2 /A3) and ET (MOD16A2/A3) from 2000 through 2009 to understand the state and changes of GPP and ET across DEA's spatiotemporal landscapes. Current MODIS GPP and ET products do not have estimates for the arid areas across the globe due to low vegetation cover for estimating leaf area, leading to unavailability of MODIS-derived LAI/fPAR (Mu et al., 2011). This restricted our analysis and discussion to within only about 55.7% of the DEA region (Fig. 1.6);

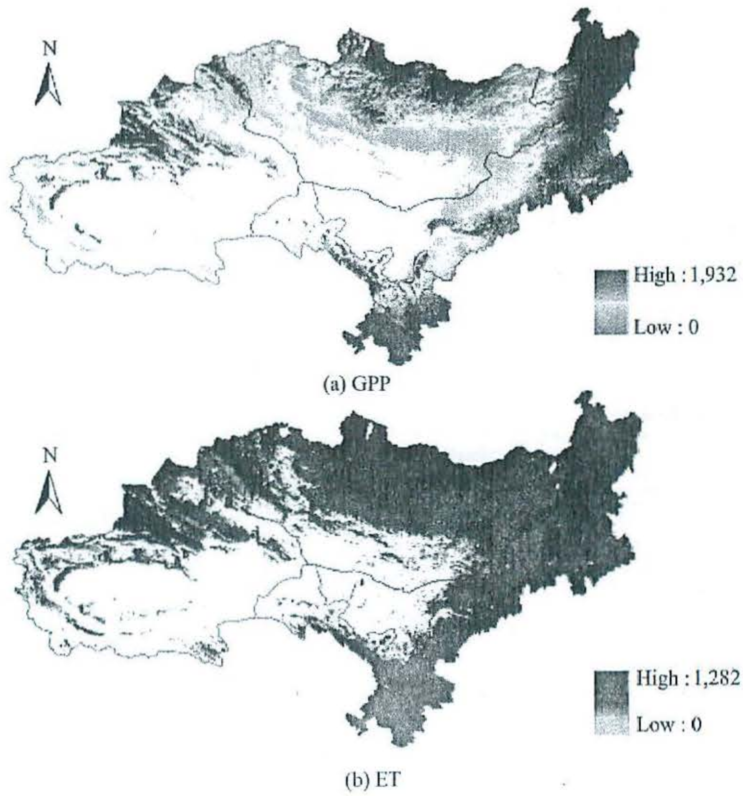

Fig. 1.6 Decadal mean gross primary production (GPP, a) and evapotranspiration (ET, b) of the DEA region (2001–2009).
Data source: NASA's Earth Observing System (EOS) Clearinghouse (ECHO)-MOD17A3 with 500 m resolution (http://reverb.echo.nasa.gov/reverb/).

although the GPP and ET for the remaining 45.3% are near zero and, thus, negligible. Nevertheless, our discussion below is still possible and is based on the differences among the three ecoregion biomes (forest, grassland, and desert, Fig. 1.1) as well as among the five administrative units.

The mean (±standard deviation) GPP of the three dominant biomes for the study period (2000–2009) varied from 166.3±96.0 g C m^{-2} yr^{-1} in the desert biome to 303.9 ±151.9 and 508.5±248.0 g C m^{-2} yr^{-1} in the grassland and forest biomes (Fig. 1.7). These results should be cautiously interpreted because a relatively large amount of area is treated as "no vegetation" by the MODIS team (i.e., no data) in barren areas. Yet, the total GPP for DEA is $(0.8243\pm0.3011)\times10^9$ g C yr^{-1} and the average ET is 276.1±96.6 mm yr^{-1}. In addition to the three dominant biomes for the DEA region, we also obtained zonal statistics of GPP and ET in grassland, desert, and forest biomes at the provincial level. It is also clear that the intra-annual variations of the same biome in different administrative units were not always similar. IM and GS showed higher GPP at all three biomes than the other three administrative units. For example, GPP of the forest biome in GS was 736.0±271.7 g C m^{-2} yr^{-1}, while

