

Chapter 13

Ecogenesis of the Huang He Headwaters

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Abstract The Huang He headwaters (33–36°N) occupy stepped suites of intermontane basins between 3000 and 6000 m asl separated by rugged gorges, hills and high mountains. Located in Qinghai’s Sanjiangyuan region, the headwater’s heterogeneous climate ecotypes reflect diverse habitat-meteorological relationships, producing boreal and temperate forests, subalpine shrublands, heathlands and meadows, alpine meadows and nival screefields. This chapter applies transdisciplinary research methods and complex open system geoscientific methods to assess the polygenetic origins and adaptive evolution of ecosystems in the headwaters region. Reconnaissance surveys included benchmark audits of rangeland valleys, undertaken over five years in all seasons. Appraisals of ecological dynamics and adaptive coevolution of rangeland ecosystems over Palaeolithic–Mesolithic–Neolithic times demonstrate how widespread deforestation and drainage of wetlands for pastoral grazing induced the emergence of “golf course” grasslands. Unintended consequences arising from traditional pastoral cultures included widespread soil erosion, subsequently leading to severe salinity and flash flooding, and ending in extreme pastoral desertification. The long-term ecological and socio-economic consequences of these watershed calamities on downstream communities are succinctly acknowledged by the renowned epithet for the Huang He as *China’s Sorrow*. As access to safe drinking water declines, and casualties mount

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from watershed dysfunctions, remedying ecological degradation of the headwaters region is an urgent priority for China. The challenges are not insurmountable, but the choices are few. While engineering and conservation measures may alleviate some symptoms, restoring ecological functionality of the Huang He watershed and its essential life support systems requires ecological strategies for reviving watershed systems, while providing sustainable alternatives to pastoral grazing.

Keywords Watershed ecology • Cultural ecography • Resource economics • Grazing impacts • Rangeland salinity • Pastoral desertification

13.1 Introduction

Human-induced desertification is more often than not paramount in countries reliant on pastoral agricultures, aggravating climate change beyond normal levels (UNEP 2010). United Nations agencies have identified desertification as a key driver of global conflict and instability, food and water insecurity and entrenched poverty. UN Secretary-General Ban Ki Moon (2011, 2014) has called for urgent action to support communities in crisis. In his address to the United Nations Convention to Combat Desertification in Buenos Aires, Argentina, on 28 September 2009, he commented “*Desertification and land degradation destabilize societies, entrench poverty and exacerbate climate change*”.

This chapter outlines a range of ecological indicators revealing a history of incremental human impacts throughout the Qinghai–Tibet rangelands, leading to soil desiccation, watershed salinity and pastoral desertification. It outlines methods for auditing watersheds for compliance with United Nations Agenda 21 (UN A21): the internationally agreed principles for integrating sustainable development and environmental protection. Our conclusions contain recommendations for adapting to climate change, reversing desertification and reviving sick streams, rivers and lakes. We note that experience in China and elsewhere shows that reversing processes of ecological degradation requires engaging communities in participatory watershed programmes for sustainable development of watershed ecosystems.

The study is conducted from the transdisciplinary perspectives of watershed ecography, cultural ecology and resource economics. Our prognoses and interpretations are based on extensive field surveys conducted from 2010 to 2014. Our research reveals how ecogenesis of watershed habitats and their communities in the Huang He (Yellow River) headwaters region has involved a raft of atmospheric, terrestrial and ecological processes that are continuously interacting and adapting in space and time. In these dynamic circumstances, the origins and evolution of watershed habitats and their communities are profoundly polygenetic. When conditions and time permitted, co-evolution entailed complex processes of adaptive ecosynthesis. More often, however, these processes were so badly disrupted by human activities that whole ecosystems have degraded and collapsed in a calamity of erosion, salinity and pastoral desertification.

This chapter begins with the premise that rangeland watersheds are complex open systems uniting dynamic living communities in ways that are inherently unpredictable. Because everything in a watershed is connected functionally by living communities through energetic processes, ecological food chains and complex spatial relationships, closed system methods are scientifically invalid as a platform to study rangeland watersheds. Complex open system geosciences are required to (a) understand the ecogenesis of dynamic living communities, (b) diagnose the ecological status of habitats, communities and ecosystems and (c) provide strategies and solutions for restoring the Huang He headwaters region.

