Chapter 1
Introduction: Landscape and Ecosystem Diversity in the Yellow River Source Zone

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Abstract The Upper Yellow River lies at the margins of and atop the Qinghai–Tibet Plateau. This chapter provides an overview of contemporary understandings of the geography, geology, climate, geomorphology and palaeoenvironments, vegetation, and fauna of the area. Tectonic uplift and river incision have induced a wide range of charismatic landscapes, many of which retain a significant imprint from Quaternary environmental changes, especially the glaciated mountains, vast lake, river, permafrost, desert and loess landscapes, and countless wetland areas. The plateau is an important alpine biodiversity hot spot. The high elevation, along with prevailing semi-arid/arid climatic conditions and associated vegetation cover, has created distinctive but vulnerable ecosystems. Large grassland areas support sparse populations of nomadic herdsmen. Mounting evidence suggests that human activities over thousands of years have induced a regime shift from forest cover to grazing-adapted grassland across much of the plateau. In recent decades, population growth has accompanied demands for economic expansion as part of the 'Great Development of the West' in China. Climate change and human activities threaten the landscapes and ecosystems of the Upper Yellow River. Telltale signs of accelerated environmental adjustments include retreating glaciers, melting permafrost, decreasing river flows, shrinking lakes and wetlands, hillslope instability, degrading vegetation, declining grassland productivity, salinity problems, and

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G.J. Brierley et al. (eds.), *Landscape and Ecosystem Diversity, Dynamics and Management in the Yellow River Source Zone*, Springer Geography,
DOI 10.1007/978-3-319-30475-5_1

accelerated desertification. In outlining the structure of this book, this chapter draws attention to three key threads of enquiry: the primacy of landscape diversity and notions of place as an integrative platform for applied research, the importance of field-based understandings alongside remotely sensed applications, and how viewing humans as part of ecosystems helps to shape prospects for more effective approaches to environmental management.

Keywords Landscape · Ecosystem · Geodiversity · Climate change · Human impact · Degradation · Ecosystem services · Environmental management

1.1 Opening Statement: What the Book Is About and Why It Has Been Written

Concerns for environmental and societal security are especially pronounced in those parts of the world where strong pressures for development exist alongside severe threats to biodiversity and the natural environment. These tensions lie at the heart of the sustainability agenda. They are played out on an ongoing basis in the source zone of the Yellow River, where societal pressures for rapid economic development compete against desires to preserve the natural resources upon which that development depends.

The source zone of the Yellow River is perhaps most renowned for its topographic setting atop the Qinghai–Tibet Plateau—the highest plateau in the world (Fig. 1.1). The plateau has an average elevation of 4000 m above sea level and an area of about 2.6 million km^2, stretching approximately 1000 km north to south and 2500 km east to west. Framed alongside adjacent mountain ranges, this area is sometimes referred to as the ‘Third Pole’ or the ‘Roof of the World’ (Qiu 2008). The area is peculiarly cold for its latitude—colder than anywhere else outside the polar regions. After the Antarctic and the Arctic, the Qinghai–Tibet Plateau and surrounding mountains make up the Earth’s largest store of ice, with more than 100,000 km^2 of glaciers (Qiu 2008; Yao et al. 2012). In addition to being the source region for many of the world’s great rivers, including the Tsangpo–Brahmaputra, Mekong, Yangtze, and Yellow Rivers, much of the surface of the high central plateau drains internally to large basins, such as the Qaidam and Qinghai Lake basins. The Sanjiangyuan (Three River Source Zone) comprises the headwaters of the Yellow, Yangtze, and Lancang (Mekong) Rivers. This region is known as the ‘kidney of the earth’, the ‘cradle of living forms’, and ‘the water tower of China’, acting as a vital reservoir for water resources in East Asia (Qiu 2008; Yao et al. 2012). Approaches to environmental management atop the plateau have enormous implications for much of China and, beyond, exerting a significant influence upon the social and economic development of China, India, Nepal, Tajikistan, Pakistan, Afghanistan, and Bhutan—collectively home for one-fifth of the world’s population (Yao et al. 2012).

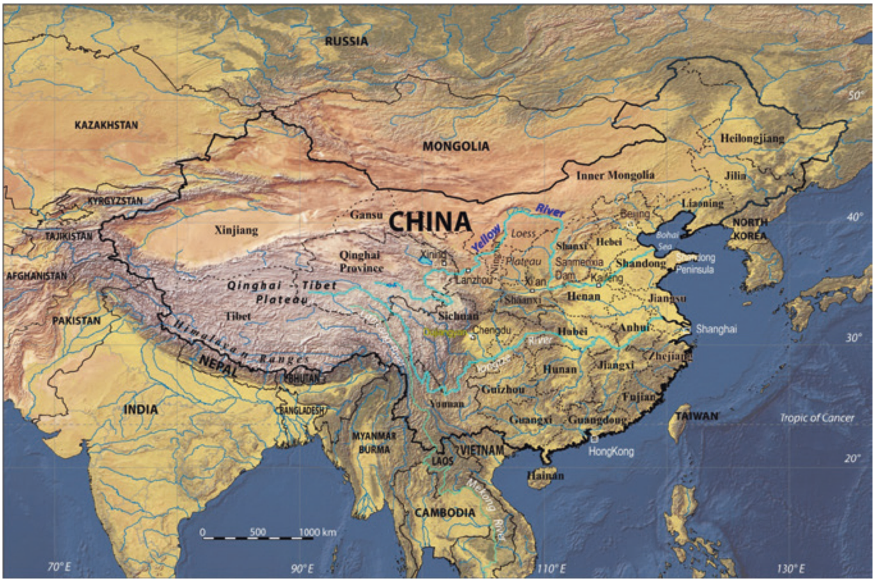

Fig. 1.1 The Yellow River Source Zone lies within the Qinghai–Tibet Plateau. This is the highest and largest plateau in the world, extending over an area of 2.58 million km^2. Elevations range from 3000 to 5000 m. Qinghai Province is shown in relation to adjacent mountain and desert area in China and neighbouring states. Collectively, the headwaters of the Yellow, Yangtze, and Lancang (Mekong) rivers make up the Sanjiangyuan (Three River Source Zone) in southern Qinghai Province

This book provides an overview of the remarkable landscapes and ecosystems of the Upper Yellow River in the north-eastern part of the Qinghai–Tibet Plateau. Tectonic uplift and river incision have induced a wide range of charismatic landscapes in this region, many of which retain a significant imprint from Quaternary environmental changes (Fig. 1.2). Large sedimentary basins were infilled by vast volumes of lacustrine, riverine, and aeolian (wind-blown) sediments over millions of years. These basins and intervening mountain ranges were then incised and reworked by the Upper Yellow River and its tributaries, creating dramatic gorges and extensive terrace sequences that are up to 1 km deep and tens of kilometres wide (Craddock et al. 2010). Uplift and river capture have realigned rivers and created new inland-draining basins, such as the Qinghai Lake. The imprint of past climates is seen in the glaciated mountains, vast lake, river, permafrost and desert landscapes, and countless wetland areas. Aeolian processes mould and reshape landscapes, with localized areas of active sand dunes representing a mere 'drop in the ocean' relative to the vast volumes of finer-grained loess deposits that drape the north-eastern part of the region and the adjacent Loess Plateau.

The climate of the region is harsh and inhospitable. Although the average annual temperature is below 0 °C, the area is subjected to very long hours of sunshine. Annual precipitation across the region decreases from the south-east to north-west, ranging from 250 to 750 mm.

Subdued landscapes of the 'headwaters' region of the Upper Yellow River above Zhaling Lake

Eling Lake, close to the headwaters of the Yellow River - the 'Mother River of China'

Dunes and wetlands at Star Lakes near Maduo

Antelope crossing a tributary of the Upper Yellow River near Maduo. Note the largely decoupled hillslope-valley floor interactions in this area

Tributary of the Upper Yellow River between Huashixia and Dari, with the Anyemachen Mountains in the background

Incisional landscapes of Chengen He, a tributary of the Upper Yellow River that has incised through the vast deposits of a previously inland-draining' (trapped) basin

Fig. 1.2 Characteristic physical landscapes of the Qinghai–Tibet Plateau

The high elevation, along with prevailing semi-arid/arid climatic conditions and associated vegetation cover, has created distinctive but vulnerable ecosystems, with many iconic and endemic species, some of which are threatened or endangered (Fig. 1.3). Spatial distributions of many living forms have been marginalized in this area. The plateau is an important alpine biodiversity hot spot, with estimates of the number of plant species ranging from 9000 to 12,000 (Liu et al. 2014).

Eroding sandstone landscapes of the middle reaches of the Upper Yellow River

Majestic sandstone landscapes of the middle reaches of the Upper Yellow River

Dramatic terraces of the Upper Yellow River at Kesheng, Henan County

A majestic telescopic fan of the Upper Yellow River downstream of Tongde

Dissected sandstone (Danxia) landscapes at Guide, adjacent to an anabranching reach of the Upper Yellow River

Dissected sandstone (Danxia) badland landscapes of the Upper Yellow River at Guide

Fig. 1.2 (continued)

Over 20 % of these species are endemic. Biodiversity tends to decrease with altitude, as well as towards the colder and drier north-west. Ecosystem types in the region range from subtropical rain forest in the south-east to alpine desert in the north-west. Much of the region now has a sparse cover of shrubs and occasional trees, with alpine grasslands comprising more than 50 % of the whole plateau area (Chen et al. 2014; Qiao and Duan 2016, Chap. 6). Large areas of grassland, characterized by a flourishing herbaceous layer when healthy, support sparse populations of nomadic herdsmen.

Fig. 1.3 Distinctive fauna of the Upper Yellow River

A distinct anthropogenic signature sits atop the natural variability of the region (Fig. 1.4). Despite its inhospitable environment, the Qinghai–Tibet Plateau is now occupied by over seven million people, mostly indigenous Tibetans. Tibetan families account for the vast majority of the herding families, with a small number of other nationalities such as Chinese Han, Hui, Sala, and Mongolian. The population is very small relative to the vast area.

The plateau was once considered one of the world's most recently populated areas by humans. However, archaeological, linguistic, and genetic findings have transformed this perspective in recent decades. Emerging understandings indicate that the population of this region has multiple origins, extending back at least 20–30,000 years (Aldenderfer and Yinong 2004; Brantingham and Xing 2006; Qin et al. 2010). Genetic studies indicate that the uniquely evolved physiological capacities seen among modern Tibetan populations required long-term exposure to high-elevation selective pressures. Seasonal foraging in high-elevation settings of the plateau likely began between 30,000 and 15,000 years ago. More permanent

Tibetan cultural values are a characteristic feature of the region

Agriculture at the margins (near Qinghai Lake), where water is a prized asset, and desertification an inevitable risk

A typical grassland scene. Tending yak is the mainstay of the agricultural economy of Qinghai Province

Yak grazing landscapes of the Qinghai-Tibet Plateau

A typical grassland scene: low relief landscapes and wetlands with yak between Huashixia and Maduo

Alpine meadow vegetation … 'golf course' rangelands of the Upper Yellow River

Typical grassland scene, Qinghai Province

Bee keeping among the rapeseed (canola) near Qinghai Lake

Regional towns such as Tongde are largely agriculturally based, with limited industrial development

Xining, the capital of Qinghai Province, is by far the largest city in the Upper Yellow River Basin

Fig. 1.4 Characteristic sociocultural landscapes of the eastern part of the Qinghai–Tibet Plateau occupation of the plateau probably did not begin until about 8200 years ago, when herders from low-elevation environments were driven further afield by emerging settled agricultural groups. By 6000 years ago, herders in mid-elevation areas were joined by agriculturalists, so herders migrated to still higher altitudes (Qin et al. 2010).

