Landscape Ecol (2015) 30:1579–1598
DOI 10.1007/s10980-015-0209-1

Special issue: ***Landscape patterns and ecosystem processes in the Mongolian Plateau*** (Guest Editors: J. Fang and Y. Bai)

RESEARCH ARTICLE

Historical landscape dynamics of Inner Mongolia: patterns, drivers, and impacts

Jianguo Wu · Qing Zhang · Ang Li · Cunzhu Liang

Received: 6 February 2015 / Accepted: 6 May 2015 / Published online: 15 May 2015

Abstract
Context Understanding the causes and consequences of land use and land cover change in drylands is crucial for global sustainability. Inner Mongolia consists of arid and semiarid ecosystems of global importance.
Objectives Our main goal was twofold: to review the patterns and drivers of land use and land cover change in Inner Mongolia, and to discuss ecological impacts and strategies for promoting landscape and regional sustainability.
Methods We took an interdisciplinary and retrospective approach, based on historical records and remote sensing data.
Results Inner Mongolia has evolved from an ocean to a forested region and then to a dryland area in the past millions of years. As a cradle of Chinese civilization, Inner Mongolia has experienced a series of land transitions from localized primitive agriculture that occurred in prehistoric times to broad-scale nomadic pastoralism that lasted for a few 1000 years, and to sedentary pastoralism with increasing agriculture and urbanization since the 1960s. The general land use pattern has long been shaped by the interactions between nomadic pastoralism and agrarian culture. The major drivers of land use and land cover change include: climate, demography, socioeconomic structures, institutional changes, and technological innovations.
Conclusions The landscapes of Inner Mongolia have evolved historically through several phases, and the profound and unsustainable landscape transformations during the past 50 years have been driven primarily by land use policies. Strategies based on landscape sustainability science are needed to curb ecosystem degradation and promote sustainability in the region.

Keywords Mongolian Plateau · Inner Mongolia · Landscape history · Land use and land cover change · Socioeconomic drivers · Grasslands · Rangeland degradation and sustainability

J. Wu
Center for Human-Environment System Sustainability (CHESS), State Key Laboratory of Earth Surface Processes and Resource Ecology (ESPRE), Beijing Normal University, Beijing 100875, China

J. Wu
School of Life Sciences and School of Sustainability, Arizona State University, Tempe, AZ 85287, USA

J. Wu · Q. Zhang · C. Liang
Sino-US Center for Conservation, Energy, and Sustainability Science (SUCCESS), Inner Mongolia University, Hohhot 010021, China

Q. Zhang (✉) · C. Liang
College of Life Sciences, Inner Mongolia University, Hohhot 010021, China
e-mail: qzhang82@163.com

A. Li
State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China

Introduction

Land use and land cover represent a main object of study in ecological and geographical sciences, as well as other fields dealing with human-environment systems (Forman and Godron 1986; Turner et al. 1990; Lambin et al. 2003; DeFries et al. 2004a; Foley et al. 2005; Wu 2006; Turner et al. 2007). Land use and land cover are two related but different terms; the former is defined by the purposes for which humans use the land, whereas the latter is defined by the physical attributes of the earth's land surface. Land use and land cover change (LUCC) has been recognized widely as a primary driver for biodiversity loss and ecosystem degradation worldwide, and has become a key research topic in landscape ecology and sustainability science (Wu and Hobbs 2002; Turner et al. 2007; Wu 2013a, b). Much of the research on LUCC so far has focused on forested landscapes, and less effort has been directed to the spatial patterns and ecological processes of dryland systems (Wu 2013a). However, the world's drylands, consisting mainly of deserts and grasslands in arid and semiarid regions, are vast in size and crucial for global sustainability, as they occupy about 41 % of the earth's land surface where more than 38 % of the total global population reside (Reynolds et al. 2007). In addition, about 90 % of the people in dryland areas live in developing countries where the lowest levels of human well-being are found (MEA 2005). It is important, therefore, to galvanize more research into the world's dryland systems, particularly, on landscape and regional scales.

The Mongolian Plateau is well known for its vast grasslands, the Gobi desert, and, of course, the stories of Genghis Khan and his Mongol Empire. The plateau is located in Central Asia, and comprises the eastern part of the world's largest grassland—the Eurasian Steppe—which stretches over some 8000 km from northeastern China to Mongolia, the former Soviet Union, and Hungary (Fig. 1a). The Mongolian Plateau covers an area of approximately 260 million ha (about 1 million square miles), bounded by the Greater Xing'an Mountains to the east, the Yin Mountains to the south, the Altai Mountains to the west, and the Sayan and Khentii mountains to the north. While the plateau is an essential part of the global drylands, its ecology was poorly understood until quite recently, as compared to most other drylands in Africa, Australia, North America, and South America (Li 1964; Wu and Loucks 1992; Kang et al. 2007; Han et al. 2009).

Once completely part of China, the Mongolian Plateau has been divided politically into two main parts since the 1940s: the Inner Mongolia Autonomous Region of China in the south (IMAR or Inner Mongolia for short) and the independent state of Mongolia in the north (Fig. 1b). Mongolia and Inner Mongolia have had quite different land use policies during the past several decades, resulting in contrasting socioeconomic and environmental changes in the two parts of the same plateau (Bai et al. 2012; Wang et al. 2013; Chen et al. 2015; Zhao et al. 2015). Landscape transformations in Inner Mongolia have been much faster with more severe ecological impacts than in Mongolia, particularly since the turn of the twentieth century (Lu et al. 2009a, b; Chen et al. 2013; Hilker et al. 2014; Chen et al. 2015). These ecological problems have been better documented for Inner Mongolia than for Mongolia. Several studies in this special issue further explore a number of these ecological issues.

To effectively deal with the current ecological problems and develop sustainability solutions for Inner Mongolia, it is necessary to understand the history and culture of its landscapes. The objectives of this paper, therefore, are to review the historical landscape dynamics of Inner Mongolia, examine its environmental and socioeconomic drivers, and seek strategies for promoting landscape and regional sustainability. This article is also intended to provide a historical and landscape context for this special issue, to which this paper belongs.

Environmental setting and landscape pattern of Inner Mongolia

Inner Mongolia (IMAR) runs more than 3000 km from southeast to northwest, covering an area of 120 million ha(3.3 times the size of Germany) and accounting for 12 % of China's land area (Fig. 1b). This region consists of six plateaus from east to west: the Hulunbuir Plateau, the Xilingol Plateau, Wulanchabu Plateau, the Ordos Plateau, the Bayannoir Plateau, and the Alashan Plateau (thus, the term Inner Mongolia here represents a greater area than the narrowly defined Inner Mongolian Plateau bounded by the Yin Mountains to the south). The topography of this region

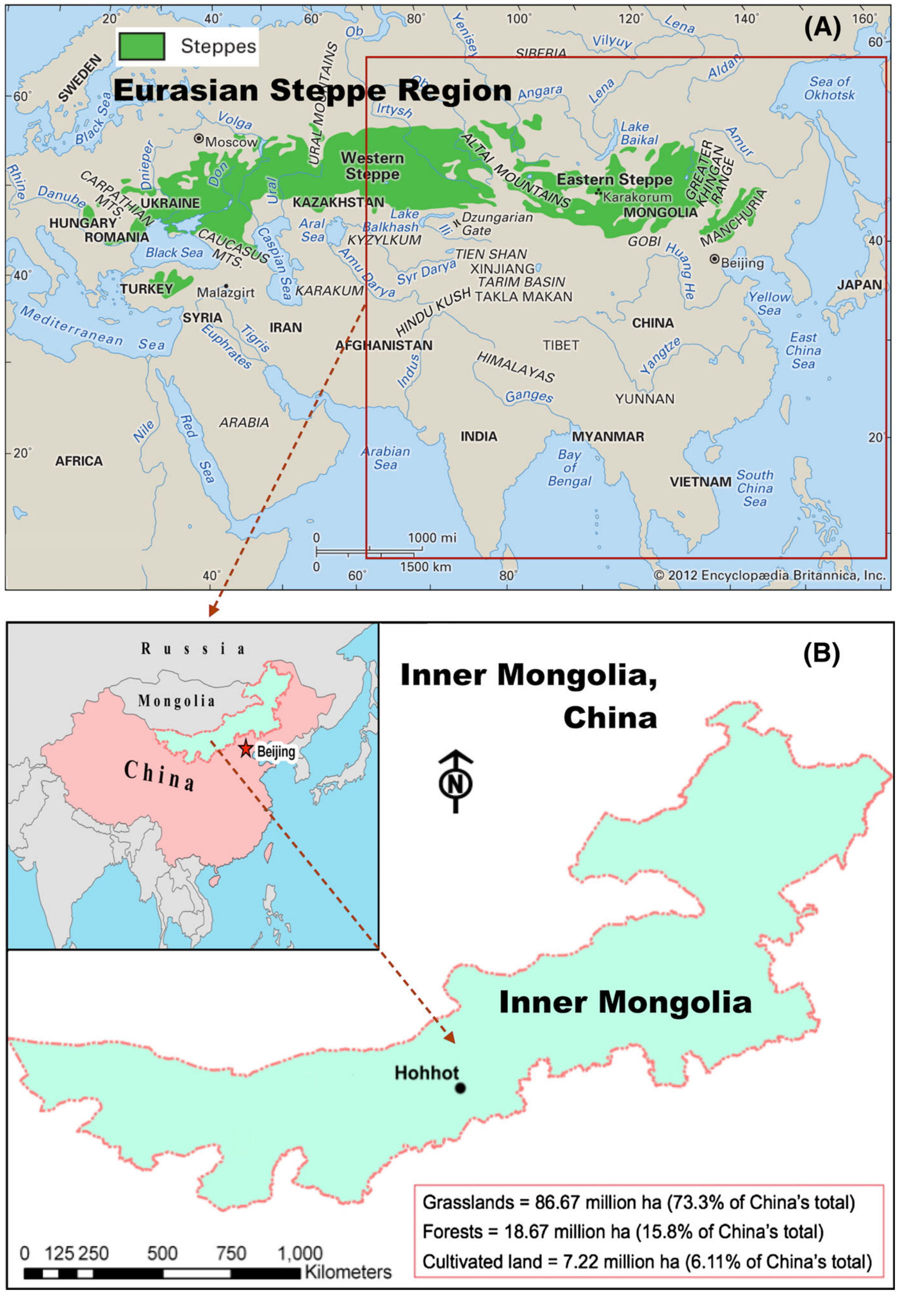

Fig. 1 Location map of the Eurasian Steppe Region (**a**) and the Inner Mongolia autonomous region (**b**)

is characterized by vast plains with numerous low rolling hills and tablelands, with elevation decreasing gradually from west to east and from south to north (ranging from 1400 to 700 m above the sea level). Under a prevailing continental climate, different climatic zones can be differentiated based on temperature and precipitation patterns from east to west: temperate semi-humid (dominated by forests), semi-arid (dominated by grasslands), and arid zones (dominated by deserts). Across the region, the mean annual temperature ranges from −2 to 6 °C, with a frost-free season of 70–160 days. The mean annual precipitation varies from about 40–450 mm, with 80–90 % of annual precipitation falling between July and September when temperature is also high (Fig. 2a, b). This concurrence of precipitation and temperature