13.2 Concerns for the Health of the Upper Yellow River and Its Rangelands

The Qinghai–Tibet rangelands are high-altitude regions traversed by the tallest mountain ranges on the planet and dissected by some of the largest rivers. Because these mountain rangelands are the birth place of Asia’s most important river systems, they are known as the *Reservoir of Asia*. Though geographic extremes are characteristic features, these are not isolated or remote regions, for the Qinghai–Tibet rangelands are the crossroads of Asia with a cultural heritage of human occupation extending back to the last Ice Age.

The Huang He is known as the *Mother River of China* ~ reflecting its geographic location and cultural importance in the northern heartland of Chinese culture. With a history of repeated episodic floods, the Huang He has become better known by another epithet ~ *China’s Sorrow*. There is a tragic irony underlying the dual epithets, one that demands attention from communities living along and depending on the River. For the Huang He is not happy nor healthy: China’s Mother River is no longer capable of serving key ecological or hydrological functions required of living rivers. Even in her remote headwaters regions, essential life support systems are succumbing to human-induced salinity and pastoral desertification. The warning signs are widespread. Unless unsustainable land use activities are curtailed, she could die.

To explore how this situation arose and to better understand human cultural impacts, in our chapter we investigate the origins and evolution of watershed habitats and ecosystems in the Huang He headwaters (Fig. 13.1). The focus is on how habitats and ecosystems have adapted to and evolved with human activities since people settled the region during the last Ice Age. Our chapter is presented in three parts from the combined perspectives of (a) watershed ecography, (b) cultural ecology and (c) resource economics. For the most part, our chapter summarises rangeland research revealing how Tibetan, Mongolian and Islamic pastoral cultures inhabiting the headwaters region have transformed their mountain rangelands and disrupted watershed ecosystems in critical ways that aggravated droughts and floods, and induced pastoral desertification.



Fig. 13.1 The Huang He headwaters region lies mainly between 3000 and 5000 m asl. The region has an altitude range from over 6000 m (Maqen Kangri 6282 m) to below 3000 m (Longyangxia Reservoir lies at an elevation of 2600 m asl). The heterogeneity of the region's terrain includes deep river gorges, high rugged mountains, close knit hills and valleys and wide open intermontane basins. Given the region's long history of human occupation, the cultural landscapes of the region are comprised on polygenetic habitats and communities reflecting many millennia of human impacts shown on the satellite image (*left*), the headwaters region has lost so much of its forest and woodland communities that it is commonly described as a region of natural grasslands. The region is highlighted on the physiographic map (*right*)

13.3 Approach and Methods

The critical thing to remember about watershed systems is that the rivers, the hill-slopes, the mountain-tops, and the flood formed bottom-lands, are really all part of one watershed system.

All are integrated with each other (Curry 1976).

The approach, methods and perspectives of complex open system geosciences are integrative, synthetic and geospatial. While intractable mathematics can represent energy flows and chaotic behaviour, the geospatial approach is more widely comprehended. This entails gradually piecing together watershed habitats and their communities with their meteorological energies. It integrates the cultural heritage and histories of human activities and assesses their cumulative resource impacts and interrelationships. Through this, a comprehensive, unified assessment is possible, revealing the underlying ecographic patterns and ecological processes that drive dynamic ecogenesis.

Complex open systems scientific methods were introduced to the West by the transdisciplinary team which developed the Atom Bomb in the mid-1940s. The methods were later developed for more peaceful purposes by Russian Nobel Prize winner Ilya Prigogine, his German contemporary Ferdinand von Bertalanffy, and subsequently by North American resource ecologists Clive Holling and Carl Walters (Tane 2009). These principles contrast starkly with the analytical and statistical methods and perspectives of closed system sciences applied by Newton,

Darwin and eighteenth-to-nineteenth-century physical sciences, where time is assumed to be fixed and constant in order to allow linear cause-and-effect logical analysis. Closed system assumptions are strictly invalid when studying complex open systems with dynamic living communities such as watershed ecosystems. Alpha-numeric closed system sciences are unable to reveal the complex spatial relationships, feedback links and resilience thresholds that impact upon habitat conditions and the collapse of ecosystems.