There is mounting evidence to suggest that human activities over thousands of years have induced a regime shift in vegetation dynamics across much of the plateau from forest cover to grazing-adapted grassland ecosystems (Miehe et al. 2009). While grassland vegetation would have been present within the open basins and valleys of the plateau, woody vegetation and trees would have been found on sunny mid-slopes and sheltered gorges (Tane 2011). However, these forested areas have disappeared over the last 6000 years, due likely to human activities (Herzschuh et al. 2010; Miehe et al. 2009). The history of nomadic people herding yaks possibly stretches back over 8800 years (Miehe et al. 2008a, b, 2009). The emergence of modern grazing systems around 2200 years ago instigated the establishment of grazing-adapted *Kobresia* pastures (see Miehe et al. 2009, 2011, 2014; Schlütz and Lehmkuhl 2009).

Livestock grazing is the main component of the regional economy (Fig. 1.4). Although agriculture is practised up to an elevation of 3300 m, the area of tillage atop the plateau is very limited, restricted primarily to fertile valley floors at the margins of the plateau. It accounts for only 0.3 % of the land area of the Yellow River Source Zone.

Low population numbers, the low intensity of farming practices, and the lack of industrial development have restricted the impacts of human activities upon landscapes of the region. In general terms, animal husbandry practices associated with the predominantly Tibetan peoples of this area have been 'sustainable' for several thousand years. However, population growth and development pressures are increasing—both in their extensiveness and their intensity. Demands for economic expansion as part of the 'Great Development of the West' have been supported by extensive infrastructure programmes that make the region increasingly accessible, helping to establish primary industries, mining developments, and tourism. Inevitably, the rapid development of the region is impacting upon traditional lifestyles and land use practices. Some researchers contend that population increases and policy-induced land use changes since the 1980s have led to overgrazing and consequent grassland degradation, wetland loss, and desertification (Fan et al. 2010; Gao 2016, Chap. 10; Li et al. 2012; Li et al. 2016a, Chap. 7; Qiao and Duan 2016, Chap. 6; Li and Wang 2016, Chap. 8; Tane et al. 2016, Chap. 13; Zhang et al. 2015). Others attribute these changes to shifts in climate (see discussion in Li et al. 2016a, Chap. 7). To date, a coherent picture of the underlying mechanisms causing these changes is yet to emerge (see Chen et al. 2013; Harris 2010; Li et al. 2013). Lack of clarity on these issues adds to uncertainty as to the most appropriate management responses (see Brierley et al. 2016b, Chap. 15; Harris et al. 2015; Wen et al. 2013; Wu et al. 2013; Zhang et al. 2013).

The United Nations Convention to Combat Desertification (UNCCD) defines land degradation such as that seen in the landscapes of the Upper Yellow River as 'a persistent reduction in biological and economic productivity' (UNCCD 1994).

It is especially prevalent in dryland regions, where degradation exerts adverse impacts on biomass productivity and landscapes and ecosystems are characterized by extremely low primary productivity, nutrient poor soils, and sparse and patchy vegetation, impacting upon prospects for food security, biodiversity, and environmental sustainability (Mueller et al. 2014). Physical processes of land degradation include soil erosion by wind and water and changes to soil structure such as crusting and compaction. Significant chemical processes include acidification, leaching, salinization, and nutrient depletion. Biological processes include alterations to plant cover and ecosystem functionality (e.g. invasive species) resulting in a loss of biodiversity. Collectively, these processes reduce soil fertility and the economic productivity of the land. As a consequence, these systems become increasingly vulnerable to social and environmental perturbations, impacting on the ecosystem services provided by these landscapes.

Both climate change and human activities threaten the landscapes and ecosystems of the Upper Yellow River. In recent decades, telltale signs of accelerated environmental adjustments have become evident: retreating glaciers, melting permafrost, decreasing river flows, shrinking lakes and wetlands, hillslope instability, degrading vegetation, declining grassland productivity, salinity problems, and accelerated desertification (Fig. 1.5). Mean temperature across the plateau as a whole has increased by up to 0.3 °C a decade over the last 60 years—approximately three times the global rate (Piao et al. 2011; Qiu 2008). Climate and cryospheric changes have been especially pronounced over the last three decades (Kang et al. 2010). Increasing precipitation trends in central areas of the plateau in recent decades contrast with decreasing trends at the plateau margins. Evaporation is increasing across the area. As a result, river discharge shows a declining trend in the semi-humid and humid zones in the eastern and southern plateau. Permafrost areas are especially at risk, as rising temperatures cause the active ground layer—which freezes and thaws every year—to thicken. This not only presents challenges for construction and infrastructure maintenance, but also endangers the plateau's alpine ecosystems (Qiu 2008). The lower limit of permafrost has risen by 40–80 m over the last 50 years, with the total area declining by about 7 % (Jin et al. 2007).

Significant controversy surrounds approaches to the protection of environmental values in the region, with differing perspectives upon the role of local peoples as agents of landscape change, impacts upon ecosystems (especially grassland and wetland degradation), and prospective environmental futures (see Brierley et al. 2016b, Chap. 15). Balancing the benefits of economic development and societal well-being against environmental risks and desires for conservation and rehabilitation is a critical challenge. Immense environmental, political, developmental, and cultural issues are at play.

Despite the global significance of the area, in biophysical and sociocultural terms, the formal literature on the landscapes and ecosystems of the Upper Yellow River is remarkably thin and lacking in coherence. Sound, integrated guidance for informed decision-making is lacking. The marked variability in the diversity of landscape forms and processes is seldom appreciated, with few attempts to appropriately contextualize understandings in spatial and temporal terms.

Retreating glacier atop the Qinghai-Tibet Plateau, viewed from the Xining-Lhasa railway

Changes to permafrost impact upon hillslope processes such as these solifluction lobes at Huashixia

Hillslope wetlands, valley margin features and floodplain ponds are sensitive to climate and land use change

Desertification threatens local areas of the Upper Yellow River basin as a result of changing vegetation patterns

Dust/sand storm at the margins of Qinghai Lake

Plateau pika: Friend or foe? Ecosystem engineer or pest?

Fig. 1.5 Environmental and sociocultural values of the Upper Yellow River and adjacent regions that are under threat

Biological diversity is inextricably linked to the variety of landscapes in any ecoregion. Geodiversity is fundamental to habitat diversity, presenting a major control on the distribution of life, as ecological potential is highly dependent on the quality and quantity of available habitat. Understanding controls on the quantity, quality, and distribution of natural habitat provides fundamental insights into the health and resilience of associated ecosystems and their potential for recovery if degraded. More importantly, analyses of landscapes also provide an integrative basis to assess economic opportunities and sociocultural connections, from which a sense of identity and belonging emerges.

Biophysical attributes also exert a critical influence upon ecosystem services, such as water quality and quantity, habitat availability and viability, nutrient cycling, soil fertility/health (including microfauna), and key measures of ecosystem functionality. These issues are fundamental to societal well-being. Despite their importance, scientific understandings of environmental issues in the source zone of the Yellow River remain fragmented, with relatively little integration among fields such as geomorphology, terrestrial and aquatic ecology, hydrology (water resources), climatology, and human ecology (see Qi 2016, Chap. 11). More importantly, discipline-bound framings seldom extend across to meaningful incorporation of socio-economic and cultural associations, and local knowledge. Such fragmentation engenders incomplete and possibly incorrect understandings of socio-ecological systems, limiting our capacity to generate appropriate approaches to the management of complex environmental issues. Appropriate management programmes strive to establish healthy, productive, and resilient ecosystems that are able to recover from, rather than resist, disturbance. A sound information base that conveys coherent process-based understanding of spatial and temporal diversity, variability, and evolutionary traits is a fundamental requirement for effective management practice.

Among many factors, the inaccessibility of the region has inhibited efforts to generate coherent, systematic understandings of key biophysical attributes of the landscapes and ecosystems in this region. In recent decades, this shortcoming has been rectified, in part, by much greater availability of remotely sensed information. While such data sources provide an invaluable basis to establish a sense of context and variability, they are only a partial alternative (and not entirely appropriate) substitute for field-based analyses.

This book seeks to start to address this shortcoming, using a geomorphic (landscape) approach to relate locally derived, field-based understandings of landscapes and ecosystems to broader, remotely sensed applications undertaken across the Upper Yellow River. In this book, the distinctive landscapes of the Upper Yellow River provided a fundamental backdrop for collaborations among researchers from differing cultural and disciplinary backgrounds, including environmental scientists (geomorphologists, hydrologists, soil scientists, ecologists (terrestrial and aquatic)), agricultural scientists, and engineers. A concerted effort has been made to link threads together in an effective manner, reflecting upon spatial and temporal variability across the region.

Scientific and managerial controversies abound in the source zone of the Yellow River. Examples of major issues include the following:

- The specific timing of the development and infilling of sedimentary basins atop the Qinghai–Tibet Plateau, their relationships to phases of tectonic uplift, and subsequent responses to river incision (and associated timings of river capture that fashioned the evolution of drainage networks) are yet to be resolved.
- Although it is now broadly recognized that the Last Glacial Maximum (around 15,000 years ago) was much smaller than previous phases of glacial expansion, the magnitude and extent of past phases of glacial activity remains contentious.

- Accurate and comprehensive understanding of lake, desert, and sand dune histories is underdeveloped.
- Relationships between landscape forms and processes and vegetation interactions, soil development, biodiversity patterns and traits, etc., are poorly established.
- Controversy surrounds the history of human settlement atop the plateau and associated impacts upon environmental conditions. Additional insights are required to assess how and why humans adapted to (and in turn impacted upon) environmental conditions upon the plateau.
- There is significant disagreement about the extent, timing, gravity, and underlying causes of environmental degradation in differing parts of the region, and the designation and implementation of management responses. Key examples include issues such as ecological migration programmes through an imposed reserve (Ran et al. 2016, Chap. 14), and approaches to the management of grassland, wetland, and desertification issues (such as the use of enclosures, revegetation programmes, whether plateau pika is a fundamental ecosystem engineer or a pest).

One thing is for sure—there are countless opportunities for future research in this region!

The key premise of this book is a simple one—we must have appropriate understandings of resources before we can manage them effectively. Despite assertions that 'wilderness is dead' (Wohl 2013), and recognizing explicitly that we live in an increasingly human-dominated world (the Anthropocene), there are still some truly remarkable and remote areas where we remain in awe of nature's beauty and overwhelming majesty. Somehow, the vast yet diverse landscapes and ecosystems of the Upper Yellow River make humans feel quite insignificant! However, the pronounced and pervasive sociocultural imprint on the landscapes and ecosystems of the region presents ongoing concerns for human relations to nature, and our quest for notional 'harmony' in efforts to ensure that a 'duty of care' protects distinctive attributes of the region into the future. It is hoped that the scientific foundations outlined in this book can be used alongside local understandings to develop shared, authentic, and genuinely grounded approaches to environmental management of this remarkable place. Our intent is to support the development of socially situated science that effectively bridges and combines fieldwork and remotely sensed applications. However, prospects for the emergence and uptake of truly shared understandings are one thing—it is their uptake and ongoing adaptation that fashions environmental outcomes.