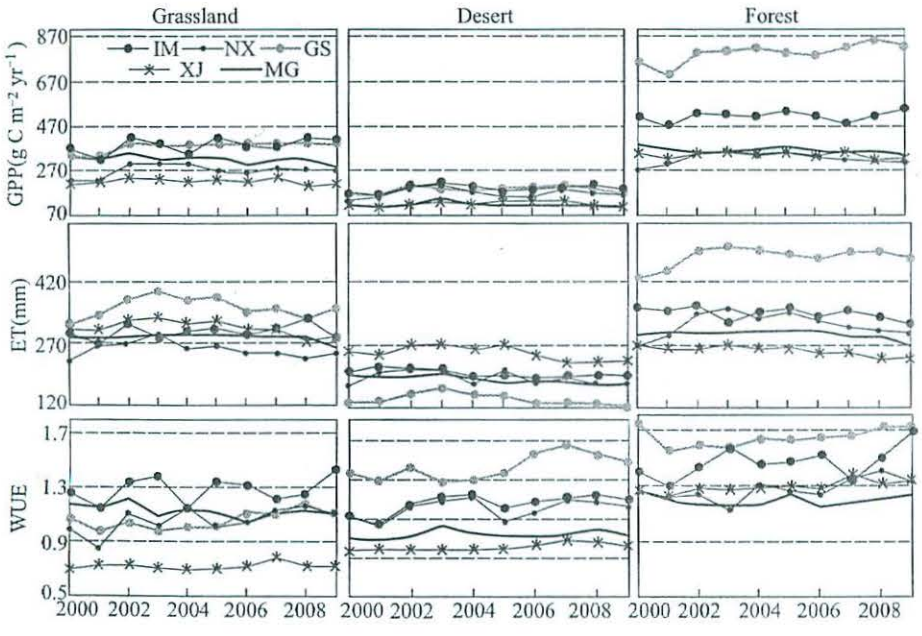

Fig. 1.7 Changes in GPP (g C m^{-2} yr^{-1}), ET (mm) and WUE of three dominant biomes in the five administrative units of the DEA region from 2000 to 2009, showing the nonparallel intra-annual variations among the biomes and provinces
Data source: same as in Fig. 1.6.

the forest biome in neighboring NX was about half of GS (51.7%) at 336.7±159.1 g C m^{-2} yr^{-1}. These differences are likely due to the favorable temperature and precipitation combination (Fig. 1.4) (see also Lu et al., 2011). ET of the forest biome (368.1±147.9 mm yr^{-1}) was expected to be higher than that at the grassland (267.1±96.5 mm yr^{-1}) or desert (194.5±45.5 mm yr^{-1}) biomes. However, these biome differences also varied among the five administrative units. The ET level in GS, for example, varied greatly among the three biomes at 182.4, 349.3, and 468.4 mm yr^{-1} for the desert, grassland, and forest biomes, respectively, while the biome differences in XJ seemed rather small (268.6–275.0 mm yr^{-1}), with ET of the grassland biome occasionally exceeding that of the forest biome. MG showed the smallest intra-annual variation of ET. When integrating GPP and ET into a concept of water-use efficiency (WUE=GPP/ET), there seemed to be different patterns among the biomes and administrative units. First, the clear-cut conclusion on WUE among the biomes is not very apparent. In GS and XJ, WUE of the forest and desert biomes was higher than that of the grassland biome, while the biome difference in NX was very small. Unlike GPP and ET, WUE differences among the units appeared independent of biomes. For the desert biome, WUE was lower in XJ and MG and the highest in GS. For the grassland biome, XJ has the lowest WUE but there were no significant differences for the grassland WUE among the other four units. For the forest biome, WUE was the highest in GS and the lowest in MG.

The temporal and spatial changes of GPP, ET and WUE reflect both climatic conditions and land use (Figs. 1.4 to 1.6). Although no effort has been made to perform systematic and comprehensive analyses on partitioning the contributions of climate and land use on GPP and ET, our preliminary analysis on this topic indicated that land use was responsible for 64.3% and 83.6% of GPP and ET variation, respectively, while climate explained only 26.8% and 14.5%. In other words, the impact of land use on GPP and ET dynamics is 2.4 and 5.8 times higher than that of climate. Logically, these conclusions will likely vary by biome and administrative unit.