In healthy functional ecosystems, suites of habitats are characterised by synergistic ecostructures. Elsewhere, when human activities and their impacts diminish vegetation cover and degrade soils, they disrupt ecological processes and the heat/water balance of watersheds. Spatial discontinuities, time lags and energy fluxes impact upon their dynamic behaviour. By allowing solar radiation at ground level to reach critical levels, sunburn, soil erosion and salinity inevitably lead to human-induced desertification (Tane et al. 2014).

To help clarify our scientific perspective, the literature review of the Qinghai–Tibet Plateau by Harris (2010) is considered to reflect an Anglo-American perspective of pastoral rangelands that applies closed system scientific thinking. While Harris provides a useful critique of pastoral rangeland research, we consider his review to be flawed by mistaken assumptions and significant omissions, thereby generating unreliable and misleading conclusions.

Transdisciplinary geosciences are gradually revealing how the complex processes of ecogenesis in the Huang He headwaters region have been driven mainly by anthropocentric processes. Since Harris published his critical review, widespread desertification in the Qinghai–Tibet rangelands has been referred to as a global calamity by Tibetan religious leaders and UN agencies. The desertification dilemma is no longer doubted, though the reasons for its occurrence continue to be debated.

For clarity, an overview of open system scientific methods applied in this study is outlined below. A summary of the steps entailed in such analyses is presented in Table 13.1 to distinguish the methodology employed from the closed system science approach of Harris (2010) and others seeking scientific explanations in terms of linear causality.

13.3.1 Scientific Methodology

The scientific methodology used in this study was developed over 30 years (1973–2003) in transdisciplinary studies of rangeland watersheds in North America, Australia, New Zealand, India and China. Referred to as *Eco³ Sustainability Audits* (Tane 2009; Tane et al. 2014), this method is employed for assessing watersheds for compliance with international law for sustainable development and environmental protection (UN Agenda 21). *Eco³ Sustainability Audits* integrate watershed ecography, cultural ecology and resource economics in strategic steps and sequences that feed back on each other. The sequence of steps cannot be altered or reversed without compromising scientific validity (Tane and Nanninga 1992, 1995).

Table 13.1 Heuristic modelling of rangeland ecosystems

Stage 1
1. An open invitation to conduct field-based open systems research from a host agency was necessary to provide a suitable foundation for managing the research programme and undertaking the field studies. In this case, Qinghai University research leaders invited the lead author to conduct a reconnaissance watershed audit of the Huang He headwaters.
2. The next step involved extensive reconnaissance surveys and field studies over five years encompassing all four seasons. This involved traversing the headwaters region repeatedly to observe, read and record the cultural ecography, watershed ecology and resource economies of the region (Fig. 13.2). The transdisciplinary method employed was empirical, practical and applied. An overview of the rangeland geography, cultural ecography and watershed ecology was compiled from field surveys before undertaking any desktop studies.
3. The third step was comparative research of the geographic, ecological and meteorological conditions to construct a suite of geospatial models representing potential watershed ecosystems. Visits to village communities, sacred sites and religious temples were important in establishing the cultural framework for setting the cultural ecography parameters. A visit to Kumbum Lamasery near Xining provided a very useful introduction to cultural parameters. Repeated visits to archaeological archives and museums were important. Attending cultural celebrations like public festivals and traditional Tibetan family weddings was also rewarding for developing the ecographic framework.
Stage 2
4. Desktop research reviewing the literature and scoping research followed after the first stage was completed.
5. To reconcile assumptions and conflicting scientific opinions, the second-stage field work incorporated mountain traverses, valley transects and specific site inspections to produce topographic catenas of habitats and their communities, to generate analogue models of watershed ecosystems and to establish benchmarks for ongoing monitoring purposes.
6. The sixth step was to formulate specific topics for presentation and reporting, making preliminary presentations to colleagues and postgraduate students; and preparing short essays on specific themes.
Stage 3
7. Addressing challenges, disagreements and disputes. This required additional desk top research on topics that remained equivocal.
8. Clarifying and resolving the situation empirically was the business end of the project. Further field work was required to address and resolve several issues.
9. Preparing the field report and manuscript with references. This was supported by a three-way review by professional peers, academic referees and community representatives.