The remainder of this chapter presents contextual information on the geology, climate, geomorphology/soils, palaeoenvironmental conditions, vegetation, fauna, and human activities of the Upper Yellow River. The chapter concludes with a summary of the structure of the book. Prior to considering these issues, a geographic overview of the Yellow River Basin sets the scene for more detailed investigations of the landscapes and ecosystems of the region.

1.2 An Overview of the Yellow River Basin

The Yellow River (Huang He in Chinese Pinyin) has a special place in the hearts and minds of many Chinese people. As a source of great prosperity, it is often referred to as China's pride, the Mother River and the 'cradle of Chinese civilization'. The river has long-standing cultural associations. In traditional Chinese folklore, it was considered to flow from heaven as a continuation of the Milky Way (Elvin and Liu 1998). Conversely, the river is sometimes referred to as 'China's sorrow' or the 'Scourge of the Sons of Han'. Floods along the lower course of the river in 1332–1333 and in 1887 and 1931 are among the most devastating natural disasters anywhere in the world, as subsequent famines and disease killed more than a million people in each instance.

The Yangtze and Yellow rivers provide major links between the world's largest continent (Asia) and its largest ocean (the Pacific). From its origins in Qinghai Province, the Yellow River flows across eight other provinces and autonomous regions before emptying into the Yellow Sea north of the Shandong Peninsula (Fig. 1.6). The river provides water for around 150 million people, approximately 9 % of China's population. It is 5464 km long and drains an area of 753,000 km^2 (IRTCES 2005). Its basin extends approximately 1900 km from west to east and 1100 km from north to south. It is the third longest river in Asia and the sixth longest river in the world.

The average annual discharge of the Yellow River is greater than 2100 m^3 s^{-1}. Around 60 % of the annual flow occurs during the rainy season from July to

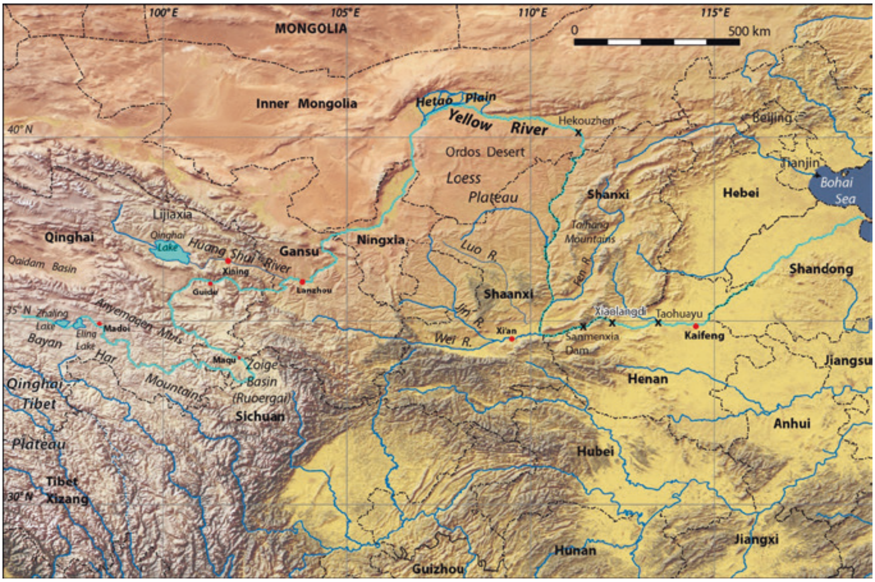

Fig. 1.6 A geographic overview of the Yellow River Basin

October, reflecting a strong monsoon-driven influence. The name ‘Yellow’ refers to the perennial colour of the muddy river water in the middle-lower reaches. Indeed, the traditional Mongolian name for the middle course was the ‘Black River’, in reference to high sediment loads. This is one of the most sediment-laden rivers in the world, with concentrations as high as 920 kg m^{-3} and annual sediment loads of around 1.6×10^9 tons (a peak of 3.9×10^9 tons was estimated for 1933). Although the Yellow River ranks 26th in the world in terms of drainage area, it is second only to the Amazon in terms of sediment delivery to the oceans.

Two major steps demarcate pronounced changes in topographic gradient along the course of the Yellow River: between the Qinghai–Tibet Plateau and the Loess Plateau upstream of Lanzhou and between the Loess Plateau and the North China Alluvial Plain near Xiaolangdi (Fig. 1.7). This book is concerned solely with the area above the first step, at the margins of and atop the Qinghai–Tibet Plateau.

From its source at an elevation of around 4600 m, the Upper Yellow River first flows east through a series of basins and deep gorges and then turns north-east at the city of Lanzhou in Gansu Province (Figs. 1.6 and 1.7). Officially, the Upper Yellow River extends from the river source to Hekouzhen in Inner Mongolia Autonomous Region at an elevation of 1000 m (see Section 1.3; Fig. 1.6; IRTCES 2005). Based on this designation, the Upper Yellow River contributes about 56 % of the total run-off but only 10 % of sediment load of the whole river basin (Huang et al. 2016, Chap. 4; Wang et al. 2006; Xu et al. 2007). Unlike middle and lower reaches, the upper section of the river has been subjected to limited flow regulation impacts. However, dam developments in various gorges at the margins of the Qinghai–Tibet Plateau are placing increasing pressure upon the flow and sediment regimes of the Upper Yellow River. Because of the low population numbers and densities, the extensive nature of farming practices, and the lack of industrial development, water quantity remains abundant in this region, and water quality is good (Ouyang et al. 2010). The river flows clear for large parts of the year, with low levels of sediment concentration and pollutants, only earning its ‘Yellow’ name in middle and lower reaches. The local Tibetan name for the upper river is Ma Chu (river of the peacock).

In contrast to the upper course, much of the middle and lower courses of the Yellow River has been subjected to intensive human disturbance throughout its long history, including deforestation, land reclamation, dam construction, and levee building (see Brierley et al. 2016a, b, Chaps. 3 and 15). Beyond Lanzhou, the river flows for many hundreds of kilometres through the Ordos Desert, an easterly extension of the Gobi Desert in Ningxia and Inner Mongolia, and the Loess Plateau (Fig. 1.6). As early as in the Qin Dynasty, from 245 to 206 B.C, ancient irrigation canals were built along the wide alluvial plains in this area. Subsequent water resource developments have greatly altered flow and sediment dynamics in this reach. Officially, the 1200 km middle reach of the Yellow River extends from Hekouzhen to Taohuayu in Henan Province, decreasing in elevation from 1000 to 110 m (Fig. 1.6; IRTCES 2005). This reach passes through the Loess Plateau, the primary source of the high sediment load of the river, the Ordos Plateau, Hetao Plain, and the Taihang Mountains. About 30 % of total run-off and nearly 90 % of total sediment load come from the middle reach. Low run-off and high sediment loads result in hyperconcentrated flows.

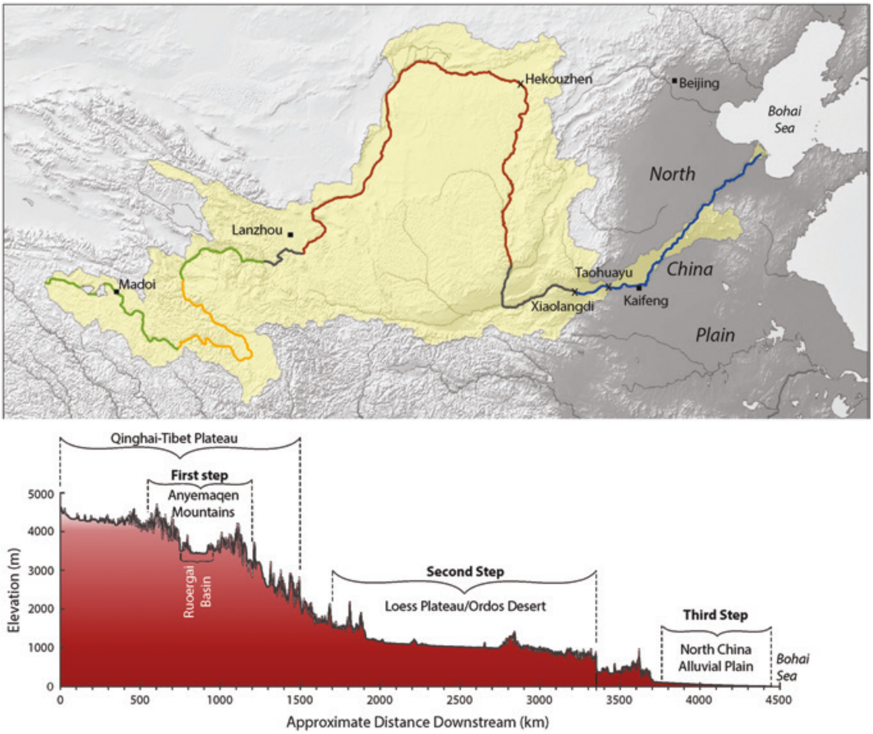

Fig. 1.7 The three topographic steps that make up differing altitudinal and landscape zones of the Yellow River across China. The *upper basin* lies predominantly atop the Qinghai–Tibet Plateau, the margins of which lie just to the west of Lanzhou. The *middle course* drains the Loess Plateau, from where large sediment loads are derived (hence the name of the river). The *lower course* extends over a wide lowland plain and has been characterized by major avulsions and associated hazards throughout historical time. We thank Tami Nicoll for assistance in developing this diagram

The second step at the margin of the Loess Plateau and the North China Plain marks the beginning of the lowland alluvial plain near Xiaolangdi (Figs. 1.6 and 1.7). Officially, the 768 km long lower reach of the Yellow River extends from Taohuayu east of the Taihang Mountains to the Bohai Sea, with elevation decreasing from 110 m to sea level (IRTCES 2005). The river enters the plains at the city of Kaifeng, where it changes from a torrent to a broad meandering stream that has now been enclosed by dikes. From west to east, the alluvial plain is made up primarily of alluvial fan, floodplain, and estuarine delta plain deposits. Rapid delta growth, along with changing sedimentation patterns and subsidence during the Quaternary, has exerted a primary control upon migration patterns of the Lower Yellow River, shifting the position of the river mouth. Hyperconcentrated flows have induced serious sedimentation and flood protection problems in this area. Major aggradation and levee development have perched the active channel zone above the adjacent plain. At Kaifeng, the lower course of the Yellow River lies

10 m above the adjacent floodplains. This area has a long history of flood disasters—a situation that has been recurrently exploited at times of war. Reduced sediment loads along the Yellow River in recent decades reflect the combined impact of flow regulation, climate change (reduced precipitation, especially in middle and lower reaches), and the influence of land use programmes (especially soil and water conservation projects; see Wang et al. 2015).