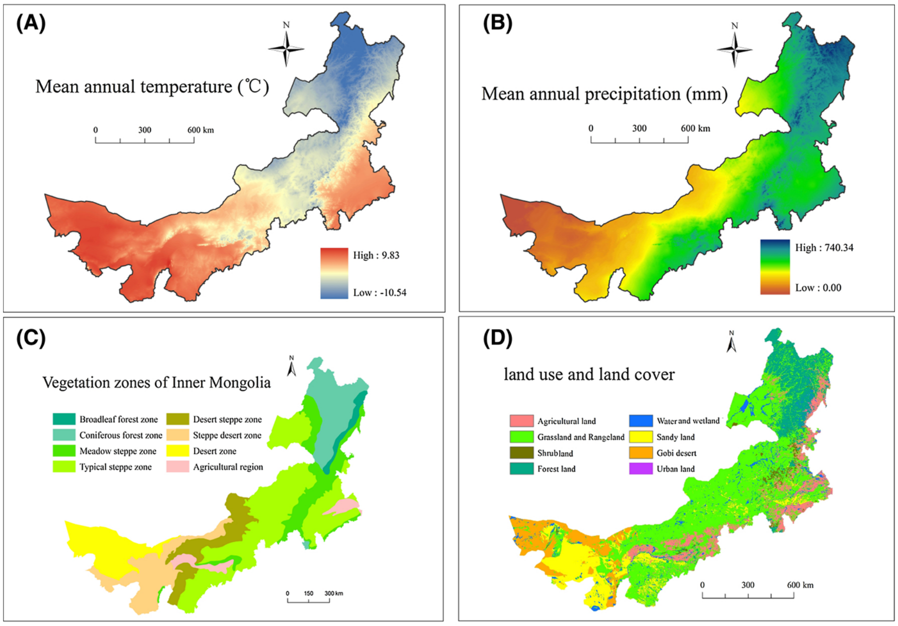

Fig. 2 Maps of the vegetation zones (**a**), mean annual precipitation (**b**), mean annual temperature (**c**), and land use and land cover pattern (2000) of Inner Mongolia

peaks favors plant growth, which is a distinctive climatic characteristic that distinguishes the Eurasian steppes from the other major grasslands of the world—the North American prairies, the South American pampas, and the African veld and savannah—where precipitation is much higher.

Along the east–west precipitation gradient, Inner Mongolia has several types of zonal vegetation (broad-scale, climate-defined natural vegetation): the temperate coniferous and deciduous forests, meadow steppe, typical steppe, desert steppe, steppe desert, and desert (Fig. 2c). Grasslands (steppes) of different kinds are the most dominant vegetation type, covering 78.8 million ha (about 67 % of IMAR's territory). Corresponding to the zonal vegetation types, several major soil types are found, including chernozem (meadow steppe), chestnut (typical steppe), and calcic brown (desert steppe and steppe desert) soils. In addition to zonal vegetation, several types of non-zonal vegetation, mainly sandy lands and wetlands, are found in the region (Fig. 2d). Major sandy lands include Horqin (4.8 million ha) and Hulunbuir (900,000 ha) in the east, Hunshandak (4 million ha) in the middle, and Maowusu (4.4 million ha) and Kubuqi (2 million ha) in the west. The exact area of each sandy land varies with climate and human activities. Most wetlands are found in the eastern part of Inner Mongolia along major rivers and lakes (Fig. 2d).

The Eurasian steppe region as a whole has the highest indigenous plant and animal biodiversity among the world's major grasslands second only to African savanna (World Conservation Monitoring Centre 1992; Sala et al. 1996). Because of the broad gradients of precipitation and temperature, the presence of mountains and wetlands, and the particular geologic and evolutionary history, Inner Mongolia has developed a diverse and unique flora and fauna which are representative of the Mongolian Plateau. In total, the biota of Inner Mongolia consists of more than 2600 species of vascular plants and 550 species of vertebrates, including over 370 bird species, 65 mammal species, 21 reptiles, 8 amphibian species, and 82 fish species (Ma 1985; Xu 1988; Zhao and Zhao 2013). Perennial bunchgrasses (e.g., genera of *Stipa, Festuca, Agropyron, Cleistogenes,* and*Koeleria*) and rhizome grasses (e.g., *Leymuschinensis*) are dominant in most steppe communities throughout the region. Both wetlands and sandy lands support high levels of species diversity for both plants and animals. Wetlands are used as habitat by some internationally noted migratory birds, such as white-naped crane (*Grusvipio*), red-crowned crane (*Grusjaponensis*), and swans (*Cygnus* spp.).

Plant endemism is a salient feature of the species diversity in Inner Mongolia. Four groups of endemic species have been identified for this region: (1) steppe endemic species (e.g., *Allium mongolicum*, *Adenophora biformifolia,* and *Gypsophila desertorum*), (2) desert endemic species (e.g., *Tetraena mongolica, Potaninia mongolica, Tugarinovia mongolica,* and *Pugionium calcaratum*), (3) sandy land endemic species (e.g., *Artemisia ordosica*),and (4) mountain endemic species (e.g., *Allium alaschanicum* and *Anemone alaschanica*). The desert region of Inner Mongolia is one of the eight biodiversity centers of China—the only one in the arid and semiarid region of the country. The desert area alone has more than 100 endemic species, including *Tetraena mongolica, Potaninia mongolica, Tugarinovia mongolica, Stilpnolepis centiflora, Pugionium calcaratum, Ammopiptanthus mongolicus,* and *Elachanthe mumintricatum*. Habitat differentiation in the interior of Inner Mongolia is a primary driver for the high level of plant endemism (Zhu et al. 1999; Zhao and Zhu 2003; Liang et al. 2004; Wu et al. 2005; John et al. 2008).

Emergence of arid landscapes and prehistoric cultures on the Mongolian Plateau

Over the past millions of years, the Mongolian Plateau has evolved from an ocean to a region fully covered by forests and then to a land mosaic dominated by grasslands and deserts (Fig. 3) (Li 1979; Zhou 1994; Bayaer 2005; Hao and Chimeddorji 2011). During the Permian Period of the Paleozoic Era, the plateau was covered by primitive tropical rain forests under an extremely humid climate. As climate became colder in the early Eocene Epoch of the Tertiary Period, subtropical deciduous broadleaf forests and coniferous forests became the main vegetation types in this region. About 60 million years ago, the Indian Subcontinent began to collide into the Eurasian Continent (Chen et al. 2010; Wu et al. 2014a), consequently uplifting the Tibetan Plateau to form the Himalaya Mountains that run across five countries (i.e., China, Bhutan, India, Nepal, and Pakistan).

As the Himalayas mountains blocked the warm moist air mass coming from the Indian Ocean in the south, the regional climate of the Mongolian Plateau became colder and drier. Drought-resistant grasses then moved in, leading to the emergence of steppes on the Eurasian continent about 7 million years ago during the late Tertiary Period (Li 1979; Li et al. 1990). Extensive grassland landscapes across the Mongolian Plateau were formed during the Pleistocene Epoch of the Quaternary Period (about 2.4 million years ago); by contrast, not until 20,000 to 100,000 years ago did grassland landscapes take their form on the Tibetan Plateau (Li 1979; Li et al. 1990). Due to the impacts of glacial and interglacial events during the early Quaternary Period, the climate became even dryer and cooler, and deserts and sandy lands (e.g., Badain Jaran Desert, Kubuqi Desert, Hunshandake Sandy Land, and Mu Us Sandy Land) gradually appeared. By then, the landscapes of the Mongolian Plateau, dominated by dryland systems, took shape (Li et al. 1990; Bayaer 2005).

Geophysical and climatic factors were primarily responsible for the changes in land form and ecosystems across the Mongolian Plateau in prehistoric times. Archeological evidence (e.g., cultural relics from the Paleolithic Period and the Neolithic Period)indicates that primitive humans already appeared in Inner Mongolia about 700 thousand years ago during the Old Stone Age, making Inner Mongolia one of the cradles of Chinese civilization (Zhang et al. 1997; Fang 1999; Xu and Wang 1999). Several prehistoric cultures (4000 years ago or earlier) were developed in this region, including the Dayao Culture in the vicinity of Hohhot about 700,000 years ago, the Hetao Culture in the Ordos-Hetao region about 50,000 years ago, the Jalainur Culture in the Hulunbuir region about 10,000 years ago, and the Hongshan Culture near Chifeng about 5000–6000 years ago. These ancient human activities included farming, nomadism, hunting, and fisheries. With small populations in localized areas, the effects of these prehistoric civilizations on the environment as a whole were conceivably insignificant.

Land use change in Inner Mongolia during the dynastic era (Xia Dynasty-1912)

Changing dynasties and two dominant cultures

The dynastic era of China refers to the period from the Xia Dynasty (ca. 2070 BC–1600 BC) to the Qing Dynasty (1636 BC–1912 AD). The recorded history of China begins with the Shang Dynasty (ca. 1600 BC–