Note The three steps were repeated several times before resolving issues with the highest uncertainties. Readers will note that the progression of stages reverses the order normally used by closed system scientists, who generally begin with a hypothesis, complete desk top research; and engage in statistical sampling to test their hypothesis. Field work is usually undertaken after the hypothesis is formulated and desktop research completed. While this approach is suitable for analysing closed systems like machines, linear cause-and-effect analyses are scientifically invalid methods when studying complex open systems incorporating dynamic living communities

The scientific methodology involved transdisciplinary teams engaging in repeated field surveys using skills and technologies developed for complex open system geosciences. For best results, superior field-based skills are required in surveying and mapping habitat/regolith relationships, followed by the application of geospatial technologies to model ecosystems and their meteorological processes.

The approach follows international land evaluation methodologies developed by UNESCO from the 1960 to 1990s for international watershed programmes (Holling 1978; Tane 2009) and refined for China's situation in audits of Lake Poyang (Tane and Yu 2002) and reforested watersheds on the Loess Plateau (Tane et al. 2014).

To avoid scientific bias and prejudicial perceptions, academic hypotheses and theories (along with existing alpha-numeric knowledge) are sidelined until after primary field work is completed. This enables a clear, open mind capable of strategically observing and assessing watersheds ecographically, ecologically and economically. Contemplative observation and recording (Wilhelm 1962; Watts 1972) is followed by heuristic, learning-by-doing experiments to observe, see and read terrains without mental filters or preconceptions (Walters and Holling 1990).

13.3.2 Geographic Scales for Studying Watershed Ecosystems

The lack of accurate, up-to-date true image mapping made it necessary to undertake extensive field investigations (9 field trips over 5 years) to collect sufficient information to complete this review. Figure 13.2 shows the routes taken. Transects and traverses were carried out at strategic locations and repeated several times at key sites.

Satellite imagery was helpful in gaining a geographic overview. However, the available satellite imagery lacked the scale, accuracy and image resolution necessary to identify and map habitats reliably. Scale issues are critical when mapping habitats and classifying landforms and terrains in mountain rangelands and river floodplains (Tane and Nanninga 1992, 1995).

Continental scale mapping (>1:1,000,000) gives the impression the headwaters region is part of an extensive high country plateau with low relief. Although continental scale studies (>1:500,000–1:1,000,000) provide broad impressions, they cannot capture or represent watershed communities or their habitats reliably. For a century or more, the Sanjiangyuan region combining the headwaters of the Huang He, Yangtze and Mekong rivers has been described as part of the Qinghai–Tibet Plateau. This assessment is induced by using inappropriate cartographic scale maps. At geographic scales used for landform studies (1:100,000–1:250,000), the impression of plateau landforms disappears and diverse suites of mountain rangeland, river valley and intermontane basin landforms are revealed.

Nor is it possible to extrapolate reliably by sampling local sites. Microstudies (<1:1000) reveal details of local idiosyncrasies. However, because rangeland watersheds are dynamic open systems with highly variable meteorological conditions and spatial heterogeneity, results from microstudies cannot be extrapolated to larger geographic areas such as river floodplains, mountain watersheds or rangeland regions. The complex meteorological conditions, diverse geomorphologies and heterogeneity of habitats and ecosystems make such predictions unreliable.