1.3 Defining the Yellow River Source Zone

Specifying the boundaries of the Yellow River Source Zone is a contentious issue, with little consensus regarding the definition of the geographical scope of the region. The catchment area and administrative districts of the Yellow River Source Zone are shown in Fig. 1.8. Differing authors have used at least five different interpretations of the boundaries of this zone:

- Pan and Liu (2005) stated that Yellow River Source Zone is the hinterland of Qinghai–Tibet Plateau, located in the south of Qinghai Province, including Madou, Maqin, Chengduo, Qumalai, Dari, and Gande Counties and covering a total area of 64,700 km^2.

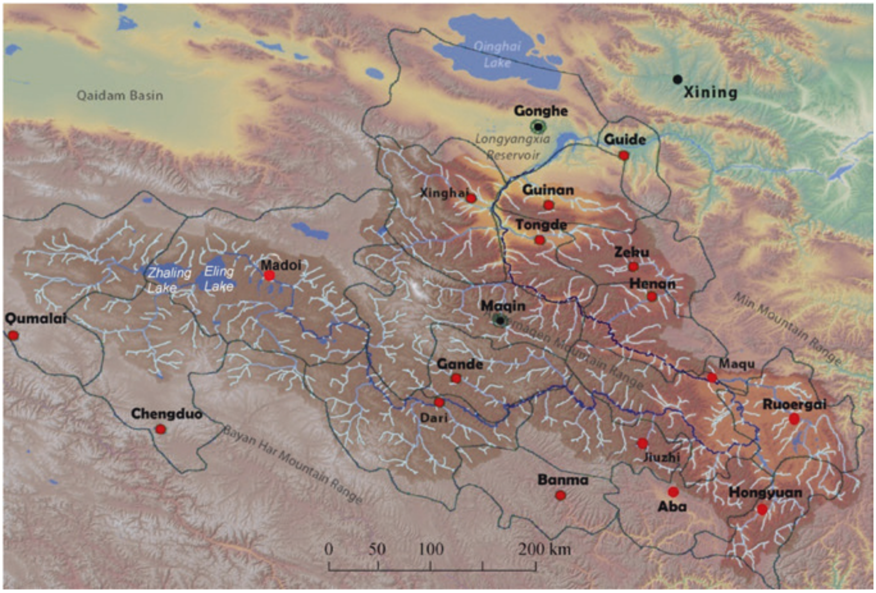

Fig. 1.8 The catchment area and administrative districts of the Yellow River Source Zone. The catchment area is from Blue et al. (2013). Districts for the 19 counties are derived from the administrative maps of Qinghai, Sichuan, and Gansu provinces

- Some researchers indicated that the Yellow River Source Zone extends from the upper area of the Riyue Mountains east of Qinghai Lake and includes Longyangxia Dam. The geographical scope of this region covers an area of 92,000 km^2 (Feng et al. 2004).
- A biophysical, catchment-framed approach views the Yellow River Source Zone as comprising the administration districts upstream of Longyangxia Reservoir in the north-eastern section of the Qinghai–Tibet Plateau (Blue et al. 2013; Nicoll et al. 2013). This area includes 19 counties, with 15 counties in Qinghai (Qumalai, Chengduo, Madou, Dari, Gande, Banma, Jiuzhi, Henan, Zeku, Maqin, Tongde, Xianghai, Guinan, Gonghe, and Guide); three counties in Sichuan (Aba, Hongyuan, and Ruoergai); and one county in Gansu (Maqu). The geographical scope of this region covers a total area of 177,162 km^2.
- In the official designation used by IRTCES (2005), there are three sections of the Upper Yellow River atop the Qinghai–Tibet Plateau, and a fourth section of the Upper Yellow River extends downstream to Hekouzhen in the Inner Mongolia Autonomous Region.
- Finally, the Yellow River Source Zone can be described solely in relation to administrative districts within Qinghai Province. In this definition, the Yellow River Source Zone refers to 15 counties, with six counties in Golou, four counties in Huangnan, and five counties in Hainan Prefectures, and covers a total area of 137,700 km^2 (see NDRC 2014).

Different chapters in this book refer to differing geographic areas across the region. Some chapters incorporate comment on the Qinghai–Tibet Plateau and adjacent mountain ranges (Han et al. 2016, Chap. 12), while others refer to the Sanjiangyuan (Three River Source Zone, including headwater areas of the Yellow, Yangtze, and Lancang (Mekong) Rivers, e.g. McGregor 2016, Chap. 2; Li et al. 2016b, Chap. 9). Most chapters refer specifically to the catchment-framed delineation of the Upper Yellow River within the confines of the Qinghai–Tibet Plateau, setting the downstream boundary of the region at the margins of the plateau close to the provincial boundary between Qinghai and Gansu. This area includes three counties in Sichuan and one county in Gansu (these counties are located at the First Great Bend of the Upper Yellow River; see Fig. 1.8). In the socio-economic chapter (Ran et al. 2016, Chap. 14), analysis is restricted to data derived solely from administrative counties within the Yellow River Source Zone that lie within Qinghai Province. The specific area that is considered is outlined at the beginning of each chapter.

1.4 An Introduction to the Geography of the Upper Yellow River

1.4.1 Geology

Uplift of the Himalayas and the Qinghai–Tibet Plateau as a result of the collision of the Indian and Asian continents has been the most prominent tectonic event in the world over the last 40–50 million years. By about 50 million years ago, the fast north-moving Indo-Australian plate (15 cm/year) had completely closed the Tethys Ocean. The relatively light sedimentary rocks from the former ocean floor were readily crumpled into the mountain ranges that now form the Himalaya. The geologic base of the Qinghai–Tibet Plateau is comprised of Precambrian metamorphic rocks with an overlying complete stratigraphic sequence from lower Palaeozoic rocks upwards (Liu et al. 1980).

The plateau was formed in several uplift phases, with progressive stepwise uplift of distinct blocks towards the north-east (Li et al. 2014a, b; Liu-Zeng et al. 2008; Tapponnier et al. 2001). As the Indo-Australian plate continues to be driven horizontally below the Qinghai–Tibet Plateau (at about 50 mm per year), the plateau continues to be forced upwards. However, the surface is currently being eroded at about the same rate, such that total elevation increase in actively growing mountain ranges is around 1 mm per year (Lehmkuhl and Owen 2005). About 1.8 million years ago, dramatic adjustments to river courses in the eastern and south-eastern edge of the plateau created the contemporary courses of the Upper Yellow and Yangtze rivers (Craddock et al. 2010; Li et al. 2014a, b).

Uplift of the plateau was accompanied by a series of large strike–slip faults that run north-west–south-east through the region and associated extensional normal faulting. Current slip rates on these faults average 1–20 mm per year (Tapponnier et al. 2001). Many of the internally drained basins on the plateau are related to these fault systems, either directly by creation as a pull-apart basin (e.g. the Kunlun fault complex; Fu and Awata 2007), or as past foreland basins that eventually cut off former river outlets due to tectonic uplift of the surrounding ranges (e.g. the Qinghai Lake Basin; Colman et al. 2007; Tapponnier et al. 2001). Strong structural control has offset some rivers by up to 90 km (Fu and Awata 2007). Stream networks at the south-eastern plateau margin, where incision has created gorges more than 2 km deep, have a distinct tectonically induced asymmetry, with all major rivers having a parallel north-west to south-east alignment, and more than 90 % of the drainage lying the western side of the river (Wang et al. 2010).

The Upper Yellow River drains the north-eastern part of the Qinghai–Tibet Plateau. The present configuration of the basin developed around 1.8 million years ago, evolving to its present pattern through stepwise incision of knickpoints in response to the stepwise uplift of the plateau. Incision proceeded rapidly, at an average rate of ~350 km per million years (Craddock et al. 2010). Major sedimentary basins in this area (Zoige, Gonghe, Tongde) likely originated as fault basins during uplift of the plateau (Wang et al. 1995) and are currently separated from each other by actively growing mountain ranges (Craddock et al. 2010). These basins gradually infilled over time to create the low-relief landscapes present today, primarily through lacustrine deposits in the case of Zoige Basin (Wang et al. 1995) and fluvial aggradation in the Tongde and Gonghe basins (Harkins et al. 2007). Basin evolution occurred in a similar manner to 'bathtub infilling', with sediments flooding the closed basins created by uplift of the bordering mountain ranges (Nicoll et al. 2013). The pathway of incision has cut through these various bedrock sections and basin fills. The most recent phase of uplift-induced incision

(~0.03 million years ago) dissected the Nanshan Mountains of Guinan County and the western Qilian Mountains, thereby connecting with the Ruoergai Basin (Li et al. 1996; Harkins et al. 2007). Although river incision through the basin fills may have been a response to ongoing tectonic uplift (Harkins et al. 2007), some contend that it may reflect a climatic trigger (Craddock et al. 2010; Perrineau et al. 2011; Li et al. 2014a, b).

Much of the source region of the Yellow River is underlain by sedimentary rocks (especially sandstone red beds, with some dolomitic limestone), minor volcanic rocks, and occasional granite. Weathering of sedimentary rocks generates soils with a high content of hydromica and chlorite minerals. Loess is widely distributed across the north-eastern corner of the plateau, while evaporite deposits are prominent in many inland lakes.

1.4.2 Climate

Tectonic factors have exerted a key influence upon climatic and environmental conditions across the region. Uplift of the Qinghai–Tibet Plateau created drier and colder conditions. It brought about and intensified the Asian monsoon. The plateau is seasonally buffeted both by the summer monsoons from the south-east and south, the northerly winter monsoon, and the westerly winds from central Asia (McGregor 2016, Chap. 2, see Fig. 1.9). The Asian monsoon can be divided into the dry winter component driven by the large Siberian anticyclone, and the wet Indian and East Asian summer monsoons. The seasonal monsoon wind shift and weather associated with the heating and cooling of the Tibetan plateau is the strongest monsoon on Earth.

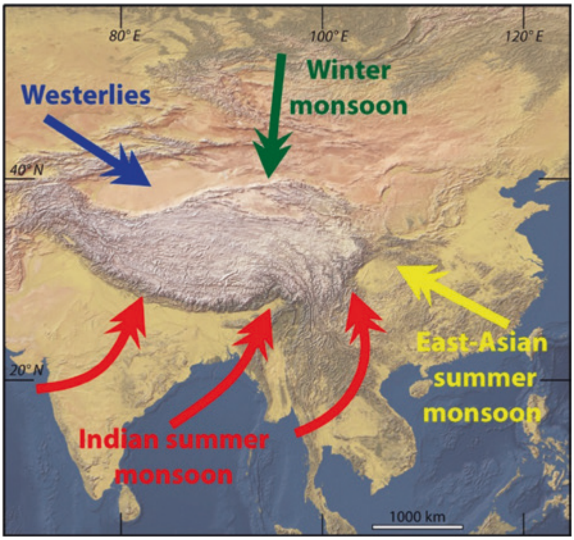

Fig. 1.9 Dominant weather systems in Qinghai Province

Due to its high altitude, the Qinghai–Tibet Plateau has a cold and dry alpine (high-altitude, semi-arid steppe) climate, with an annual mean temperature of −2.3 °C. Mean precipitation ranges from 100 to 500 mm per annum in different parts of the plateau, increasing from the north-west to the south-east of the Upper Yellow River Basin. The alpine continental climate is characterized by clear separation of dry and wet seasons. The cold season is controlled by high-pressure systems over Mongolia. Northerlies prevail, and the climate is dry and cold. In summer, the subtropical high-pressure systems of the west Pacific become strong, with warm, wet air masses gradually displacing the Mongolian high. The south-west monsoon brings warmer low-pressure systems with abundant water vapour that creates more precipitation. Summers are cool and humid. July is generally the hottest month of the year. About 70–75 % of the annual precipitation falls during the rainy season from June to September. Radiation is very intense, with more than 2500 sunshine hours per year. The snow cover is distributed primarily above 4000 m in the Anyemaqen Mountains from early October to mid-April, with the snow line rising to around 4700 m in late May. The coincidence of snowmelt with an increase in precipitation results in an abrupt rise in river run-off in June. The annual potential evapotranspiration is around 1400 mm. Given the high altitude and very thin air, the growing period is short and there is no absolute frost-free period. Major windstorms induce significant aeolian activity. Global warming in recent decades has induced warmer regional temperatures, especially in winter, but there has been marked regional variability in precipitation changes.