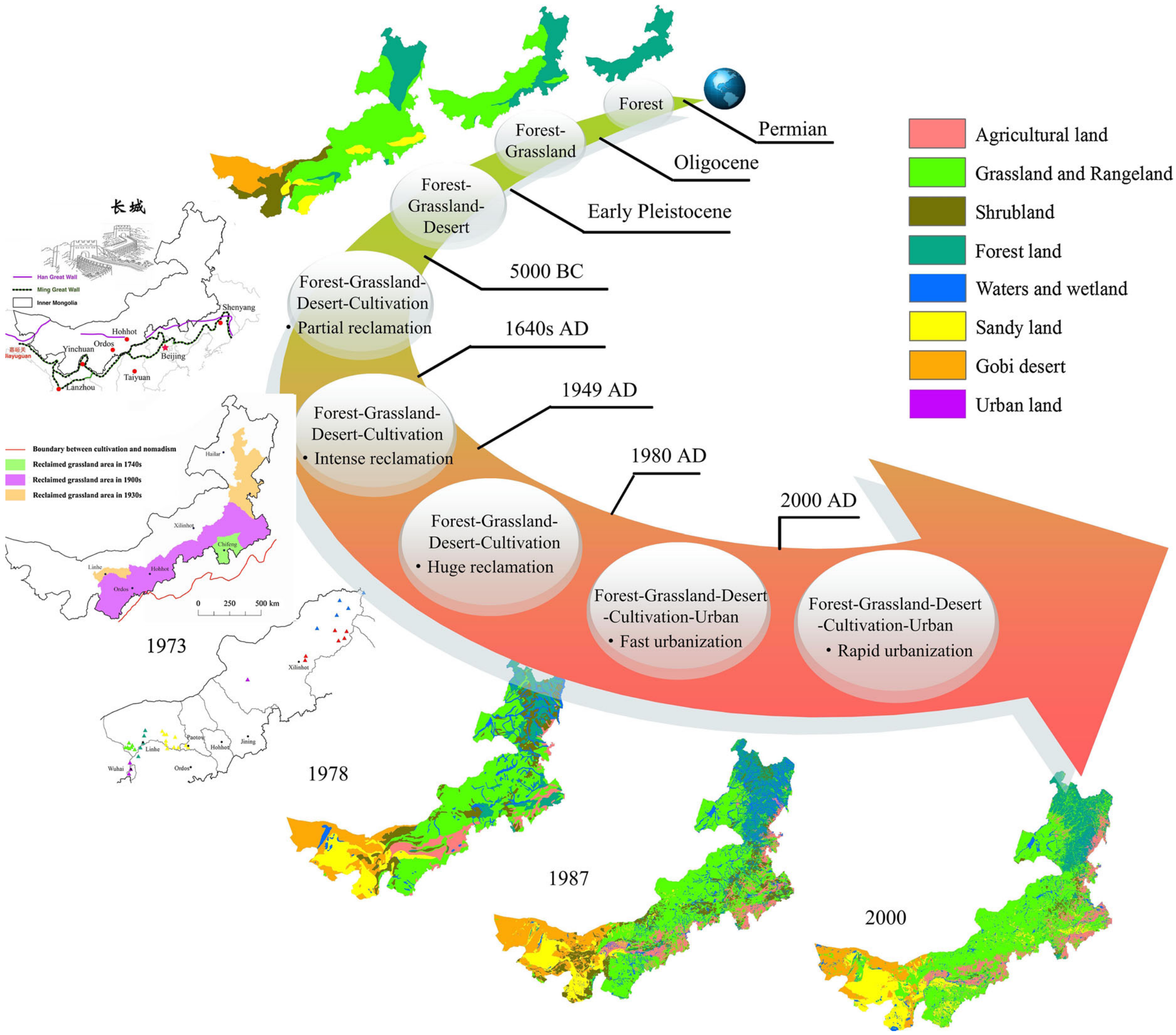

Fig. 3 A schematic representation of historic landscape dynamics of Inner Mongolia

1046 BC) for which there are both written records and archeological evidence. Before pastoralism, agrarian culture had emerged in the Central Plain of China around 1250 BC during the Shang Dynasty (Ren et al. 2013). Nomadic pastoral culture became a dominant way of life on the Mongolian Plateau in the periods of the Spring and Autumn (770 BC–476 BC) and Warring States (475 BC–221 BC) (Hao and Chimeddorji 2011). The transition from hunting and gathering culture to nomadic pastoralism was certainly a critical shift in land use on the plateau, as a consequence of domesticating wild animals (Li et al. 1990).

During the dynastic era of China, more than a dozen ethnic groups of nomads lived in Inner Mongolia, including Shanrong, Donghu, Huns (Xiongnu), Wuhuan (originally a branch of Donghu), Xianbei (originally a branch of Donghu or Shanrong), Tujue(Turks), Qidan (Khitan; originally a branch of Xianbei), Nüzhen (Jurchens), and Mongols (originally a branch of the Shiwei tribe belonging to Donghu). Xianbei was the first nomadic group that ruled the central China at the end of the first century, which subsequently promoted the mixture of agrarian and nomadic cultures. In the mid-sixth century, Turks defeated other nomadic tribes in Inner Mongolia, and created the Turkic Khanate (552AD–745 AD), which increased the blending of western and eastern cultures in the region. After ruling the plateau for about

200 years, the Turkic Khanate was eliminated by the Tang Dynasty (618AD–907 AD).

In the early 12th century, the military power of the Mongols began to rise up in the Hulunbuir grassland region. In the early thirteenth century, Genghis Khan (1162 AD–1227 AD) united several Mongolian tribes through military campaigns, and established the Great Mongol Empire (1206 AD–1259 AD) on the Mongolian Plateau. Genghis Khan and his descendants conquered Xixia, Liao, and Jin dynasties, and rapidly expanded the territory of their empire. In 1271, under the reign of Genghis Khan's grandson, Kublai Khan, the Mongols founded the Yuan Dynasty (1271 AD–1368 AD), with its capital in Beijing (Da Du), and its territory stretched throughout most of Asia and eastern Europe during its prime. After finally conquering south China, the Yuan Dynasty ended the Song Dynasty in 1279, and unified all the lands of China, including the entire Mongolian Plateau in the north, the Hainan Island in the south, and everything in between. As the first unified Chinese dynasty established by an ethnic nationality, the Yuan Dynasty played an important role in blending nomadic with agrarian cultures, as well as mixing eastern and western cultures. About a century later, the Yuan Dynasty was eliminated by the Ming Dynasty (1368 AD–1644 AD), and most Mongolian tribes were driven to the north of the Gobi (or the Great Desert) in the Mongolian Plateau. The Ming Dynasty was the last Chinese dynasty controlled by the Han people who were identified with agrarian culture. In 1644, the Manchu—another nomadic ethnic group—took control of China, establishing the Qing Dynasty (1644 AD–1911 AD).

Land use change as driven by natural and sociocultural factors

The previous section indicates that Inner Mongolia was occupied by nomadic people throughout the dynastic era. Yet, primitive agriculture first occurred in the southern part of Inner Mongolia ca. 8000–7000 BP, from the western hills of the Greater Xing'an Mountains through Jining and Hohhot to the west of Baotou (Fang 1999). About 4300–3500 BP, the primitive agriculture began to decline with increasingly dry and cold climate, while nomadic pastoralism started to develop, eventually replacing agriculture as the dominant land use in Inner Mongolia (Zhang et al. 1997; Fang 1999). This historic transition in land use was mainly a result of humans adapting to the prevailing climate change over a long period of time. Ever since, this belt-like region that runs roughly east–west along the south edge of Inner Mongolia has been an agro-pastoral transitional zone in northern China. In 211 BC, the Qin Dynasty moved 30,000 households from the central plains to Hetao and Ordos areas in Inner Mongolia to solidify its control of its northern frontier, and by the Western Han Dynasty (206 BC–8 AD) the Hetao region already became an important grain production area (Bao and Enkhee 2009). The total population in the Inner Mongolian region was 1.75 million in 2 AD, with 57 % of it being Han Chinese; it reached 2.15 million in the early nineteenth century, with Mongolians and Han Chinese each accounting for about 50 %; by 1902 the Han Chinese population alone exceed 1.5 million (Bao and Enkhee 2009).

Empirical evidence suggests that the dividing line between nomadic pastoralism and cultivation tended to move southward when climate was cold and dry, and vice versa (Fang 1999; Zheng et al. 2014). In addition to the climate factor, the ebb and flow of military power between nomadic empires in the north and agrarian dynasties in the south also has played an important role in shifting the line back and forth. To resist aggressions from nomadic empires, several Chinese dynasties spent enormous amounts of resources to construct the Great Wall (beginning in the Spring and Autumn and Warring States Periods, but most noticeable during Qin, Han, and Ming dynasties). Thus, the Great Wall signifies the nomadism-agriculture boundary (Zhang et al. 1997; Fang 1999). The Great Wall built during the Han Dynasty (202 BC–220 AD), when the climate was warm and humid, was located north of the Ordos region, whereas the Great Wall constructed in the Ming Dynasty (1368 AD–1644 AD) when the climate was cold and dry, was situated south of the Ordos region (Fig. 4). For about 2000 years, however, the political, economic, and cultural exchanges between the nomadic pastoralism and agrarian societies occurred over a much broader zone, including large areas south of the Great Wall and north of the Yellow River.

During the late Qing Dynasty, crop cultivation began to encroach northward into the heartland of Inner Mongolia on an unprecedented scale. Although grassland reclamation and immigration of agrarian populations to pastoral regions were prohibited by law in the early period of the Qing Dynasty, these restrictions were subsequently run over by social and environmental changes (Bao and Enkhee 2009). Early agriculture started in Chifeng in the southern edge of Inner Mongolia in the 1740s (Fig. 5). The first large-scale conversion of grassland to farmland occurred between 1876 and 1902 (Fig. 5). Prolonged drought swept through most of northern China in 1877 to 1878, resulting in a great famine and about 200 million starving refugees (historically known as the Ding-Wu Exceptional Drought or "Ding Wu Qi Huang"). This disaster was particularly severe in Shanxi and Hebei provinces, both adjacent to Inner Mongolia. A large number of hungry peasants rushed to Inner Mongolia and cultivated grasslands for survival. The government

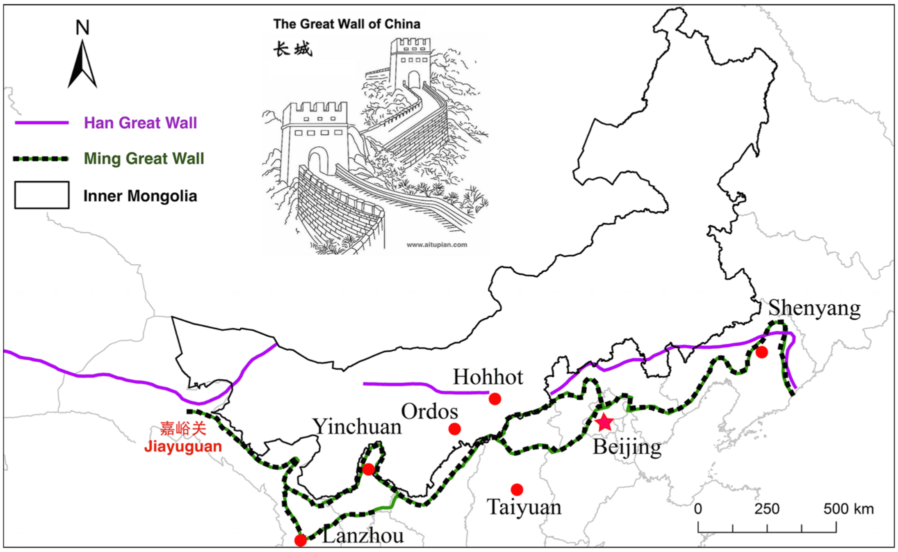

Fig. 4 Approximate locations of the Great Wall built in the Han Dynasty and the Ming Dynasty, which has been widely considered as the dividing line between nomadic pastoralism to its north and agrarian culture to its south