1.4 Scientific and Societal Challenges for Adaptations in DEA

Global climatic change, human activities via various land-use practices and natural disturbances are considered the primary drivers for the ecosystem functions and services of any region. Development of a sound adaptation plan, therefore, is becoming a necessity for the sustainable future of a region such as DEA. One cannot develop a sound adaptation strategy without understanding the interactive changes between the natural and human systems on this "crowded planet" (Bulkeley, 2001; Palmer et al., 2004; Liu et al., 2008). Fortunately, many teams have extensively documented the similarities and differences in the past, present, and future of the DEA region (i.e., data and expertise availability). Accompanied by advanced technology (e.g., remote sensing products, models, available eddy-flux towers, etc.), we could reach out to these teams for a comprehensive analysis of the interactions between the human system (HS) and natural system (NS) toward science-based adaptation plans for the region (Fig. 1.8). Yet, this type of synthesis effort has not been made by any research team. Another research priority for the future of the DEA region is to examine and model the interactive changes of HS and NS at different temporal and spatial scales in order to develop sound adaptation plans for the changing climate and land use. Specifically, we need to understand how global climate change (including warming and climatic variability) and land-use change regulate both biophysical and socioeconomic functions through exploring the underlying processes and vulnerability analyses. Generally speaking, climate change and human stresses will place unequal pressure on each element of HS and NS matrices. Yet, because of the intra-connections among the elements and between the two matrices, one element of either matrix will have the potential to trigger the changes of the other elements. These changes, however, can be predicted when important un-

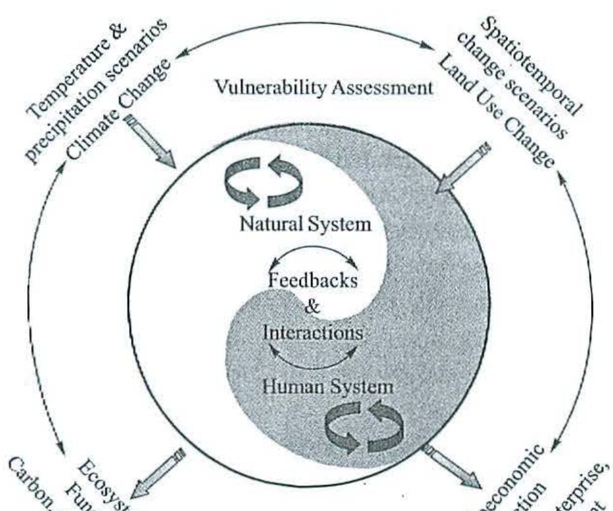

Fig. 1.8 Proposed conceptual framework for exploring the linkages between biophysical and socioeconomic parameters as well as their coupled effects on the interactions and feedbacks within and between the human system (HS) and natural system (NS).

derlying processes are understood and incorporated in a comprehensive model that includes both biophysical and socioeconomic influences.

A more pressing issue related to socioeconomic changes (e.g., population growth and institutional changes) impacts on ecosystem functions, which are often delineated by administrative boundaries (e.g., Zhen et al., 2010). These differences will likely yield different land-use intensities in each province and alter the function and dynamics of ecosystems, which, in turn, will have negative feedback on economic development and future policy. Using the livestock statistics of IM and MG as an example, major policy changes in both regions appear to be responsible for the shifts in livestock population (Fig. 1.2c; Qi et al., 2012). In IM, the substantial increase in livestock in the late 1980s was largely a result of livestock and grassland tenure reform, while the drop in livestock around 2000 was caused by grassland restoration policies enacted around 1998–1999. The substantial livestock increase since 2004 was likely caused by growing demand driven by fast economic growth and market reform. However, climatic extremes and episodic events (e.g., El Niño) complicated the dynamics of livestock populations (e.g., 18% mortality in MG due to the extreme snow and cold winter of 2009–2010). Recently, in southern DEA, the Chinese government announced several major policies (e.g., subsidy and reward program for the country's herdsmen over the coming years to reverse and prevent damage to grasslands, http://news.xinhuanet.com/english2010/china/2011-05/06/c_13862052.htm), while the Xinjiang Division of the National Development and Reform Commission disclosed that it will invest 1.8 billion RMB in sand prevention and control projects around the Tarim River Basin (http://english.peopledaily.com.cn/90001/90776/90882/7375561.html). These new policies will produce direct and immediate LCLUC in DEA. One caution associated with the coupled human and natural systems (CHN) is to realize that both the drivers and the dependent variables are hierarchically organized (i.e., county-prefecture-province-country) and have different spatial and temporal resolutions. Socioeconomic data are often collected at the county level annually by the national census program or at ten-year intervals, suggesting that our analysis will have to be conducted according to this hierarchy. In contrast, ecosystems are spatially organized by climate, soil, and/or land cover types.