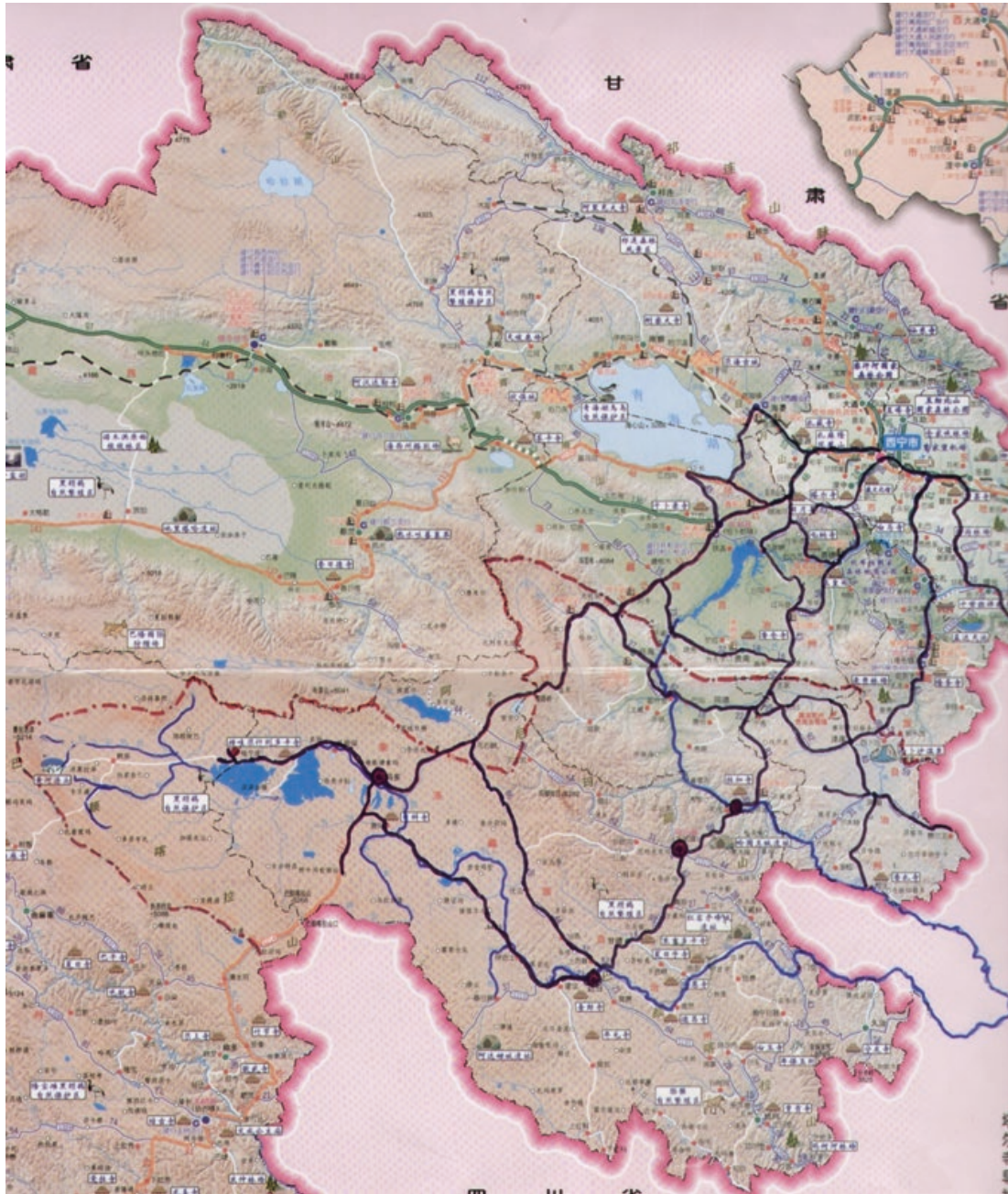


Fig. 13.2 Field work routes and site locations. Extensive field surveys and site observations undertaken with an open contemplative mind, and conducted over several years through all four seasons, were required

Field studies of watershed habitats and ecosystems are typically carried out at cartographic map scales from 1:5,000 to 1:20,000 in order to achieve final mapping scales from 1:25,000 to 1:100,000. At 1:100,000 scales or greater, the minimum map unit (>10 ha) does not allow for accurate or reliable mapping of critical riparian ecotones and the edge habitats that play such an important part in watershed ecosystems. Often just a few metres wide, riparian ecotones and their terraqueous ecostructures play crucial roles in the overall performance of watershed ecosystems (Naiman and Descamps 1990; Tane 2009; Tane et al. 2014; Tane and Williams 1999).

13.4 Part 1: Watershed Ecography

Asia's *Rangeland Reservoirs* include the headwaters of the Huang He, Yangtze, Mekong, Salween, Irrawaddy, Brahmaputra, Ganges and Indus rivers. These rangeland watersheds sustain hundreds of millions of people from diverse ethnicities. Political boundaries that separate the region into several countries result in fragmented governance of critical watershed systems.