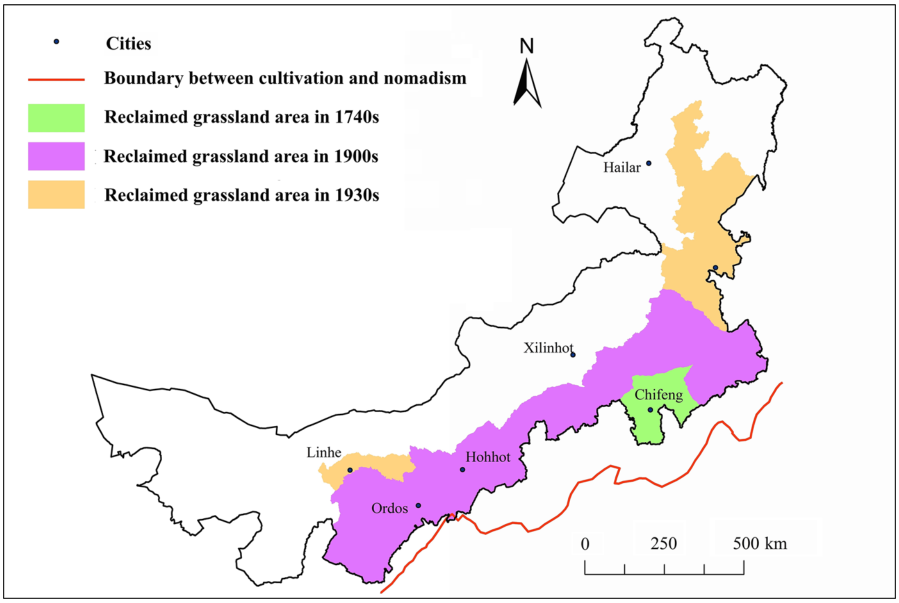

Fig. 5 Three major grassland-to-farmland conversion episodes in Inner Mongolia during the Qing Dynasty and the era of Republic of China

of the Qing Dynasty tolerated these famine immigrants, and large areas of grassland from Ordos in the west to Horqin in the east were converted to farmland during this period (Xia 1993). Moreover, under the pressure of raising funds to pay off the Boxer Indemnity (an unequal treaty signed in 1901 between the Qing Empire and the Eight-Nation Alliance), the Qing government enacted a reclamation policy in 1902 and sent out armed officials to implement it. This became the largest grassland-to-farmland conversion event during the dynastic era.

In a nutshell, during China's dynastic era of almost 4000 years, the agrarian and nomadic cultures had a long history of military conflicts and social and economic exchanges, with periodic migrations of peoples back and forth between the Central Plain and Inner Mongolia. This period was characterized by the long-term dominance of nomadic pastoralism and episodic but large-scale grassland-to-farmland conversion events, which took place mainly during the Qing Dynasty. Major drivers of land use change during this period include climate change, wars, and other sociocultural factors (especially government policies on land use).

Land use change in Inner Mongolia during the modern era (1912–present)

Land use change in the period of Republic of China (1912–1949)

The Xinhai Revolution in 1911 overthrew China's last imperial dynasty, and led to the establishment of the Republic of China (ROC) in 1912, with Sun Yat-Sen as the provisional president. The 38 years between 1912 and 1949 was one of the most chaotic periods in China's modern history, politically and socially. During this period, large areas of natural grasslands were converted to crop fields as a consequence of immigration of agrarian populations from the surrounding provinces, governmental policies for reclamation, and the lawless behavior of local landlords, often in the name of supporting armies to resist foreign imperialist aggressions (Lattimore 1940).

For example, more than 18,000 ha of grasslands were lost to farming in the south-central part (used to be called the Suiyuan region) of Inner Mongolia alone between 1912 and 1928 (Bayaer 2005). In the 1930s, greater areas of grasslands in the Horqin and Ordos regions were converted to agricultural fields under the direction of the government of ROC and local warlords (Lattimore 1940), resulting in another large grassland-to-cropland conversion event in China's history (Fig. 5). In addition, after occupying the northeast of China, the Japanese imperialist invaders not only massacred millions of innocent Chinese people, but also converted vast areas of grassland into crop fields and plundered enormous amounts of natural resource (e.g., timber, coal, and minerals) in Inner Mongolia to supply their inhuman and brutal military aggression against China and several other Asian countries (An 1995). Since the 1930s, the southern and northeastern parts of the plateau have been cultivated permanently (Figs. 3, 5).

Land use change in the period of People's Republic of China (1949–present)

1949–1978

From the last century of the Qing Dynasty to 1949, grasslands were mostly owned by clans and landlords, with transhumant pastoralism dominating the Inner Mongolia region. After the founding of the People's Republic of China (PRC) in 1949, however, the government began to own everything within its territory. Through the process of "Land Policy Reform", also known as "Land Revolution" in the early 1950s, the Chinese government collectivized pastoralists and the rangelands into People's Communes. From 1949 to 1978 (the beginning of China's economic reform and open-door policy), China's land use policies in Inner Mongolia focused on grain production while deemphasizing animal husbandry, resulting in the loss of large areas of grasslands to agriculture. Grassland conversion during this period was wide-spread across much of Inner Mongolia. Most noticeably, 800,000 ha of grasslands were cultivated between 1949 and 1952 to help the nation's economy to recover from the devastating civil war. During the "Great Leap Forward"(1957–1959), China had a nationwide mass movement for steel making and grain production, which actually resulted in a "great leap backward" because of misguiding policies and rash advances in socioeconomic development.

The Great Leap Forward was followed by the so-called "Three Years of Economic Hardship" or

"Three Years of Natural Disasters" between 1959 and 1961 during which tens of millions of people starved (also known as the "Great Chinese Famine" in the west). This large-scale famine was caused mainly by the government's erroneous policies and officials' misconducts, as well as droughts and flooding in some regions ("70 % of human-induced disasters and 30 % of natural calamities") (Chen 2004). In response to the food crisis, the government put forward "Grains First" policies, and additional 700,000 ha of grasslands were converted to farmland from 1959 to 1961. During the Cultural Revolution (1966–1976), the government not only demanded herders to produce their own grains, but also created the Inner Mongolian Production Army Corps of 170,000 people who were stationed across Inner Mongolia (Fig. 6). The Production Army Corps had dual responsibilities of producing food and defending the northern frontier of China against the possible invasion of the Soviet Union. More grasslands were converted to crop fields, some of which were located in the heartlands of the meadow steppe and typical steppe regions (Fig. 6).

The total cultivated area in Inner Mongolia increased from about 4 million to 5.3 million ha from 1949 to 1978, with a peak of over 6 million ha in 1961 (Fig. 7a). Human population increased from about 6 million in 1949 to 18.2 million in 1978 because of improved infant survival rate and large influxes of immigrants (Fig. 7b). During the same period, the total counts of livestock increased nearly 5 times from fewer than 10 million in 1949 to about 45 million in 1978 (Fig. 7c). These numbers suggest that a rapid increase in land use intensity in Inner Mongolia occurred even during the early decades of the PRC era, and that fast population growth was certainly an important factor for the increased demand for more land for food production.

1978–2000

After China started economic reform with an "open-door" policy in 1978, ideas of market economy began to penetrate into centrally planned economic policies. Since then, China's economic development has been moving forward at an unprecedented rate, resulting in profound landscape changes nationwide. Another major grassland-to-farmland conversion wave in Inner Mongolia occurred from 1987 to 1996, increasing the total area of cultivated land to more than 7 million ha (Fig. 7a). These newly cultivated grasslands were mainly distributed in the eastern and southwestern parts of Inner Mongolia (Wang and Su 1999). Non-vegetated areas and sandy lands also greatly increased during this period of time. For example, the area of Hunshandak Sandy Land increased nearly 50,000 ha between the late 1980s and the late 1990s (Chen et al. 2006), and non-vegetated areas in the Xilingol grassland increased by 143,400 ha from 1990 to 2000 (Hu et al. 2012). For Inner Mongolia as a whole, the total area of bare and sandy lands increased by 346,700 ha,

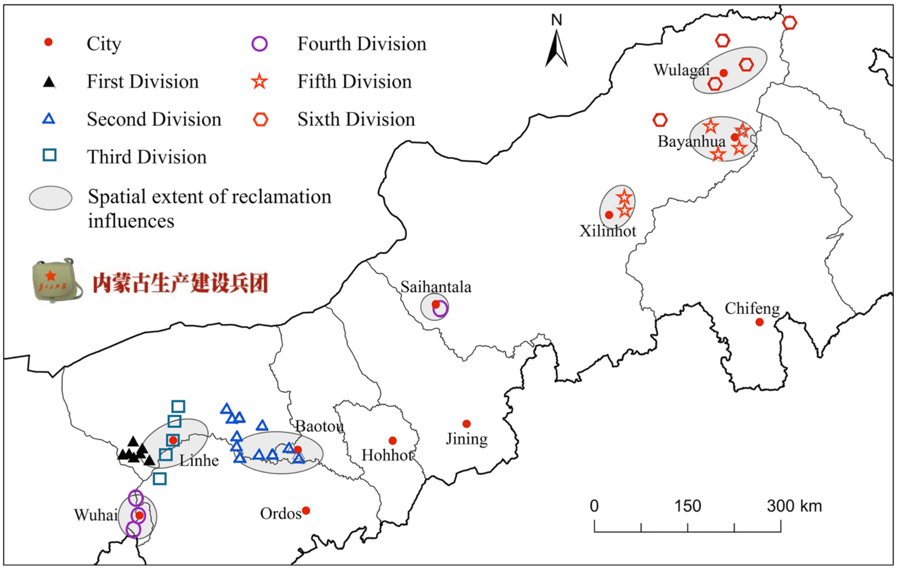

Fig. 6 Spatial distribution the Inner Mongolian Production Army Corps (1969–1975), showing the locations the six divisions of 170,000 people. The spatial extent of reclamation influences depicts the total area of cultivation and urbanization surrounding the original military barracks