1.4.3 Geomorphology and Palaeoenvironments of the Upper Yellow River Basin

The Qinghai–Tibet Plateau covers most of the Tibet Autonomous Region and Qinghai Province, as well as parts of Ladakh in Jammu and the state of Kashmir in India. Elevations are greater than 4500 m in the interior and 3000 m on the peripheries. Towering mountain ranges surround this vast plateau (Fig. 1.1). The plateau itself is not flat. Indeed, tectonic uplift, river incision, and the imprint of palaeoenvironmental conditions have created a wide range of landscapes that include snow-capped mountains and glaciers, high plateaus, intermontane basins, wide valleys, and extensive lakes. China's largest extant closed-basin lake, Qinghai Lake, is located on the north-eastern margins of the plateau. Proceeding to the north and north-west, the plateau becomes progressively higher, colder, and drier.

Landscape diversity in the Upper Yellow River Basin reflects the imprint of climatic signals superimposed upon a tectonic template. Active feedback between tectonic processes and incision preferentially concentrates erosion along the eastern margin of the Qinghai–Tibet Plateau. Strong uplift and associated river incision denuded the mountains and created extensive gully networks on the plains. The interior of the plateau is essentially shielded, despite regionally variable tectonic and drainage network activity, with low-relief landscapes characterized by low erosion rates. Given the active tectonic setting and variable climate conditions, the region is prone to significant natural hazards associated with earthquakes, hillslope instability, floods and droughts, windstorms, and permafrost-related processes.

The source of the Yellow River lies in the Yueguzonglie Basin in the Bayan Har Mountains, at an elevation of 4600 m (Fig. 1.1). The mean altitude of the Upper Yellow River above Lanzhou is around 3600 m. Several wide basins are separated by major mountain ranges along the course of the Upper Yellow River: the Bayan Har Mountains define the southern edge of the Yellow River catchment, and the Anyemaqen Mountains run WNW-ESE through the middle of the upper catchment. The north-west boundary is demarcated by the Chaka sub-basin, an internally drained basin that is generally considered to be part of the larger Qaidam Basin. The Qilian Mountain and the Huang Shui, the largest tributary of the Upper Yellow River, mark the margin between the Qinghai–Tibet Plateau and the Inner Mongolia Plateau. To the south and west of the Yellow River watershed, tributaries to the Yangtze cut down through the plateau margin to the Sichuan Basin.

Glaciers within the Upper Yellow River Basin were limited in extent during the Last Glacial Maximum and reached their maximum extent well prior to that time (Heyman et al. 2011; Lehmkuhl and Owen 2005; Owen et al. 2003, 2005, 2006). Multiple phases of glaciation are evident, with local ice caps covering entire elevated mountain areas at the maximum extent. However, absence of glacial traces in intervening lower-lying plateau areas suggests that local ice caps did not merge to form a regional ice sheet around the Bayan Har Mountains. Rather, glacial landforms are restricted to mountain blocks that protrude above the surrounding plateau area (Heyman et al. 2008, 2009). Complex glacial histories in this region through the mid-Late Quaternary reflect the role of two climatic systems: periods of strong monsoons and mid-latitude westerlies (Murari et al. 2014; Owen and Dortch 2014).

Permafrost extends over an area of around 1.5 million km^2 of the Qinghai–Tibet Plateau (i.e. more than 70–80 % of the plateau interior; Jin et al. 2007). The present distribution of permafrost was established when most of the plateau had reached its present general elevation in the Late Pleistocene. During the Holocene (about 10,800 years B.P. to present), a general warming trend has induced degradation and shrinkage in the areal extent of permafrost, inducing extensive settling of the ground surface and desertification. However, a periglacial climate has been retained across much of the region during this period. A complex history of changes in depth and areal extent of permafrost, fashioned largely by elevation, has accompanied phases of climate change (Jin et al. 2007).

Quaternary sediments are abundant across the Upper Yellow River Basin, with extensive lacustrine and river deposits, and localized aeolian (sand dune and loess) sequences. Changing environmental conditions associated with tectonic uplift, denudation processes, climate change, and alterations to the hydrologic regime have brought about remarkable shifts in lake levels. Maximum lake levels were reached during the most intense phase of the monsoon system, while lake lowstands have been associated with cool and dry phases during the Pleistocene.

Qinghai Lake has been a closed-basin lake (no river outlet) since 36,000 years ago (Yan et al. 2002). It is China's largest extant closed-basin lake. Lake highstands around 36 m above the modern lake level appear to date to 70–110,000 years ago, with Early Holocene highstands no more than ~12 m above modern (Rhode et al. 2010; Liu et al. 2011, 2012). Progressive lowering of the water level in Qinghai Lake during the last half century is mainly a result of negative precipitation–evaporation balance within the context of global warming (Colman et al. 2007).

Desert evolution in the Qaidam Basin, to the north-west of the Upper Yellow River Basin, was mainly controlled by shrinkage of the Asian summer monsoon and the strengthening influence of the westerlies which increased the aridity of the basin (Yu and Lai 2014). The effectiveness of aeolian processes and associated soil development has varied markedly over time. At Lake Donggi Cona (4090 m asl), lake highstand sedimentation and lake level changes also responded to changes in Asian monsoon variability (Dietze et al. 2010). Lake lowstands occurred during the cold and dry phases of the Pleistocene. The increase in monsoon-related precipitation caused the lake to rise during the Early to Mid-Holocene. The end of the subsequent highstand sedimentation marks the shift to a dry and cool period during the Late Holocene.

Synchronicity of cold and dry periods with sparse vegetation cover and abundant loose fine-grained materials promotes effective aeolian processes. Trapping of deposits, in turn, is conditional upon appropriate accommodation space with sufficient land surface roughness, such that wind speeds are diminished and deposition can occur. This may require sufficient precipitation to generate ground cover. Optimal conditions for aeolian processes are typically experienced during periods of deglaciation, as significant bodies of loose, fine-grained sediment are exposed, vegetated cover is negligible, and winds may be severe. Alternatively, high availability of materials may accompany drier phases when the fine-grained sediments of lake beds (or river systems) are exposed (IJmker et al. 2012; Lehmkuhl and Haselein 2000; Stauch et al. 2012). The development of lake-marginal dunes (lunettes), dune fields, and infilled plateau landscapes is the product of multiple phases of deposition, stabilization, and reworking.

Geochemical and sedimentological characteristics of widespread sand dune fields and sand sheets on the north-eastern Qinghai–Tibet Plateau are indicative of a local source (IJmker et al. 2012). Finer-grained loess materials have typically been transferred much greater distances. Aeolian sediments on the Qinghai–Tibet Plateau indicate two different climatic modes (IJmker et al. 2012). During the Early Holocene, wetter conditions supported the retention of aeolian sediments. The reactivation of sediment in the Late Holocene due to small-scale disturbances in the vegetation cover points to a cooler and drier climate. Local climatic conditions, especially related to effective moisture, have induced a complex history of well-sorted aeolian sand, palaeosols, and loess deposits in the Gonghe Basin (Qiang et al. 2013).

Warmer conditions and degradation of permafrost have influenced the origin, age, formation, and stability of periglacial sand sheets and dunes (Jin et al. 2007;

Zhang et al. 2005). In the recent period, since the Little Ice Age, increasingly arid and warmer climate conditions, alongside land use changes, have induced well-developed mobile sand dunes and ridges, with desertification processes burying highways, farmlands, and grasslands in some cases. Modern aeolian sediment transport on the plateau happens mostly during winter, when vegetation cover is reduced and air masses associated with the dry winter monsoon and westerlies prevail (IJmker et al. 2012). Intervening periods may be characterized by erosion (reworking and/or removal) of aeolian deposits (e.g. Stauch et al. 2012).

The largest Loess Plateau in the world is located just to the north-east of the Qinghai–Tibet Plateau. It covers an area over 400,000 km^2, extending from north-eastern Qinghai through Gansu and covering much of Shanxi, northern Henan, and Shaanxi (Fig. 1.1). Typical thickness of loess deposits ranges from 50 to 80 m, masking the detailed relief of the underlying surfaces. Gradual strengthening of the Asian winter monsoon combined with a global cooling trend underpinned the development of thick loess deposits across the north-eastern part of the plateau (An et al. 2001). As loess is homogeneous, fine-grained, and poorly consolidated, with its calcium carbonate cement being readily soluble in water, it is very erodible. Gully incision and channel network expansion within the extensive cover of loess deposits have created dissected hills and ridges and extremely high sediment yields. Multiple phases of gully development on the Loess Plateau reflect large-scale monsoonal climatic shift coincident with neo-tectonic uplift of the land mass (Huang et al. 2012). Historically, erosion has been accentuated by land use changes, but recent reforestation programmes have arrested this process.

The landscape classification scheme developed by Nicoll et al. (2013) differentiates among 10 landscape types in the Upper Yellow River Basin (Fig. 1.10). Areas classified as *palaeo glacial valleys* are concentrated in the south-west of the area, within the Anyemaqen and Bayan Har Mountains (Heyman et al. 2008; Stroeven et al. 2009). Subdued glacial landscapes are characterized by U-shaped glacial valleys up to 2 km wide, clustered around higher mountain massifs along with meltwater channels, large glacial outwash fans, and lakes formed within glacially scoured basins. Depositional features include moraines, hummocky terrain, and drumlins (Stroeven et al. 2009). Due to their high elevation, permafrost exists over much of the area, with wetlands prominent on the lower valley floors.

The *plateau uplands* cover nearly 25 % of the Upper Yellow River Basin. This high-elevation area is relatively cold and dry, with a mean annual temperature below freezing and precipitation of approximately 320 mm. Permafrost development is evidenced by periglacial landforms such as patterned ground and frost-heave mounds, as well as thaw-induced landslides on shallow hillslopes. Drainage is generally poor, and wetlands are dominant. The landscape is relatively low relief, with broad valleys and internal basins that have been infilled with lacustrine and alluvial deposits.