The north-eastern sector is the Sanjiangyuan region in Qinghai Province. It contains the headwaters of the Huang He, Yangtze and Mekong rivers. To understand how Tibetans (and much later the Mongolians and Muslims) with their domestic herds of hardy ungulates impacted on the Huang He headwaters requires understanding the origins and evolutions of watershed habitats and ecosystems. We begin by examining the watershed ecography (Bardon 1991; Sveiby and Skuthorpe 2006; Tane 2009; Tane and Nanninga 1992) and ecographic relationships with ecological energetics and microclimate ecotypes in the headwaters region.

13.4.1 Watershed Ecography of the Headwaters Region

The headwaters of the Huang He lie in central Asia between 33 and 36°N where solar radiation levels are very high, well above minimum levels for cultivating crops. Elevated to 3000–6000 m asl, the climate and conditions of the headwaters region are much cooler and more challenging than their lowland-latitude equivalents. In these high-mountain districts, ecosystems forged by cultural activities and human impacts over millennia may seem improbable. However, a raft of evidence is revealing Mesolithic pastoral nomads settled the region during post-glacial warming from as early as 10,000 years ago onwards (Kaiser et al. 2007; Aldenderfer et al. 2011; Mieke et al. 2014; Han et al. 2016, Chap. 12). By 8800 years BP when warmer conditions made the climate even more suitable for human settlement, substantial tracts of cool temperate woodlands and forests growing on warmer hillslopes and in mountain thermal belts were being cleared by Tibetan settlers (Mieke et al. 2008, 2009, 2014).

While such high-altitude habitats may appear only marginally suitable for human occupation, Tibetan settlements were consolidated by cultivating barley and domesticating yak, among other hard-hoofed animals (horses, ponies, sheep and goats). The yak is arguably the toughest, most versatile grazing ungulate globally. Yak can graze at elevations above 5000 m asl, well into alpine zones. They are good swimmers capable of crossing rapids, icy rivers and lakes. They also have the climbing agility of mountain goats. The yak is the totemic animal of Tibetan culture. Together with barley, they form their basic resource economy (Fig. 13.3).

The rangelands of the Huang He headwaters descend towards the east and north in stepped suites of open intermontane basins separated by steep mountain ranges, dissected by stream valleys and river gorges (Weiner et al. 2003/06, refer Brierley



Fig. 13.3 Grazing livestock combined with growing barley are the economic base of Tibetan farming systems

et al. 2016b, Chap. 3). Emerging from discharge springs and small streams on the footslopes of Yagradadze Mountain (5214 m asl) and Bayan Har Mountains (5266 m asl), their spring-fed streams unite to form a multitude of ponds and streams in the open-basin terrains between the ranges. By the time they reach Zhaling Lake, the streams have grown into a small river forging a curvilinear network of anabranches and distributary swales within an episodic floodplain reflecting glacial outwash origins.

After passing through two large sediment retention basins occupied by Zhaling and Eling lakes (4200 m asl), the course of the river is diverted southwards by a mountain block downstream of Maduo (Golog Zangzuzie Hizou). The river then travels in an easterly direction parallel to the Anyémaqén Range, exiting into Sichuan and Gansu provinces, before the river cuts through the ranges and heads back north into Qinghai to enter Longyangxia Reservoir. In its wandering course, the Huang He displays wide-ranging geomorphologies reflecting diverse geology and hydrography.

13.4.2 Rangeland Meteorology and Microclimatic Considerations

Meteorological processes prevailing on the Qinghai–Tibet rangelands influence weather conditions across much of Asia (Zou et al. 2014). Solar radiation and summer heating of the Qinghai–Tibet rangelands generate high-pressure systems that draw in warm moist air flows from the Indian Ocean (Weiner et al. 2003/06, refer McGregor 2016, Chap. 2). The reliability of the monsoon rains ensures food security for much of Asia. It comes at a huge cost including episodic and periodic floods. Unsurprisingly, climatic conditions and their underlying meteorological processes have played a major role in the ecogenesis of Qinghai–Tibet’s mountain rangelands (Ruijun 2006). Major drivers of regional climatic conditions, meteorological processes and climatic conditions also affect local microclimates.

Each summer warm moist air masses flowing in from the Indian Ocean are pushed high into colder atmospheric realms by central Asia's mountain rangelands, generating orographic rainfall measured in metres. Located on the lee side of parallel mountain ranges, the Huang He headwaters occupy rain shadow areas receiving residual rains from the monsoons, sometimes as little as 300–400 mm per year. Annual rainfall is quite variable; indeed, average rainfall is an unreliable ecological indicator of moisture availability and ecosystem potential in most mountain rangelands.