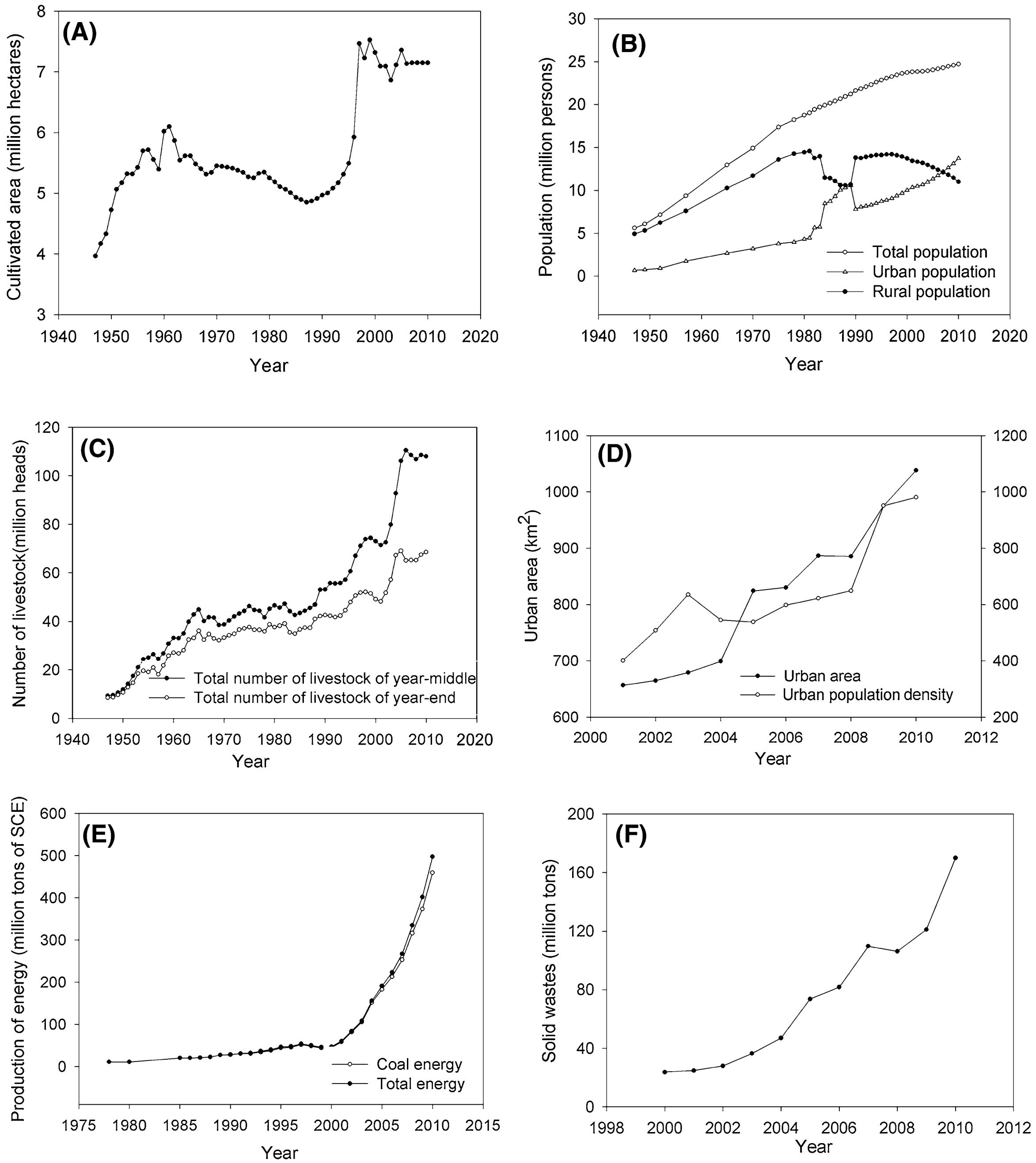

Fig. 7 Changes in some important socioeconomic variables in Inner Mongolia since 1949: **a** Total cultivated area, **b** human population, **c** livestock population, **d** urban area and urban population density, **e** energy production, and **f** solid wastes produced. All the data were from Inner Mongolia Statistical Yearbook (http://www.nmgtj.gov.cn)

while grassland area decreased by 454,589 ha from 1990 to 2001 (John et al. 2009; Hu et al. 2012).

The livestock population (mid-year head counts)increased from about 45 million in 1978 to more than 75 million in 2000, and this number exceeded 100 million in 2005 (Fig. 7c). Such breakneck increase rate of livestock, especially after the mid-1980s, was unprecedented in the history of Inner Mongolia. Fast economic development promoted rapid urbanization which in turn stimulated population growth and massive rural-to-urban migrations (Fig. 7b, d). With continuing increases in human and livestock populations in Inner Mongolia, land use activities, particularly overgrazing, became a primary cause for large-scale grassland degradation across the region (Tong et al. 2004; Jiang et al. 2006; Li et al. 2012). The total area of degraded grasslands in Inner Mongolia increased from 35.57 % in 1985 to 60.08 % in 1995 (Li 1997). Due to new urban developments, coal mining, and farmland expansion, Inner Mongolia became much more fragmented than ever (Li 2008; John et al. 2009; Hu et al. 2012). In the same time, the total area of wetlands and water bodies decreased substantially (John et al. 2009; Tao et al. 2015).

During this period of time, the Chinese government made two historic institutional changes for its pastoral lands: the de-collectivization and privatization of natural grasslands in the early 1980s and the promulgation of the Grassland Law in 1985 (amended in 2003).After 1949, the government owned all the grasslands and most livestock, with all pastoralists organized into "communes". In 1983, the commune system was disbanded with the establishment of the "Household Contract Responsibility System" (HCRS), a major policy reform that has profoundly influenced the agricultural and pastoral regions of China ever since. Between 1983 and the early 2000s, the Inner Mongolia government implemented the HCRS policy in its pastoral lands (progressively from a few pilot areas to the entire region), distributing grasslands and livestock to individual herding households. While this policy was quite successful in promoting land productivity in agrarian areas, its implementation in the pastoral region resulted in increasing stocking rate, reduced livestock mobility, and highly fragmented grassland landscapes (Li et al. 1999; Zhang et al. 2009).

2000-present

Several colossal dust storms rumbled through hundreds of cities and villages, entraining dusts and industrial pollutants along the way and blanketing the sky of Beijing between 1998 and 2001. These dust storms originated from dryland areas mainly in Inner Mongolia. They disrupted many people's normal work and life, caused serious health concerns, and thus soon became a frequent headline in China's news media. As part of the Chinese government's plan to combat dust storms and protect the environmental quality of Beijing, a series of large-scale ecological conservation and restoration projects were initiated, including the Beijing-Tianjin Wind and Sand Source Control Project, the Natural Forest Protection Project, and the Grain to Green Project. This marked a turning point in the history of land use policy in Inner Mongolia (Ye et al. 2000; Li et al. 2012).

Since 2001, both grassland and forested areas in Inner Mongolia have continued to increase while agricultural land has shown a declining trend (Fig. 7a). Specifically, from 2001 to 2010 grasslands increased from 86.7 million to 88 million ha, and forest cover increased from 17.57 to 20.00 % (Inner Mongolia Autonomous Region Bureau of Statistics 2002–2011). Land desertification has been curbed to some extent, as evidenced by the vegetation recovery of sandy lands from Ordos in the west (Zhang et al. 2014) to Horqin in the east (Zhang et al. 2012) and the decreasing area of bare land in a number of places throughout the Inner Mongolian region (John et al. 2009; Hu et al. 2012).

Despite these recent positive trends in ecological restoration, increasing human activities since the 1950s have resulted in a number of ecological problems across the Inner Mongolia region. For example, biodiversity, ecosystem function, and ecosystem services have declined in the region because of increasing human demands for resources, improper management practices, and misguided land policies (Wu and Loucks 1992; Li 1997; Tong et al. 2004; Squires et al. 2009). Many endemic species and unique plant communities have disappeared or become endangered (Li et al. 1990; Kang et al. 2007; Xu et al. 2010). Almost all the grasslands in Inner Mongolia are now degraded at varying degrees, and over average the current grassland primary productivity has decreased to only about 50 % or less of that of undisturbed steppes (Xu et al. 2000; Jiang et al. 2006). Reduced vegetation cover and biodiversity loss not only decreased grassland productivity, but also simplified the community structure (e.g., species composition, functional groups, and food webs), thus undermining ecosystem stability and resilience against climate change and other environmental disturbances (Bai et al. 2004, 2007; Liu et al. 2011). Furthermore, soil erosion by wind and water have become a wide-spread problem in many areas of Inner

Mongolia since the 1960s, contributing to the problem of dust storms. In addition, the total area of surface water has been decreasing, groundwater level has been dropping, and many lakes have disappeared, with the rest shrinking in size (Liu et al. 2013; Tao et al. 2015).

These large-scale grassland degradation did not occur until the 1960s primarily because of such anthropogenic factors as overgrazing, grassland-to-farmland conversion, mining, and urbanization (Li 1997; Wu and Hobbs 2002; Tong et al. 2004; Squires et al. 2009; Dong et al. 2011; Li et al. 2012). For example, the major reasons of decreasing water resources include increasing water demands for crop irrigation, industrial activities, and urbanization (Fig. 7). The urban area of the 20 largest cities in Inner Mongolia increased form 65,669 to 103,832 ha from 2001 to 2010 (about 1.6 times; Fig. 7d). During the same period, coal production increase from 58.30 million to 459.35 million tons of standard coal energy (nearly 8 times; Fig. 7e), while the total amount of solid wastes also increased several times (Fig. 7f). Coal mining not only destroyed large areas of grassland directly, but also exhausted or polluted surface and ground water near and afar. However, these and other related environmental and ecological problems are yet to be carefully studied. Even more dramatically than cultivation, large-scale surface mining and urban sprawl are profoundly transforming the structure, function, and future destiny of landscapes across Inner Mongolia.

Discussion

General patterns of historic land use change in Inner Mongolia

For thousands of years, the most salient characteristics that distinguish nomadic pastoralism from agrarian culture can be summarized into one word: mobility. Nomadic pastoralism relies heavily on moving livestock around seasonally and yearly to avoid overgrazing and to adapt to high climatic variability, and is a "coarse-grained" land use form that traditionally operates over broad scales. In this case, both people and their livestock are always on the move—roaming around the vast grasslands with a great deal of risk and uncertainty. By contrast, agrarian culture is characterized by the fixation of people to their land, and is typically a "fine-grained", laborious land use form that usually operates on local scales. In this case, people and their belongings are basically sedentary—having a high degree of fidelity to the "place" that provides a sense of security and comfort. Inner Mongolia has been dominated by grassland and desert landscapes since more than 2 million years ago. Human land use in this region has experienced a series of transitions from localized primitive agriculture and fisheries that occurred in prehistoric times to broad-scale nomadic pastoralism that lasted for a few 1000 years and to sedentary pastoralism with increasing agriculture and urbanization during the past several decades.