Moderate and steep hillslope landscape classes are primarily located within the Bayan Har and Anyemaqen mountain ranges. Overall, moderate and steep hillslopes cover 39 % of the Upper Yellow River Basin, with 23 % above the approximate 4100 m elevation limit of permafrost influence. The majority of these

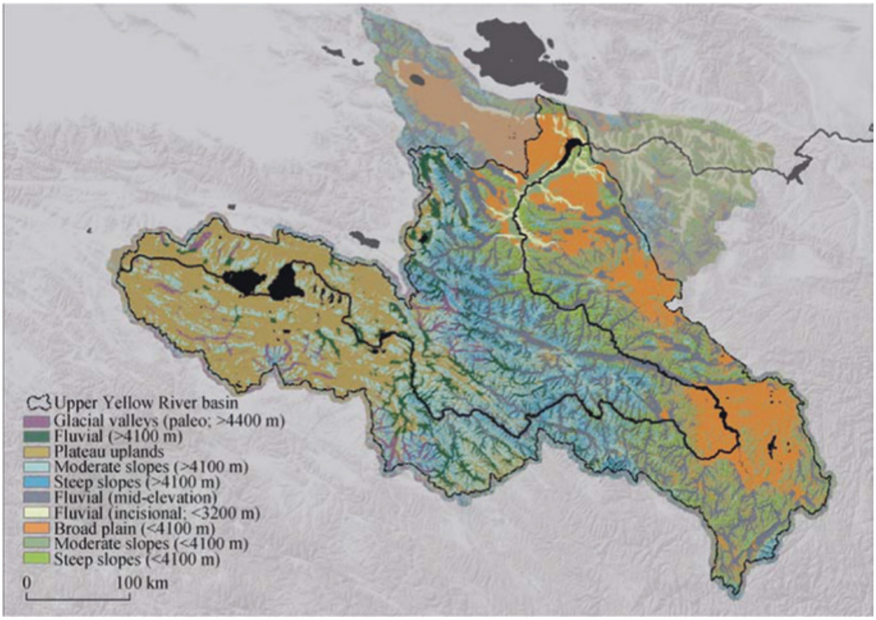

Fig. 1.10 Primary landscape types of the Upper Yellow River Basin (Nicoll et al. 2013)

hillslopes (28 %) are moderately sloping, with gradients less than 40 %. While hillslope instability is more prominent on steeper hillslopes, the combination of thin soils, sparse vegetation, widespread human influence, and freeze–thaw action induces greater instabilities than may be predicted based on gradient alone Hu et al. (2016, Chap. 5).

Fluvial landscapes make up 21 % of the Upper Yellow River Basin. Low gradients (<1 %) and wide valley floors of many headwater reaches on the upper plateau surface result in disconnected landscapes with an array of channel planform types and a multitude of wetlands (see Brierley et al. 2016a, Chap. 3; Li et al. 2016b, Chap. 9). Rates of fluvial erosion are relatively low. Many tributaries are disconnected from the mainstream and pond behind levees, developing a series of wetlands during the wet season. Structural controls are prominent within the mountain ranges downstream of the upper plateau, where bedrock gorges are common. Local transitions from confined to unconfined valley settings are accompanied by corresponding changes in channel planform and associated landforms (Yu et al. 2014a). Much of the available sediment load within this area may be due to direct or indirect glacial conditioning (Chen et al. 2011; Lehmkuhl and Owen 2005). Large alluvial fans composed primarily of glacial outwash materials now act both as sediment sources and confining features for many of the streams.

Incisional landscapes are located within tributary systems and the Yellow River itself downstream of the Anyemaqen Mountains. In these settings, fluvial valleys have cut down dramatically and are now relatively isolated from the main plateau surface.

Extensive terrace sequences in excess of 500 m high are evident in those areas where the river has cut through extensive basin-fill deposits (Harkins et al. 2007).

Alongside this tectonic control, the elevation-induced climate gradient has resulted in pronounced variability in the influence of vegetation upon channel planform types along the Upper Yellow River (Brierley et al. 2016b, Chap. 15; Yu et al. 2014). The *broad plain* landscape class covers 15 % of the Upper Yellow River Basin and consists of wide, relatively flat plains that are below the lower limit of permafrost (Nicoll et al. 2013). The geographic extent of this class largely covers three main sedimentary basins: the Zoige (Ruoergai) Basin near the first bend of the Yellow River, the Tongde basin downstream of the Anyemaqen Mountains, and the Gonghe Basin, bordered to the north-west by the Qaidam Basin. There is a significant climatic gradient between these basins. The Zoige Basin has a wetter climate, with much of the area covered by the Ruoergai wetland (Li et al. 2015). In contrast, the Tongde and Gonghe basins are semi-arid, with aeolian processes forming both vegetated and active (unvegetated) dune fields. As the trunk stream of the Yellow River has incised through the basin fills, changing base levels have triggered secondary incision of tributary systems.

1.4.4 Vegetation

Vegetation cover in the Yellow River Source Zone includes alpine and sub-alpine meadows, steppes, coniferous forest, broadleaf forest, needle-leaf forest, swamp and aquatic vegetation, cushion plants, shrub, and zones of sparse vegetation (Fig. 1.11). Alpine and sub-alpine meadows (grasslands) are dominant, with isolated remnants of montane and sub-alpine broadleaf and conifer forest on steep hillslopes and remote areas up to 4500 m high (Herzschuh et al. 2010). The grasslands are comprised of low-productive, cold-tolerant perennial plants such as kobresia (*Kobresia* spp.), needlegrass (*Stipa* spp.), sedge (*Carex* spp.), saussurea (*Saussurea* spp.), roegneria (*Roegneria* spp.), bluegrass (*Poa* spp.), wild ryegrass (*Elymus* spp.), and speargrass (*Achnatherum* spp.). The height of forage is low, ranging between 10 and 30 cm. Notable variability in radiation on north- and south-facing hillslopes also induces significant variability in patterns of plant communities. Regional vegetation patterns are shown in Fig. 1.12.

Tectonic uplift and geological isolation played important roles in shaping species diversity across the region. Some species likely retreated to the plateau edge during the glacial ages and then recolonized the platform during the interglacial ages and/or at the end of last glacial maximum (Liu et al. 2014). In contrast, other species survived the conditions experienced at the last glacial maximum in multiple refugia, even at the high-altitude platform. Indeed, some cold-preferring conifers might have expanded their distributional ranges during the Last Glacial Maximum. The largest glaciation, rather than the Last Glacial Maximum, was probably the key determinant of the distributional ranges, genetic diversity, and intraspecific divergences of the current species (Liu et al. 2014). Many plant

Coniferous forest

Broad-leaf forest

Needle-leaf forest

Shrub vegetation

Alpine meadow vegetation

Alpine steppe vegetation

Cushion plant

Swamp and aquatic vegetation

Fig. 1.11 Vegetation diversity in the Yellow River Source Zone

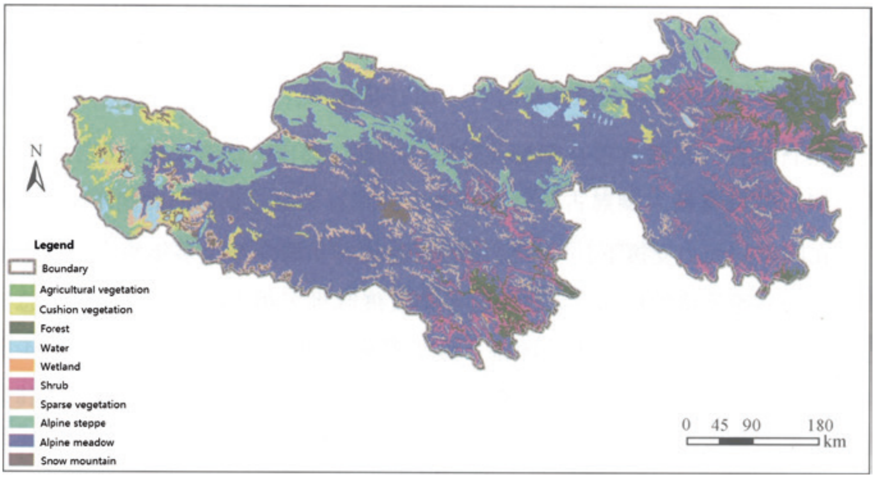

Fig. 1.12 Spatial distribution of vegetation cover types in the Sanjiangyuan region

species have adapted their reproductive strategies to meet the challenges posed by the harsh environmental conditions on the Qinghai–Tibet Plateau.

1.4.5 Fauna

Several parts of the source region of the Yellow River lie within the Sanjiangyuan National Nature Reserve, which boasts 93 species of animals, 255 species of birds, 18 species of amphibious reptiles, and at least 90 genera of insects and soil fauna (Chen et al. 2007). Many of these animals are endemic to the region and are rare or threatened. Indeed, 69 species found in this region are on the list of 'protected wildlife of national importance', of which 16 are in the first class (including the iconic Tibetan antelope (*Pantholops hodgsoni*), wild yak (*Bos mutus*), and snow leopard (*Panthera uncia*)) and 53 species are in the second class (including the blue sheep (*Pseudois nayaur*) and the Tibetan gazelle (*Procapra picticaudata*)) (Fig. 1.3).

Native small mammals on the grasslands in the Upper Yellow River, such as plateau pikas (*Ochotona curzoniae*), Chinese zokor (*Eospalax fontanierii*), and Brandt's vole (*Lasiopodomys brandtii*), are ecosystem engineers in their respective ecosystems. They contribute significantly to the preservation of native biodiversity of plants and animals as well as preserving important ecosystem functions. Their burrows offer shelter for other small mammals such as toads, lizards, insects, and other invertebrates and even provide breeding habitats for burrow-nesting birds (Lai and Smith 2003). These small mammals also introduce heterogeneity into the grasslands, generating a mosaic of different habitats that increase plant species diversity (Bagchi et al. 2006) as well as providing food for native predators (including foxes, weasels, and small cats and birds such as hawks, falcons, eagles, and owls; Samjaa et al. 2000). The small mammals also promote the recycling of nutrients and aeration of the soil (Zhang et al. 2004) and may even reduce the risk of soil erosion. To date, limited research has systematically assessed species diversity and ecological functionality in lakes, rivers, wetlands, and soils of the region.

1.5 Structure of the Book

Three critical themes fashion core threads of enquiry for this book:

(a) The development of practical (applied) research that relates specifically to landscape diversity in efforts to protect the distinctive landscapes and ecosystems of the Upper Yellow River and improve environmental conditions in areas subjected to degradation. Appropriate documentation of key resources and distinctive attributes (the values we seek to protect) and effective understanding of underlying processes that threaten ecosystem values are required to provide a starting point for appropriately informed and targeted management interventions.
(b) Increasing development pressures in the region require the adaption of precautionary approaches to environmental management that build upon coherent scientific guidance, in which field-based understandings are related directly to remotely sensed applications (and vice versa).
(c) Emphasis upon ‘place’ and the ‘local’ appropriately highlights the fundamental importance of people as part of ecosystems. Effective uptake of best available understandings builds upon coproduced knowledge of biophysical-and-cultural landscapes, providing a basis to establish common platforms for shared commitments to environmental decision-making (see Wilcock et al. 2013).

The book is structured as follows. Chapter 2 provides an overview of spatial and temporal variability in the climate of the Upper Yellow River Basin. The hydrologic regime and river diversity of the Upper Yellow River are assessed in Chaps. 3 and 4. Hillslope forms and processes in the region are appraised in Chap. 5. Human impacts upon environmental systems are assessed in terms of grassland resources (Chaps. 6 and 7), desertification issues (Chap. 8), wetland resources (Chaps. 9 and 10), and fish resources (Chap. 11). The land use history of the region, human–environmental interactions, and socio-economic considerations are summarized in Chaps. 12, 13, and 14, respectively. Chapter 15 provides a synthesis of prospective environmental futures in the region, emphasizing choices to be made in moves towards sustainable environmental management.