The role of population and prices differ in the way they drive LCLUC. The local population growth may not cause LCLUC directly, but rather indirectly, through the market and price mechanism. Population and prices would also have different impacts on various land-use types via the markets. For built-up land uses (e.g., residential), local population changes would have a much stronger impact than other land-use types because foods and other products can be directly imported/exported from/to other regions, but the residential use cannot be solved by increasing more residential areas in other regions. Changes in land values resulting from relative price changes would significantly impact the population and economy. For example, a substantial rise in meat and milk prices driven by growing demands results in increased pastoral land values, wages and economic development in the region, attracting people to the region from the rest of the country.

Mongolians who maintain nomadic pastoral practices predominantly inhabit the Mongolian Plateau. However, the majority of the pastoral households in both MG and IM began settling around permanent towns or immigrated to large urban centers in recent decades because of rapid economic growth and new policies (Havstad et al., 2008). In 2007, the number of livestock in MG reached 40 million—an increase of 15.7% from 2006, resulting in >60% of the pastureland being overgrazed. These rapid changes in both climate and socioeconomic systems will place different levels of biophysical and anthropogenic stress on the ecosystems. Adaptive management plans and policies are therefore needed to maintain ecosystem resilience to the change (i.e., adaptation). IM and MG have developed contrasting political systems since 1979, with much more rapid changes in IM than in MG, producing distinct land cover changes between 1980 and the current decade (Sneath, 1998). As a consequence of the landcover changes, severe and frequent catastrophes (e.g., dust storms) have drastically increased in IM. The landuse changes are expected to escalate over the next two decades. Additionally, significant increases in air temperature since the 1950s have been observed due to global warming; the increases varied significantly and were non-parallel among ecosystems. In 2001, the total net primary production (NPP) of the Mongolian Plateau was 434 Tg C yr^{-1}, with IM and MG accounting for 48% and 52%, respectively. At the NEESPI meeting in Beijing in November, 2007, researchers of the Purdue Climate Change Center and Institute of Geographic Sciences and Natural Resources Research, CAS (IGSNRR-CAS) predicted that climate change on the Plateau during the 21st century will be higher than the global average (e.g., Lu et al., 2009). By 2100, the projected air temperature will increase by 4.6–8.3°C and the projected annual total precipitation will increase by 122 mm to 178 mm. NPP and net ecosystem production (NEP) will continuously increase during the 21st century, with NPP reaching 586–792 Tg C yr^{-1} (i.e., 24%–68% increase from 2001) and NEP reaching 57–113 Tg C yr^{-1}(280%–650% increase from 2001) by 2100. More importantly, MG, in this century, will contribute more NEP for the plateau—an increase from the current 48% to 61%. These preliminary projections provide a good start toward developing adaptation strategies on the Mongolian Plateau. Clearly, an urgent scientific synthesis, by including multiple countries and agencies, is needed toward the strategic preparation for future adaptations plans for the region.

Acknowledgements

Our study for this chapter has been partially supported by the LCLUC Program of NASA, the Natural Science Foundation of China, the Chinese Academy of Sciences, and Henan University. Many colleagues (e.g., Lisa Delp Taylor, Lin Zhen, Jian Ni, Nan Lu, Haitao Li, Pavel Groisman, Garik Gutman, and an anonymous reviewer) contributed data, thoughtful discussion, and directions for our research.

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Chapter 2

Dryland
Context

Geoffrey M. Hen
John, and Elena

Summary: This
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2.1 Study

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