Another feature of the monsoons has far-reaching implications. Warm moist air taken up from the Indian Ocean also contains small amounts of sea salt. In wetter Asian climates, dissolved sea salts falling with rain are progressively diluted and leached out, without creating a serious problem. However, in low-rainfall districts like the Huang He headwaters, the situation is very different. Dissolved salts leach through the soils, accumulating in senescent clay layers. Salts are safely stored so long as they are retained within these clay layers. In drier intermontane climates subjected to soil erosion and pastoral desertification, however, huge loads of salts may be released as soils are eroded, exposing subsoil layers that become desiccated and dry out. Leaching of salts creates salinity hazards. With advancing pastoral desertification, tonnes of salt are flushed out of the cracked and desiccated clays, making soils and water supplies salty and unsuited for human consumption and most farming purposes. Severe dryland and stream salinity may ensue (Tane 1996; Tane and Andrews 1998).

At local scales, co-evolving mosaics of microclimates are so complex and divergent that normal climate measures like average rainfall and temperatures become unreliable indicators of habitat conditions or ecosystem potential. Making the situation even more complex and uncertain, human-induced changes to the heat/water balance at local and regional scales mean that each watershed habitat has unique microclimate attributes.

As a rule of thumb, watershed ecologists mapping habitats and their vegetation communities in mountain rangelands consider plants to obtain one-third of their moisture requirements from measurable precipitation, one-third from the direct assimilation of dew, fog, mists and low clouds, and another third from near-surface aquifers that continually wet soils. In any particular location, the actual proportions may vary considerably.

Highly heterogeneous rangelands, with variable slope and aspect conditions, experience equally variable solar energy inputs and wind exposure rankings for each and every habitat. When combined with dynamic atmospheric heat/water processes, it quickly becomes apparent that mountain rangelands and their intermontane basins have high levels of meteorological heterogeneity and uncertainty (Zou et al. 2014). This condition effectively diminishes the usefulness and reliability of normal climate indicators such as average rainfall and median temperatures.

Similar difficulties are faced in classifying soil conditions or assessing vegetation communities. As a result of variable meteorological and topographic conditions, habitats and their microclimate conditions may change within metres. In detailed studies of watershed ecosystems, statistical quadrant or transect sampling

can miss critical riparian soil ecosystems completely (Tane and Williams 1999). In the headwaters region, geographic heterogeneity is so diverse and the meteorological energetics so complex that grouping large areas into a single climate, soil or vegetation category is very misleading. Terrain types, meteorological processes and climatic conditions in high country rangelands are so spatially variable that it is necessary to investigate microclimate ecotypes at the habitat scale to achieve acceptable levels of accuracy and reliability. Comprehensive mapping and modelling of habitats and ecosystems are required to gain a reliable assessment of microclimate conditions.

Generally speaking, several interacting terrain influences affect meteorological processes in mountain rangelands:

- (a) *Altitude and exposure* at higher elevations found in the Huang He headwaters (>4000 m asl) have incoming levels of solar radiation that are more than twice that of lowland terrains at the same latitude (Ruijun 2006). This has serious consequences where vegetation cover is short or absent. Sunburnt soils become a serious problem as soil organic matter is oxidised and volatilised, leaving desiccated and mineralised skeletal soils. At the same time, readings are lower for atmospheric pressure, air density, oxygen content and atmospheric moisture (Ruijun 2006).
- (b) *Solar aspect and slope* affect local climates by increasing/decreasing solar energy $\text{m}^{-2} \text{year}^{-1}$. In the valley bottoms above 3500 m and on exposed ridges and meadows above 4500 m subalpine, severe cold air exposure and frost hollows are typical conditions. On mountain mid-slopes with sunny aspects, more temperate conditions are found in well-sheltered sites creating solar belts and thermal basins. This produces a vertical mosaic of highly diverse habitats with widely varying microclimates.
- (c) *Water stored in aquifers/biomass and atmospheric humidity* is intricately linked to microclimate conditions in dynamic ways that vary daily. Water stored in biomass and atmospheric humidity are important regulators of heat/water cycle dynamics underpinning local and regional climates (Kravcik et al. 2007). Wetlands, forests and woodlands can absorb large amounts of solar heat energy without heating the ground surface, by converting the incoming solar energy to latent heat of evapotranspiration. This process moderates temperature extremes in habitats with substantial water storage and taller vegetation biomass. By comparison, shorter terrestrial grassland communities do not perform well in this respect. Lacking the buffering effects of large amounts of water stored in their biomass, the ground heats and cools more rapidly. Unable to maintain sufficient moisture to assimilate incoming solar energy, grassland habitats heat up quickly during sunny days and lose their warmth more rapidly during the night, resulting in higher frequencies of radiant frosts, temperature extremes and soil permafrost conditions. Significant spatial and temporal differences in microclimate, vegetation and ecosystem attributes are typical of habitats in the Huang He headwaters.