Acknowledgments Research in this chapter was conducted under the auspices of the Three Brothers (Plus) project. Funding from the three institutions (The University of Auckland, Qinghai University and Tsinghua University) is gratefully acknowledged. The work was supported by grants from the Program for Changjiang Scholars and Innovative Research Team in University, Ministry of Education of China (IRT13074) and International Science & Technology Cooperation Program of China, MOST (2011DFG93160). This work also benefitted from two travel/workshop grants from NZ Education.

References

Aldenderfer, M., & Yinong, Z. (2004). The prehistory of the Tibetan Plateau to the seventh century AD: perspectives and research from China and the West since 1950. *Journal of World Prehistory, 18*, 1–55.

An, Z. S., Kutzbach, J. E., & Prell, W. L. (2001). Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan plateau since late Miocenetimes. *Nature, 411*, 62–66.

Bagchi, S., Namgail, T., & Ritchie, M. E. (2006). Small mammalian herbivores as mediators of plant community dynamics in the high-altitude arid rangelands of trans-Himalaya. *Biological Conservation, 127*, 438–442.

Blue, B., Brierley, G. J., & Yu, G. (2013). Geodiversity in the Yellow River Source Zone. *Journal of Geographical Sciences*, *23*, 775–792.

Brantingham, P. J., & Xing, G. (2006). Peopling of the northern Tibetan Plateau. *World Archaeology, 38*, 387–414.

Brierley, G. J., Yu, G. A., Li, Z. W. (2016a). Geomorphic diversity of rivers in the upper Yellow River basin. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 59–77). Berlin: Springer.

Brierley, G. J., Cullum, C., Li, X. L., et al. (2016b). Conclusion: Environmental futures of the upper Yellow River basin. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 353–369). Berlin: Springer.

Chen, Y., Li, Y., Zhang, Y., Zhang, M., et al. (2011). Late quaternary deposition and incision sequences of the golmud river and their environmental implications. *Quaternary International, 236*, 48–56.

Chen, B., Zhang, X., Tao, J., et al. (2014). The impact of climate change and anthropogenic activities on alpine grassland over the Qinghai-Tibet Plateau. *Agricultural and Forest Meteorology, 189*, 11–18.

Colman, S. M., Yu, S. Y., An, Z., et al. (2007). Late cenozoic climate changes in China's western interior: A review of research on lake Qinghai and comparison with other records. *Quaternary Science Reviews, 26*, 2281–2300.

Craddock, W. H., Kirby, E., Harkins, N. W., et al. (2010). Rapid fluvial incision along the Yellow River during headward basin integration. *Nature Geoscience, 3*, 209–213.

Dietze, E., Wünnemann, B., Diekmann, B., et al. (2010). Basin morphology and seismic stratigraphy of Lake Donggi Cona, north-eastern Tibetan Plateau China. *Quaternary International, 218*, 131–142.

Elvin, M., & Liu, C. (Eds). (1998). *Studies in environment and history: Sediments of time: environment and society in Chinese history*. Cambridge University Press. 544 pp.

Fan, J. W., Shao, Q. Q., Liu, J. Y., et al. (2010). Assessment of effects of climate change and grazing activity on grassland yield in the three rivers headwaters region of Qinghai-Tibet Plateau China. *Environmental Monitoring and Assessment, 170*, 571–584.

Feng, J. M., Wang, T., Xie, C. W., et al. (2004). A case study on the eco-environmental degradation in the source region of the Yellow River, Northeast Qinghai-Xizang Plateau. *Progress in Geography, 23*, 56–62. (In Chinese with English Abstract).

Fu, B., & Awata, Y. (2007). Displacement and timing of left-lateral faulting in the Kunlun Fault Zone, northern Tibet, inferred from geologic and geomorphic features. *Journal of Asian Earth Sciences, 29*, 253–265.

Gao, J. G. (2016). Wetland and its degradation in the Yellow River Source Zone. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 209–232). Berlin: Springer.

Han, M. Q., Brierley, G. J., Cullum, C., et al. (2016). Climate, vegetation and human land use interactions on the Qinghai-Tibet Plateau through the Holocene. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 253–274). Berlin: Springer.

Harkins, N., Kirby, E., Heimsath, A., Robinson, R., & Reiser, U. (2007). Transient fluvial incision in the headwaters of the Yellow River, northeastern Tibet, China. *Journal of Geophysical Research, 112*(F3), F03S04: 1–21.

Harris, R. B. (2010). Rangeland degradation on the Qinghai-Tibetan plateau: A review of the evidence of its magnitude and causes. *Journal of Arid Environments, 74*, 1–12.

Harris, R. B., Wenying, W., Smith, A. T., et al. (2015). Herbivory and competition of Tibetan steppe vegetation in winter pasture: effects of livestock exclosure and plateau pika reduction. *PLoS ONE, 10*(7), e0132897.

Herzschuh, U., Birks, H. J. B., Liu, X., et al. (2010). What caused the mid-Holocene forest decline on the eastern Tibet-Qinghai Plateau? *Global Ecology and Biogeography, 19*, 278–286.

Heyman, J., Hattestrand, C., & Stroeven, A. P. (2008). Glacial geomorphology of the Bayan Har sector of the NE Tibetan Plateau. *Journal of Maps, 4*, 42–62.

Heyman, J., Stroeven, A. P., Alexanderson, H., et al. (2009). Palaeoglaciation of Bayan Har Shan, northeastern Tibetan Plateau: Glacial geology indicates maximum extents limited to ice cap and ice field scales. *Journal of Quaternary Science, 24*, 710–727.

Heyman, J., Stroeven, A. P., Caffee, M. W., et al. (2011). Palaeoglaciology of Bayan Har Shan, NE Tibetan Plateau: Exposure ages reveal a missing LGM expansion. *Quaternary Science Reviews, 30*, 1988–2001.

Hu, X. S., Brierley, G. J., Cullum, C., et al. (2016). Hillslope stability in the Yellow River source region. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 101–115). Berlin: Springer.

Huang, C. C., Pang, J., Zha, X., et al. (2012). Development of gully systems under the combined impact of monsoonal climatic shift and neo-tectonic uplift over the Chinese Loess Plateau. *Quaternary International, 263*, 46–54.

Huang, H. Q., Liu, X. F., Brierley, G. J., et al. (2016). Hydrology of the Yellow River Source Zone. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 79–99). Berlin: Springer.

IJmker, J., Stauch, G., Pötsch, S., et al. (2012). Dry periods on the NE Tibetan Plateau during the late quaternary. *Palaeogeography, Palaeoclimatology, Palaeoecology, 346*, 108–119.

IRTCES. (2005). *Case study on the Yellow River sedimentation*. Beijing: International Research and Training Center on Erosion and Sedimentation. 126 pp.

Jin, H. J., Chang, X. L., & Wang, S. L. (2007). Evolution of permafrost on the Qinghai-Xizang (Tibet) Plateau since the end of the late Pleistocene. *Journal of Geophysical Research: Earth Surface, 112*(F2).

Kang, S., Xu, Y., You, Q., et al. (2010). Review of climate and cryospheric change in the Tibetan Plateau. *Environmental Research Letters*, *5*(1), 015101.

Lai, C. H., & Smith, A. T. (2003). Keystone status of plateau pikas (Ochotona curzoniae): Effect of control on biodiversity of native birds. *Biodiversity & Conservation*, *12*(9), 1901–1912.

Lehmkuhl, F., & Haselein, F. (2000). Quaternary paleoenvironmental change on the Tibetan Plateau and adjacent areas (Western China and Western Mongolia). *Quaternary International, 65–66*, 121–145.

Lehmkuhl, F., & Owen, L. A. (2005). Late Quaternary glaciation of Tibet and the bordering mountains: A review. *Boreas, 34*, 87–100.

Li, J. J., Fang, X. M., & Ma, H. Z. (1996). Geomorphological and environmental evolution in the upper reaches of the Yellow River during the late Cenozoic. *Science in China (Series D), 39*(4), 380–390.

Li, X., Brierley, G. J., Shi, D., et al. (2012). Ecological protection and restoration in Sanjiangyuan Natural Reserve, Qinghai Province, China. In: Higgitt, D. (Ed.), *Perspectives on Environmental Management and Technology in Asian River Basins*. SpringerBriefs in Geography, Netherlands. 93–120.

Li, J., Fang, X., Song, C., et al. (2014a). Late Miocene-Quaternary rapid stepwise uplift of the NE Tibetan Plateau and its effects on climatic and environmental changes. *Quaternary Research, 81*, 400–423.

Li, X. L., Perry, G. L. W., Brierley, G. J., et al. (2013). Restoration prospects for Heitutan degraded grassland in the Sanjiangyuan. *Journal of Mountain Science*, *10*, 687–698.
Li, X. L., Perry, G. L. W., Brierley, G. J., et al. (2014b). Quantitative assessment of degradation classifications in degraded alpine meadows (Heitutan), Sanjiangyuan, western China. *Land Degradation & Development, 25*, 417–427.
Li, Y. F., & Wang, Z. Y. (2016). Modeling vegetation-erosion dynamics in the Mugetan Desert, Yellow River Source Zone. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 167–182). Berlin: Springer.
Li, Z. W., Wang, Z. Y., Brierley, G., et al. (2015). Shrinkage of the Ruoergai Swamp and changes to landscape connectivity, Qinghai-Tibet Plateau. *Catena, 126*, 155–163.
Li, X. L., Perry, G., & Brierley, G. J. (2016a). Grassland ecosystems of the Yellow River Source Zone: degradation and restoration. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 137–165). Berlin: Springer.
Li, Z. W., Wang, Z. Y., & Pan, B. Z. (2016b). Wetland ecosystems of the Yellow River Source Zone. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 183–207). Berlin: Springer.
Liu, J. Q., Duan, Y. W., Hao, G., et al. (2014). Evolutionary history and underlying adaptation of alpine plants on the Qinghai-Tibet Plateau. *Journal of Systematics and Evolution, 52*, 241–249.
Liu, X., Lai, Z., Madsen, D., et al. (2011). Lake level variations of Qinghai Lake in northeastern Qinghai-Tibetan Plateau since 3.7 ka based on OSL dating. *Quaternary International, 236*, 57–64.
Liu, X., Lai, Z., Yu, L., et al. (2012). Luminescence chronology of aeolian deposits from the Qinghai Lake area in the Northeastern Qinghai-Tibetan Plateau and its palaeoenvironmental implications. *Quaternary Geochronology, 10*, 37–43.
Liu, Z. Q., Yu, X. J., Xu, X., et al. (1980). The basic geological characteristics of the Qinghai-Tibet Plateau. *Bulletin of Chinese Academy of Geological Sciences, 2*, 23–47. (in Chinese).
Liu-Zeng, J., Tapponnier, P., Gaudemer, Y., et al. (2008). Quantifying landscape differences across the Tibetan plateau: Implications for topographic relief evolution. *Journal of Geophysical Research: Earth Surface, 113*(F4).
McGregor, G. R. (2016). Climate variability and change in the Sanjiangyuan region. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 35–57). Berlin: Springer.
Miehe, G., Miehe, S., Bach, K., et al. (2011). Ecological stability during the LGM and the mid-Holocene in the Alpine Steppes of Tibet? *Quaternary Research, 76*, 243–252.
Miehe, G., Miehe, S., Böhner, J., et al. (2014). How old is the human footprint in the world's largest alpine ecosystem? A review of multiproxy records from the Tibetan Plateau from the ecologists' viewpoint. *Quaternary Science Reviews, 86*, 190–209.
Miehe, G., Miehe, S., Kaiser, K., et al. (2008a). Status and dynamics of the *Kobresia pygmaea* ecosystem on the Tibetan plateau. *Ambio, 37*, 272–279.
Miehe, G., Miehe, S., Kaiser, K., et al. (2009). How old is pastoralism in Tibet? An ecological approach to the making of a Tibetan landscape. *Palaeogeography, Palaeoclimatology, Palaeoecology, 276*, 130–147.
Miehe, G., Miehe, S., Will, M., et al. (2008b). An inventory of forest relicts in the pastures of Southern Tibet (Xizang A.R., China). *Plant Ecology, 194*, 157–177.
Mueller, E. N., Wainright, J., Parsons, A. J., et al. (2014). Land degradation in drylands: an ecogeomorphological approach. In E. N. Mueller, J. Wainright, A. J. Parsons, et al. (Eds.), *Patterns of land degradation in drylands: Understanding self-organised ecogeomorphic systems* (pp. 1–9). Dordrecht: Springer.
Murari, M. K., Owen, L. A., Dortch, J. M., et al. (2014). Timing and climatic drivers for glaciation across monsoon-influenced regions of the Himalayan-Tibetan orogen. *Quaternary Science Reviews, 88*, 159–182.