These historical changes in land use resemble the general temporal trend of land use transitions observed around the world (DeFries et al. 2004b; Foley et al. 2005): the pre-settlement stage (dominated by wild lands with low population densities)—the frontier clearing and subsistence agriculture stage (self-sufficient farming with the population mostly engaged in food production for local consumption)—the intensive agriculture and urbanization stage (characterized by diversified land uses and market economy, with increasingly more agricultural products consumed by urban populations). In Inner Mongolia, the pre-settlement stage started several 1000 years ago when ancient agrarian cultures emerged on the plateau. Subsistence economy lasted for a few 1000 years, in the form of nomadic pastoralism dominating the vast grasslands and traditional farming in the southern part of Inner Mongolia. In the 1960s, sedentary animal husbandry completely replaced nomadic pastoralism, and subsistence economy has been superseded by centrally-planned and market economy. However, this general trend of land use change should neither be understood as an inevitable consequence of socioeconomic progress nor a necessary pathway to future sustainable development, particularly in a region where the preservation of indigenous culture is of critical importance. As discussed earlier in this review, modern agricultural and urban encroachment into pastoral lands has been a primary cause of unsustainability in Inner Mongolia.

Landscape dynamics is always heterogeneous in space and nonlinear in time. A salient characteristic of land use and land cover change in Inner Mongolia is the broad-scale dichotomous pattern: pastoral lands in the north and an agro-pastoral transitional zone in the south (Fig. 2d). This transitional zone in Inner

Mongolia constitutes the major part of the Agro-Pastoral Transitional Zone of North China (APTZNC) that covers an area of 690,000 km^2, cutting across 8 provinces (Zhang et al. 1997; Wang et al. 1999; Zhao et al. 2002). APTZNC is an extensive belt-shaped region with fast landscape dynamics, and it is not only important for understanding the land use history but also for planning a sustainable future of Inner Mongolia. On a broader scale, remote sensing images clearly reveal heavier influences of human activities on landscapes in Inner Mongolia than those in Mongolia (John et al. 2008; Chen et al. 2013; Wang et al. 2013; Hilker et al. 2014; Chen et al. 2015; Zhao et al. 2015).

Major drivers of land use change in Inner Mongolia

In previous sections we identified a number of natural and human factors that were responsible for land use and land cover change in Inner Mongolia. The major drivers or causes include: climate change, human demographic changes (e.g., population growth and migrations), political regime shifts (e.g., the rise and demise of dynasties), institutional changes (especially national laws and policies on land use), economic structures (e.g., subsistence economy, centrally planned economy, and market economy), sociocultural transformations (e.g., changes in life style and value systems), and technological innovations (e.g., irrigation systems, agricultural machinery, and modern veterinary and forage storage techniques). In general, the landscape dynamics of Inner Mongolia have been driven by multiple causes and their interactions or feedbacks although certain individual factors played a dominant role during some time periods. For example, natural disasters could trigger different kinds of responses from society and governments, including changes in land use policy (e.g., prolonged droughts leading to famine and government policy for converting natural grasslands to farmland to produce food in the late-Qing Dynasty), as well as political uprisings and military conflicts (e.g., peasant revolts and wars between the nomadic north and the agrarian south during the dynastic era). The multiplicity of causes for land use change seems to be the case for all landscapes around the world, as "land-use change is always caused by multiple interacting factors originating from different levels of organization of the coupled human-environment systems" (Lambin et al. 2003).

To better understand the complex relationships among them, the drivers of LUCC may be classified into different groups, based on whether they operate on local or broader scales, whether they are fast or slow variables, whether they affect LUCC directly or indirectly, and whether they are endogenous or exogenous to the system (Geist and Lambin 2002; Lambin et al. 2003; Burgi et al. 2004). Lambin et al. (2003) proposed a typology of causes of land use change, with five "fundamental high-level causes": (1) resource scarcity leading to an increase in the pressure of production on resources, (2) changing opportunities created by markets, (3) outside policy intervention, (4) loss of adaptive capacity and increased vulnerability, and (5) changes in social organization, in resource access, and in attitudes. Furthermore, the land use change drivers can also be distinguished in terms of "proximate"(or direct)versus "underlying" (indirect or root) causes (Geist and Lambin 2002; Lambin et al. 2003). Proximate causes are human activities that originate locally from intended land use and directly affect land cover, whereas underlying driving forces are socioeconomic and institutional processes that indirectly affect land use and land cover through influencing the proximate causes on local, regional, national, and global scales (Geist and Lambin 2002).

The various drivers of LUCC in Inner Mongolia certainly can fit into these broad categories, which helps us better understand the complexity of multiple interactive factors in a historical context. Specifically, climate change has been a background driver for land use change over long and broad scales, which affects land use change indirectly and is affected by regional and global climate (Lu et al. 2009a, b; Chen et al. 2013). High variability in precipitation and temperature—a salient characteristic of the dryland climate, has always played an important role in land use and land cover change on local to regional scales. Indeed, resilience or vulnerability to extreme climatic events (e.g., droughts and snow blizzards) is one of the most effective indicators of the environmental and social sustainability of dryland systems (Squires and Yang 2009). Human demography, political regimes, policies and institutions, economic structures, sociocultural systems, and technologies may all be considered underlying causes in Inner Mongolia. They have interactively influenced proximate process (e.g., grazing, cultivation, settlements, road construction, and mining) that have directly changed the land use and land cover pattern in Inner Mongolia, particularly, during the modern era.

It is important to emphasize that, before the late-Qing Dynasty, long-term climate change (e.g., the transition from a hot and humid climate to a cold and dry climate) had long been the primary driver of landscape changes in Inner Mongolia. For example, the sandification of the Mu Us region was mainly a result of climate change and geophysical processes before the 1800s. On shorter scales of seasons and decades, climatic fluctuations have always resulted in frequent alternations of wet and dry years, consequently inducing mostly reversible land cover changes. After the 1800s, however, human factors became increasingly important, and now have overwhelmed natural forces in shaping the landscapes in the region. In particular, land use policies and economic systems have been chiefly responsible for the profound landscape transformations and myriad environmental problems in the recent decades (Li et al. 2007; Liu et al. 2008; Squires et al. 2009; Li and Huntsinger 2011; Chen et al. 2013).

Strategies for promoting sustainability in Inner Mongolia

Today, the steppes in Inner Mongolia are still vast in extent, but resemble little the past—say, the grasslands of the Genghis Khan era. Successive Chinese governments, from the Qing Dynasty to ROC and PRC, all have failed to provide ecologically sound and operationally effective land use policies to protect and sustain the biodiversity, ecosystem function, and ecosystem services of the drylands in Inner Mongolia. Myriad environmental problems are widely recognized, but most solutions—science-based or otherwise—so far have failed to achieve the expected outcomes, despite the fact that the number of research papers on Inner Mongolian dryland ecosystems has increased exponentially during the past 30 years. What needs to be done to alleviate the current environmental problems and make the region more sustainable? How can research help? A number of studies have been published to address these questions since the 1980 s, and it is neither possible nor necessary to review them all here. Instead, we briefly summarize the dominant views in the Chinese and English literature, based on which we advocate a multi-scale, transdisciplinary approach that is guided by landscape sustainability science and land system design (Wu 2013b; Wu et al. 2014b).

Since the 1960s, Chinese scientists have done painstaking studies on the causes and processes of rangeland degradation, and made numerous suggestions for improving rangeland management (Li 1984; Jiang 1988; Li et al. 1988, 1990; Zhang 1994; Li 1997; Zhang 2000; Tong et al. 2004; Liu et al. 2008; Ren et al. 2010). The late Prof. Bo Li, one of the most eminent ecologists in China's history, encapsulated most of the suggestions in his eight strategies for curbing degradation and promoting sustainability in Inner Mongolia (Li 1997): (1) Establish a system of valuation and payments for using rangeland resources; (2) Restore degraded rangelands in tandem with developing highly productive artificial grasslands in suitable places with favorable soil water conditions; (3) Keep livestock quantity in check and improve livestock quality; (4) Increase government's investment in rangeland restoration and management; (5) Reinforce the Grassland Law and strictly implement ecologically sound management policies; (6) Control human population growth in pastoral areas, especially limiting immigration from other parts of China; (7) Improve the scientific knowledge and management skills of local officials in pastoral areas through training programs; and (8) Promote rangeland research, particularly on the biophysical and socioeconomic mechanisms of land degradation and ecological restoration.

In the past two decades, the Chinese government has invested billions of yuan in scientific research and management practices in order to promote rangeland sustainability in Inner Mongolia. A large number of Chinese and international scholars have continued to study the biophysical and socioeconomic problems of rangeland degradation in this region, and generated more suggestions. For example, a recent book (Squires et al. 2009), with contributions from both Chinese and international scholars, was devoted to address the question: How can the next degradation episode be prevented in the pastoral lands of northern China? Most of the chapters were case studies by Chinese scholars who focused on arduous documentation of the myriad biophysical problems of rangeland degradation. Western scholars seemed more zealous to emphasize social and institutional problems and to offer policy solutions. In the concluding chapter, Squires and Yang (2009) suggested several strategies: develop management systems for increasing mobility and flexibility; create policies to promote alternative employment generation; develop policies for effective disaster relief and risk management; establish policies for rewarding proper use of rangeland resources and penalizing overgrazing and resource overexploitation; and promote partnerships between the state and rangeland users. In another book on China's pastoral lands, Brown et al. (2008) claimed that most Chinese studies focused on "technical solutions", and emphasized that the technical solutions need to be interfaced with reforms of policies and institutions—a suggestion which has been well understood and fully supported by many Chinese scholars (e.g., Li et al. 1990; Li 1997; Zhang 2000; Shi et al. 2004; Liu et al. 2008).

While most of these suggestions are included in, or implied by, those of Li (1997), two points in Squires and Yang (2009) stand out as being of paramount importance: livestock mobility and land use policies. In the same book, Williams et al. (2009) claimed that the loss of livestock mobility (not high stocking rate) has been a root cause of rangeland degradation in China, and that the future sustainability of these rangelands will hinge on restored livestock mobility that requires major institutional changes. The view that livestock mobility is key to sustainable pastoralism had been expressed by a number of western scholars (e.g., Sneath 1998; Humphrey and Sneath 1999; Fernández-Giménez and Swift 2003) as well as Chinese researchers (e.g., Enkhee 2003; Liu 2003; Dalintai and Alatenbagena 2005; Liu et al. 2008; Dalintai 2010; Ren et al. 2010). However, China's policies of de-collectivization and privatization of rangelands during the past several decades have resulted in increasingly sedentary and fragmentary, rather than mobile and coordinated, pastoralism in Inner Mongolia (Humphrey and Sneath 1999; Huang et al. 2009; Williams et al. 2009), although these policies were well-intended and promoted short-term economic development in the region.

It is important to note that livestock mobility needs to be operationalized between seasons and on broad enough spatial scales so that different landscape and ecosystem features can be optimally used to cope with extreme weather conditions and avoid overgrazing the rangeland. This seems the essence of transhumance (mobile pastoralism taking advantage of summer and winter pastures), which is an adaptive management strategy out of experience and necessity. Small-scale rotational grazing systems, however, may not achieve the expected goals of livestock mobility (for the debate on the effectiveness of rotational grazing or multi-paddock grazing, see Briske et al. 2008; Teague et al. 2011, 2013). To operationalize mobility on large scales, institutional changes are needed at the national, regional, and local levels, which means drastic changes to the existing land use policies. Also, restoring mobility is not to return to traditional nomadism, a form of "subsistence sustainability" which would neither be able to support today's high population densities nor to satisfy modern society's human needs. In addition, mobility is not a panacea; when stocking rates are excessively high or when a rangeland is already overgrazed, increasing mobility itself can do little to improve the situation. This means that controlling both human and livestock populations in Inner Mongolia is as important as increasing mobility.

Finally, policy makers must understand that difference is not deficiency; mobile pastoralism represents a different, but not an obsolete, culture or land use. The ecological integrity and cultural identity in Inner Mongolia are intrinsically linked (Enkhee 2003). Our review of historical landscape transformations and major drivers in this region provides many lessons from the past. Agricultural encroachment and rapid urbanization have created short-term economic gains with high spatial and social inequality and, in the same time, severe environmental and cultural problems in the long run. The most important value of these lessons is not to predict the future, but rather to guide our way to shape the future. To effectively implement the above-mentioned strategies, they must be integrated in a sustainability science framework that simultaneously considers the ecological, social, and economic dimensions of the human-environment system (Kates et al. 2001; Wu et al. 2014c). In particular, landscape sustainability science and land system design are quite relevant (Shi et al. 2004; Wu 2013b; Turner et al. 2013). Some excellent examples of sustainable land system design for pastoral areas of Inner Mongolia already exist, which aimed to optimize production and ecological functions simultaneously by taking advantage of the landscape characteristics (e.g., topography, geology, soil, climate, vegetation, and hydrology) and sociocultural settings of a given region (Zhang 1994, 2000). To move forward, future research needs to focus on the relationship between ecosystem services (supporting, provisioning, regulating, and cultural) and human well-being (object and subjective) in the face of climate and socioeconomic changes, as well as actionable knowledge and design principles for optimizing land use and land cover patterns to promote regional sustainability (Wu et al. 2014b, c).

Acknowledgments This research was supported in part by the Chinese Ministry of Science and Technology through the National Basic Research Program of China (2014CB954303, 2014CB954300).

References

An CR (1995) Economic development of the Japanese imperialism in Northeast China. Northeast Asia Forum 3:85–89

Bai Y, Han X, Wu J, Chen Z, Li L (2004) Ecosystem stability and compensatory effects in the Inner Mongolia grassland. Nature 431(7005):181–184

Bai Y, Wu J, Pan Q, Huang J, Wang Q, Li F, Buyantuyev A, Han X (2007) Positive linear relationship between productivity and diversity: evidence from the Eurasian Steppe. J Appl Ecol 44(5):1023–1034

Bai Y, Wu J, Clark CM, Pan Q, Zhang L, Chen S, Wang Q, Han X (2012) Grazing alters ecosystem functioning and C:N:P stoichiometry of grasslands along a regional precipitation gradient. J Appl Ecol 49(6):1204–1215

Bao H-X, Enkhee J (2009) A study on the population change of the Inner Mongolian pastoral area. J Inner Mongolia Univ (Philos Soc Sci) 41(4):9–13

Bayaer (2005) Land use and land cover change in inner-mongolia—a multiscale dynamic study. Inner Mongolian People's Press, Hohhot

Briske DD, Derner JD, Brown JR, Fuhlendorf SD, Teague WR, Havstad KM, Gillen RL, Ash AJ, Willms WD (2008) Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangel Ecol Manag 61(1):3–17

Brown CG, Waldron SA, Longworth JW (2008) Sustainable development in Western China: managing people, livestock and grasslands in Pastoral Areas. Edward Elgar, Cheltenham

Burgi M, Hersperger AM, Schneeberger N (2004) Driving forces of landscape change—current and new directions. Landscape Ecol 19:857–868

Chen DL (2004) An investigation of the "Three Years of Natural Disaster" from the viewpoint of disaster economics. Contemp China Hist Stud 11:83–93

Chen YF, Xu XL, Wang SY (2006) Land use/cover change and degradation trend of the Hunshandake Sandy area in Inner Mongolia plateau. J Mt Sci 24(1):60–64

Chen JS, Huang BC, Sun LS (2010) New constraints to the onset of the India-Asia collision: paleomagnetic reconnaissance on the Linzizong Group in the Lhasa Block, China. Tectonophysics 489(1–4):189–209

Chen J, Wan S, Henebry G, Qi J, Gutman G, Sun G, Kappas M (eds) (2013) Dryland East Asia: land dynamics amid social and climate change. Higher Education Press, Beijing

Chen J, John R, Zhang Y, Shao C, Brown DG, Batkhishig O, Amarjargal A, Ouyang Z, Dong G, Wang D, Qi J (2015) Divergences of two coupled human and natural systems on the Mongolian Plateau. BioScience (in press)

Dalintai ZY-S (2010) Pastoral region and market: Herders and economics. Social Sciences Academic Press, Beijing

Dalintai, Alatenbagena (2005) An institutional rethink of grassland desertification. J Guizhou Coll Financ Econ 116(3):46–50

DeFries R, Asner G, Houghton R (eds) (2004a) Ecosystems and land use change. American Geophysical Union, Washington, DC

DeFries RS, Foley JA, Asner GP (2004b) Land-use choices: balancing human needs and ecosystem function. Front Ecol Environ 2(5):249–257

Dong JW, Liu JY, Yan HM, Tao FL, Kuang WH (2011) Spatio-temporal pattern and rationality of land reclamation and cropland abandonment in mid-eastern Inner Mongolia of China in 1990–2005. Environ Monit Assess 179(1–4):137–153

Enkhee J (2003) A historical retrospect on grassland desertification: cultural dimension of development. J Inner Mongolia Univ (Philos Soc Sci) 35:3–9

Fang XQ (1999) Decline of pre-historical agriculture and formation of farming-grazing transitional zone in North China: a view from climatic changes. J Nat Resour 14:212–218

Fernández-Giménez ME, Swift DM (2003) Strategies for sustainable grazing management in the developing world. In: Allsopp N, Palmer AR, Milton SJ, Kirkman KP, Kerley GIH, Hurt CR, Brown CJ (eds) The VIIth International Rangeland Congress. Document Transformation Technologies, Durban, pp 821–831

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309(5734):570–574

Forman RTT, Godron M (1986) Landscape ecology. Wiley, New York

Geist HJ, Lambin EF (2002) Proximate causes and underlying driving forces of tropical deforestation. Bioscience 52(2):143–150

Han XG, Owens K, Wu XB, Wu JG, Huang JH (2009) The grasslands of inner Mongolia: a special feature. Rangel Ecol Manag 62(4):303–304

Hao W-M, Chimeddorji (eds) (2011) The history of inner Mongolia, vol I-VIII. People's Press, Beijing

Hilker T, Natsagdorj E, Waring RH, Lyapustin A, Wang YJ (2014) Satellite observed widespread decline in Mongolian grasslands largely due to overgrazing. Glob Change Biol 20:418–428

Hu YF, Yan Y, Yu GM, Liu Y, Alatengtuya T (2012) The ecosystem distribution and dynamics in Xilingol League in 1975-2009. Sci Geogr Sin 32(9):1125–1130
Huang JH, Bai YF, Jiang Y (2009) Case study 3: Xilingol grassland, Inner Mongolia. In: Squires CR, Lu X, Lu Q, Wang T, Yang Y (eds) Rangeland degradation and recovery in China's Pastoral Lands. CAB International, Oxfordshire, pp 120–135
Humphrey C, Sneath D (1999) The end of nomadism?. Duke University Press, Durham
Jiang S (1988) The strategy of reasonably using grassland grasslands—a case study of Xilingol. In: Inner Mongolia Grassland Ecosystem Research Station (ed) Research on grassland ecosystem, vol 3. Science Press, Beijing, pp 1–9
Jiang G, Han X, Wu J (2006) Restoration and management of the Inner Mongolia grassland require a sustainable strategy. AMBIO 35(5):269–270
John R, Chen JQ, Lu N, Guo K, Liang CZ, Wei YF, Noormets A, Ma KP, Han XG (2008) Predicting plant diversity based on remote sensing products in the semi-arid region of Inner Mongolia. Remote Sens Environ 112:2018–2032
John R, Chen JQ, Lu N, Wilske B (2009) Land cover/land use change in semi-arid Inner Mongolia: 1992–2004. Environ Res Lett. doi:10.1088/1748-9326/4/4/045010
Kang L, Han XG, Zhang ZB, Sun OJ (2007) Grassland ecosystems in China: review of current knowledge and research advancement. Philos Trans R Soc B 362(1482):997–1008
Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC, Lowe I, McCarthy JJ, Schellnhuber HJ, Bolin B, Dickson NM, Faucheux S, Gallopin GC, Grubler A, Huntley B, Jager J, Jodha NS, Kasperson RE, Mabogunje A, Matson P, Mooney H, Moore B III, O'Riordan T, Svedin U (2001) Sustainability science. Science 292:641–642
Lambin EF, Geist HJ, Lepers E (2003) Dynamics of land-use and land-cover change in tropical regions. Annu Rev Environ Resour 28:205–241
Lattimore O (1940) Inner Asian Frontiers of China. Oxford University Press, New York
Li B (1964) The history of vegetation research in Inner Mongolia. Acta Sci Nat Univ Neimongol 6(1):1–14
Li B (1979) General characteristics of the steppe vegetation in China. China's Grassl 1:2–12
Li B (1984) Grasslands and their use and improvements. Agriculture Press, Beijing
Li B, Yong SP, Li ZH (1988) The vegetation of the Xilin River Basin and its utilization. In: Inner Mongolia Grassland Ecosystem Research Station (ed) Research on grassland ecosystem, vol 3. Science Press, Beijing, pp 84–183
Li B, Yong S-P, Li Y, Liu Y-J (1990) The grasslands of China. Science Press, Beijing
Li B (1997) The rangeland degradation in North China and its preventive strategies. Sci Agric Sin 30(6):1–9
Li C, Liang C, Wang W, Liu Z (1999) Landscape fragmentation and land use strategies in the Wulagai region of Inner Mongolia. J Arid Land Resour Environ 13(1):65–72
Li WJ, Ali SH, Zhang Q (2007) Property rights and grassland degradation: a study of the Xilingol Pasture, Inner Mongolia, China. J Environ Manag 85(2):461–470
Li YC (2008) Land cover dynamic changes in northern China: 1989–2003. J Geogr Sci 18(1):85–94
Li WJ, Huntsinger L (2011) China's grassland contract policy and its impacts on herder ability to benefit in Inner Mongolia: tragic feedbacks. Ecol Soc 16(2):1
Li A, Wu JG, Huang JH (2012) Distinguishing between human-induced and climate-driven vegetation changes: a critical application of RESTREND in inner Mongolia. Landscape Ecol 27(7):969–982
Liang C, Zhu Z, Wang W, Pei H, Zhang T, Wang Y (2004) The Diversity and spatial distribution of plant communities in the Helan Mountains. Acta Phytoecol Sin 28(3):361–368
Liu S-R (2003) Human factors for large-scale ecosystem degradation in the Inner Mongolian Grassland. ScienceNet. http://www.blog.sciencenet.cn/blog-52837-29344.html
Liu Z-L, Liang C-Z, Wang L-X, Dun-Yuan H, Hua-Ming L (2008) Inheriting and advancing the essence of nomadic culture, and searching for a new course of harmonious development on the grassland. In: Organizing Committee of 2008 IGC/IRC Conference (ed) Multifunctional grasslands in a Changing World, vol II. Guangdong People's Press, Guangzhou, pp 853–856
Liu YS, Pan QM, Liu HD, Bai YF, Simmons M, Dittert K, Han XG (2011) Plant responses following grazing removal at different stocking rates in an Inner Mongolia grassland ecosystem. Plant Soil 340(1–2):199–213
Liu H, Yin Y, Piao S, Zhao F, Engels M, Ciais P (2013) Disappearing lakes in semiarid northern China: drivers and environmental impact. Environ Sci Technol 47:12107–12114
Lu N, Wilske B, Ni J, John R, Chen J (2009a) Climate change in Inner Mongolia from 1955 to 2005-trends at regional, biome and local scales. Environ Res Lett. doi:10.1088/1748-9326/4/4/045006
Lu Y, Zhuang Q, Zhou G, Sirin A, Melillo J, Kicklighter D (2009b) Possible decline of the carbon sink in the Mongolian Plateau during the 21st century. Environ Res Lett. doi:10.1088/1748-9326/4/4/045023
Ma Y-Q (ed) (1985) Flora of Inner Mongolia, vol I. Inner Mongolia People's Press, Hohhot
MEA (2005) Ecosystems and human well-being: current state and trends. Island Press, Washington, DC
Ren J-Z, Hou F-J, Xu G (2010) Conservation and inheritance of nomadic culture. Pratacultural Sci 27(12):5–10
Ren J-Z, Xu G, Qi W-T (2013) The historical footprint of ethical ideas on Chinese agricultural civilization and its urban-rural dual structure. Agric Hist China 32(6):3–12
Reynolds JF, Stafford Smith DM, Lambin EF, Turner BL, Mortimore M, Batterbury SPJ, Downing TE, Dowlatabadi H, Fernandez RJ, Herrick JE, Huber-Sannwald E, Jiang H, Leemans R, Lynam T, Maestre FT, Ayarza M, Walker B (2007) Global desertification: building a science for dryland development. Science 316(5826):847–851
Sala OE, Lauenroth WK, McNaughton SJ, Rusch G, Zhang X (1996) Biodiversity and ecosytem functioning in grasslands. In: Mooney HA, Cushman JH, Medina E, Sala OE, Schulze ED (eds) Functional roles of biodiversity: a global perspective. Wiley, Chichester, pp 129–149
Shi P-J, Li X-B, Zhang W-S, Xu W (2004) The "earth health-human health model" of biolgical resource utilization ad ecological construction. Resour Sci 26:2–8
Sneath D (1998) Ecology—state policy and pasture degradation in inner Asia. Science 281(5380):1147–1148