NDRC (National Development and Reform Commission, China). (2014). The second phase for the ecological protection and restoration of Sanjiangyuan. http://www.sdpc.gov.cn/zcfb/zcfbghwb/201404/W020150203319341893483.pdf. (In Chinese).

Nicoll, T., Brierley, G. J., & Yu, G. (2013). A broad overview of landscape diversity of the Yellow River Source Zone. *Journal of Geographical Sciences, 23*, 793–816.

Ouyang, W., Skidmore, A. K., Toxopeus, A. G., et al. (2010). Long-term vegetation landscape pattern with non-point source nutrient pollution in upper stream of Yellow River basin. *Journal of Hydrology, 389*, 373–380.

Owen, L. A., & Dortch, J. M. (2014). Nature and timing of Quaternary glaciation in the Himalayan-Tibetan orogen. *Quaternary Science Reviews, 88*, 14–54.

Owen, L. A., Finkel, R. C., Barnard, P. L., et al. (2005). Climatic and topographic controls on the style and timing of late Quaternary glaciation throughout Tibet and the himalaya defined by 10Be cosmogenic radionuclide surface exposure dating. *Quaternary Science Reviews, 24*, 1391–1411.

Owen, L. A., Finkel, R. C., Haizhou, M., et al. (2006). Late Quaternary landscape evolution in the Kunlun mountains and Qaidam Basin, Northern Tibet: A framework for examining the links between glaciation, lake level changes and alluvial fan formation. *Quaternary International, 154*(155), 73–86.

Owen, L. A., Finkel, R. C., Ma, H., et al. (2003). Timing and style of late Quaternary glaciation in northeastern Tibet. *Geological Society of America Bulletin, 115*, 1356–1364.

Pan, J. H., & Liu, J. L. (2005). Land use change and its impact in the eco-environment on the Yellow River source region during the past 15 years. *Journal of Arid Land Resources and Environment, 19*, 69–74. (in Chinese).

Perrineau, A., Van Der Woerd, J., Gaudemer, Y., et al. (2011). Incision rate of the Yellow River in northeastern Tibet constrained by ^{10}Be and ^{26}Al cosmogenic isotope dating of fluvial terraces: implications for catchment evolution and plateau building. In: R. Gloaguen, & L. Ratschbacher (Eds.), *Growth and collapse of the Tibetan Plateau: Geological Society of London Special Publication* (Vol. 353, pp. 189–219).

Piao, S., Cui, M., Chen, A., et al. (2011). Altitude and temperature dependence of change in the spring vegetation green-up date from 1982 to 2006 in the Qinghai-Xizang Plateau. *Agricultural and Forest Meteorology*, *151*(12), 1599–1608.

Qi, D. (2016). Fish of the Upper Yellow River. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 233–252). Berlin: Springer.

Qiang, M., Chen, F., Song, L., et al. (2013). Late Quaternary aeolian activity in Gonghe Basin, northeastern Qinghai-Tibetan Plateau China. *Quaternary Research, 79*, 403–412.

Qiao, Y. M., & Duan, Z. H. (2016). Understanding alpine meadow ecosystems. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 117–135). Berlin: Springer.

Qin, Z., Yang, Y., Kang, L., et al. (2010). A mitochondrial revelation of early human migrations to the Tibetan Plateau before and after the last glacial maximum. *American Journal of Physical Anthropology, 143*, 555–569.

Qiu, J. (2008). The third pole. *Nature, 454*(7203), 393–396.

Ran, Y. C., Xie, J. X., & Li, X. L. (2016). Socio-economic development and its effects on the ecological environment of the Yellow River Source Zone. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 331–351). Berlin: Springer.

Rhode, D., Haizhou, M., Madsen, D. B., et al. (2010). Paleoenvironmental and archaeological investigations at Qinghai Lake, western China: Geomorphic and chronometric evidence of lake level history. *Quaternary International, 218*, 29–44.

Samjaa, R., Zöphel, U., & Peterson, J. (2000). The impact of the vole *Microtus brandti* on Mongolia steppe ecosystems. *Marburger Geographische Schriften, 135*, 346–360.

Schlütz, F., & Lehmkuhl, F. (2009). Holocene climatic change and the nomadic Anthropocene in Eastern Tibet: palynological and geomorphological results from the Nianbaoyeze mountains. *Quaternary Science Reviews, 28*, 1449–1471.

Stauch, G., IJmker, J., Pötsch, S., et al. (2012). Aeolian sediments on the north-eastern Tibetan Plateau. *Quaternary Science Reviews, 57*, 71–84.

Stroeven, A. P., Hattestrand, C., Heyman, J., et al. (2009). Landscape analysis of the Huang He headwaters, NE Tibetan Plateau: patterns of glacial and fluvial erosion. *Geomorphology, 103*, 212–226.

Tane, H. (2011). The Yellow River watershed in Qinghai's Sanjiangyuan region. In G. Chen, X. L. Li, J. Gao, et al. (Eds.), *Wetland types and evolution and rehabilitation in the Sanjiangyuan region* (pp. 92–110). Xining: Qinghai People's Publishing House.

Tane, H., Li, X. L., & Chen, G. (2016). Ecogenesis of the Huang He (Yellow River) headwaters. In: G. J. Brierley, X. Li, C. Cullum, et al. (Eds.), *Landscape and ecosystem diversity, dynamics and management in the Yellow River Source Zone* (pp. 275–330). Berlin: Springer.

Tapponnier, P., Zhiqin, X., Roger, F., et al. (2001). Oblique stepwise rise and growth of the Tibet Plateau. *Science, 294*, 1671–1677.

UNCCD. (1994). *United Nations Convention to Combat Desertification (UNCCD)*. New York: United Nations.

Wang, Y., Wang, S., & Xia, W. (1995). Sedimentary mineralogy and environment interpretation of core RH from Zoige Basin. In Qinghai-Tibet Project Experts Committee (Ed.), *Formation, evolvement, environmental variance, and ecosystem research of the Qinghai-Tibetan Plateau*. Beijing: Science Press.

Wang, H., Yang, Z., Saito, Y., et al. (2006). Interannual and seasonal variation of the Huanghe (Yellow River) water discharge over the past 50 years: connections to impacts from ENSO events and dams. *Global and Planetary Change, 50*, 212–225.

Wang, Z., Yu, G., Brierley, G. J., et al. (2010). Stream networks and knickpoints in the Sanjiangyuan region. *Annals of Warsaw University of Life Sciences—SGGW, Land Reclamation, 42*, 79–91.

Wen, L., Dong, S. K., Li, Y. Y., et al. (2013). The effects of biotic and abiotic factors on the spatial heterogeneity of alpine grassland vegetation at a small scale on the Qinghai-Tibet Plateau (QTP) China. *Environmental Monitoring and Assessment, 185*, 8051–8064.

Wilcock, D., Brierley, G. J., & Howitt, R. I. (2013). Ethnogeomorphology. *Progress in Physical Geography*, *37*, 573–600.

Wohl, E. (2013). Wilderness is dead: whither critical zone studies and geomorphology in the Anthropocene? *Anthropocene, 2*, 4–15.

Wu, J., Zhang, X., Shen, Z., et al. (2013). Grazing-exclusion effects on aboveground biomass and water-use efficiency of alpine grasslands on the northern Tibetan Plateau. *Rangeland Ecology & Management, 66*, 454–461.

Xu, Z. X., Li, J. Y., & Liu, C. M. (2007). Long-term trend of major climate variables in the Yellow River basin. *Hydrological Processes, 21*, 1935–1948.

Yan, J. P., Hinderer, M., & Einsele, G. (2002). Geochemical evolution of closed-basin lakes: general model and application to Lakes Qinghai and Turkana. *Sedimentary Geology, 148*, 105–122.

Yao, T., Thompson, L. G., Mosbrugger, V., et al. (2012). Third pole environment (TPE). *Environmental Development, 3*, 52–64.

Yu, G., Brierley, G. J., Huang, H. Q., et al. (2014a). An environmental gradient of vegetative controls upon channel planform in the source region of the Yangtze and Yellow Rivers. *Catena, 119*, 143–153.

Yu, L., & Lai, Z. (2014). Holocene climate change inferred from stratigraphy and OSL chronology of aeolian sediments in the Qaidam Basin, northeastern Qinghai-Tibetan Plateau. *Quaternary Research, 81*, 488–499.

Yu, L., Lai, Z., An, P., et al. (2014b). Aeolian sediments evolution controlled by fluvial processes, climate change and human activities since LGM in the Qaidam basin Qinghai-Tibetan Plateau. *Quaternary International, 372*, 22–32.

Zhang, H., Gilbert, B., Wang, W., et al. (2013). Grazer exclusion alters plant spatial organization at multiple scales, increasing diversity. *Ecology and Evolution, 3*, 3604–3612.

Zhang, Y., Gao, Q., Dong, S., et al. (2015). Effects of grazing and climate warming on plant diversity, productivity and living state in the alpine rangelands and cultivated grasslands of the Qinghai-Tibetan Plateau. *The Rangeland Journal, 37*, 57–65.

Zhang, Y., Liu, J., & Du, Y. (2004). The impact of plateau zokor *Myospalax fontanierii* burrows on alpine meadow vegetation on the Qinghai-Xizang (Tibetan) plateau. *Acta theriologica, 49*, 43–51.

Zhang, W., Wang, T., Qu, J., et al. (2005). Developmental characteristics of aeolian dunes and environmental changes in the adjoining region of Puruogangri ice sheet, North Tibetan Plateau. *Environmental Geology, 48*, 15–24.