Squires VR, Yang Y (2009) How can the next degradation episode be prevented? In: Squires CR, Lu X, Lu Q, Wang T, Yang Y (eds) Rangeland degradation and recovery in China's Pastoral Lands. CAB International, Oxfordshire, pp 247–257

Squires CR, Lu X, Lu Q, Wang T, Yang Y (eds) (2009) Rangeland degradation and recovery in China's Pastoral Lands. CAB International, Oxfordshire

Tao S, Fang J, Zhao X, Zhao S, Shen H, Hu H, Tang Z, Wang Z, Guo Q (2015) Rapid loss of lakes on the Mongolian Plateau. Proc Natl Acad Sci USA 112:2281–2286

Teague WR, Dowhower SL, Baker SA, Haile N, DeLaune PB, Conover DM (2011) Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in all gras prierie. Agric Ecosyst Environ 141:310–322

Teague R, Provenza F, Kreuter U, Steffens T, Barnes M (2013) Multi-paddock grazing on rangelands: why the perceptual dichotomy between research results and rancher experience? J Environ Manag 128:699–717

Tong C, Wu J, Yong S, Yang J, Yong W (2004) A landscape-scale assessment of steppe degradation in the Xilin River Basin, Inner Mongolia, China. J Arid Environ 59(1):133–149

Turner BL II, Clark WC, Kates RW, Richards JF, Mathews JT, Meyer WB (eds) (1990) The earth as transformed by human action: global and regional changes in the biosphere over the past 300 years. Cambridge University Press, Cambridge

Turner BL II, Lambin EF, Reenberg A (2007) The emergence of land change science for global environmental change and sustainability. Proc Natl Acad Sci 104:20666–20671

Turner BL II, Janetos AC, Verburg PH, Murray AT (2013) Land system architecture: using land systems to adapt and mitigate global environmental change. Glob Environ Change 23:395–397

Wang XL, Su Z (1999) Study on temporal and spatial changes of cultivated land use in Inner Mongolia based on GIS. Arid Land Geogr 22(002):71–76

Wang J, Xu X, Liu P (1999) Land use and population carrying capacity in the agro-pastoral transitional zone of North China. Resour Sci 21:19–24

Wang J, Brown DG, Chen JQ (2013) Drivers of the dynamics in net primary productivity across ecological zones on the Mongolian Plateau. Landscape Ecol 28(4):725–739

Williams A, Wang M, Zhang MA (2009) Land tenure arrangements, property rights and institutional arrangements in the cycle of rangeland degradation and recovery. In: Squires CR, Lu X, Lu Q, Wang T, Yang Y (eds) Rangeland degradation and recovery in China's Pastoral Lands. CAB International, Oxfordshire, pp 219–234

World Conservation Monitoring Centre (1992) Global biodiversity: status of the earth's living resources. Chapman & Hall, London

Wu JG (2006) Landscape ecology, cross-disciplinarity, and sustainability science. Landscape Ecol 21(1):1–4

Wu JG (2013a) Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop. Landscape Ecol 28:1–11

Wu JG (2013b) Landscape sustainability science: ecosystem services and human well-being in changing landscapes. Landscape Ecol 28(6):999–1023

Wu J, Hobbs R (2002) Key issues and research priorities in landscape ecology: an idiosyncratic synthesis. Landscape Ecol 17(4):355–365

Wu JG, Loucks OL (1992) The Xilingol grassland. In: National Research Council (ed) Grasslands and grassland sciences in Northern China. National Academy Press, Washington, DC, pp 67–84

Wu Z, Sun H, Zhou Z, Peng H, Li D (2005) Origin and differentiation of endemism in the Flora of China. Acta Bot Yunnanica 27(6):577–604

Wu FY, Ji WQ, Wang JG, Liu CZ, Chung SL, Clift PD (2014a) Zircon U-Pb and Hf isotopic constraints on the onset time of India-Asia collision. Am J Sci 314(2):548–579

Wu J, He C, Zhang Q, Yu D, Huang G, Huang Q (2014b) Integrative modeling and strategic planning for regional sustainability under climate change. Adv Earth Sci 29(12):1315–1324

Wu J, Guo XR, Yang J, Qian G, Niu JM, Liang C, Zhang Q, Li A (2014c) What is sustainability science? Chin J Appl Ecol 25(1):1–11

Xia MF (1993) Relief and aftermath for Ding-Wu disaster in Qing dynasty. Mod Hist Res 2:21–36

Xu R-G (ed) (1988) Fauna of Inner Mongolia, vol I. Inner Mongolia University Press, Hohhot

Xu B, Wang S (1999) Inner Mongolia. Inner Mongolia University Press, Hohhot

Xu Z, Zhao M, Han G (2000) Eco-environmental deterioration and strategies for preventing it in Inner Mongolia. Grassl China 5:59–63

Xu ZW, Wan SQ, Zhu GL, Ren HY, Han XG (2010) The influence of historical land use and water availability on grassland restoration. Restor Ecol 18:217–225

Ye DZ, Chou J, Liu J (2000) Causes of sand-stormy weather in northern China and control measures. Acta Geogr Sin 55(5):513–521

Zhang X-S (1994) Principles and optimal models for the development of Maowusu Sandy Grassland. Chin J Plant Ecol 18(1):1–16

Zhang X-S (2000) Eco-economic functions of the grassland and its patterns. Sci Technol Rev 18:3–7

Zhang LS, Fang XQ, Ren GY (1997) Environmental changes in the North China farming-grazing transitional zone. Earth Sci Front 4:127–136

Zhang H, Yang G, Huang Q, Li G, Chen B, Xin X (2009) Spatiotemporal changes of landscape patterns in Hulunbuir meadow steppes. Acta Prataculturae Sin 18:134–143

Zhang GL, Dong JW, Xiao XM, Hu ZM, Sheldon S (2012) Effectiveness of ecological restoration projects in Horqin Sandy Land, China based on SPOT-VGT NDVI data. Ecol Eng 38(1):20–29

Zhang J, Niu J, Buyantuyev A, Wu J (2014) A multilevel analysis of effects of land use policy on land-cover change and local land use decisions. J Arid Environ 108:19–28

Zhao Y-Z, Zhao L-Q (2013) Key to the vascular plants of Inner Mongolia. Science Press, Beijing

Zhao Y, Zhu Z (2003) The Endemic genera of desert region in the Centre of Asia. Acta Bot Yunnanica 25(2):113–121

Zhao H, Zhao X, Zhang T, Zhou R (2002) Geographical boundary of the agro-pastoral transitional zone in northern China and related ecological problems. Adv Earth Sci 17:739–747

Zhao X, Hu H, Shen H, Zhou D, Zhou L, Myneni R, Fang J (2015) Satellite-indicated long-term vegetation changes and their drivers on the Mongolian Plateau. Landscape Ecol. doi:10.1007/s10980-014-0095-y

Zheng J, Xiao L, Fang X, Hao Z, Ge Q, Li B (2014) How climate change impacted the collapse of the Ming dynasty. Clim Change 127:169–182

Zhou QS (1994) Historical geography of Inner Mongolia. Inner Mongolia University Press, Hohhot

Zhu Z, Ma Y, Liu Z, Zhao Y (1999) Endemic plants and floristic characteristics in Alashan-Ordos biodiversity center. J Arid Land Resour Environ 13(2):1–15