13.4.3 Microclimate Ecotypes

Microclimate ecotypes commonly occurring in the headwaters region trend from temperate forests, woodlands and shrublands (up to and over 4000 m asl) through subalpine frost hollow and exposed ridge ecotones, to alpine and nival zones of permanent rock and ice. In the upper reaches, forest and woodland ecotypes are restricted to habitats and hillslopes with good solar access, moderate shelter and good cold air drainage. Frost hollows with subsoil ice are common in valley floors above 3500 m where they are (a) constrained climatically by severe cold air drainage, (b) greatly diminished biomass and (c) depleted water storage in near-surface aquifers. These factors result in more frequent and widespread freezing soil conditions.

Extensive tracts of temperate zones in the Huang He headwaters are ecologically capable of sustaining self-regenerating shrublands, woodlands and forests. Above the cold valley floors, on hills and mountain slopes with sunny aspects, thermal belts and solar basins receive enhanced levels of solar energy which moderate temperatures. Solar energy is stored in the terrain during warm, sunny periods and released during colder periods, greatly reducing the constraints and impacts of colder weather on soil and vegetation communities. Field surveys revealed the tree line extends up to 4400 m asl on sunny hillslopes at 35° N. On colder southern hillslopes, the tree line may be as low as 4000 m asl. Forest, woodland and shrubland ecotypes are still partially visible in many headwaters districts; from remnant trees and forests, as well as ecological indicators, including pioneering shrubs, fungal soils and wood charcoal in buried soils (Miehe et al. 2007; Opgenoorth et al. 2010).

13.4.4 Vegetation Communities and Tree Zones

In the Huang He headwaters, true alpine zones are restricted to the high mountain rangelands above 4500 m, giving way to subalpine meadows and rocky talus and scree with shrub communities. The only nival zones in the headwaters region are restricted to the mountaintops of Maqen Kandri and other peaks over 5500 m. As very few glaciers feed into the Huang He, glacier discharges are rather insignificant (refer Huang et al. 2016, Chap. 4).

Below the alpine zones, the ecological “tree line” forms an ecotone that is more than 100 m wide in most places. Subalpine ecotones separating forest and woodland communities from alpine areas were found between the upper woodland belt (4400 and 5000 m asl) with the elevation for the highest shrubland sites, depending on slope and aspect, solar access and wind exposure. Sheltered hillslopes with sunny aspect supported subalpine ecotone communities up to 5500 m asl.

From field evidence, a general model of climatic climax vegetation communities for the Huang He headwaters was developed. It is consistent with the generalised model of rangeland tree belts published by Miehe et al. (2007). Field surveys

revealed an intricate tapestry of microclimate ecotypes generated by highly variable rangeland terrain types each with different altitude, slope, aspect and exposure conditions. A generalised model of the microclimate ecotypes and their ecological vegetation communities for the headwaters regions is shown in Fig. 13.4.

The geographic distribution of “climatic climax” or “potential ecosystem” grassland communities are now difficult to demark on the Qinghai–Tibet rangelands, as a result of widespread habitat degradation and transformation of vegetation communities resulting from many millennia of pastoral grazing (Miehe et al. 2014). Once again it is necessary to turn to ecological indicators.

Natural grassland communities co-evolve with soils containing nitrogen fixing rhizobial bacteria on which they rely for the uptake of nutrients. Communities dominated by rhizobial bacteria are most common in terraqueous habitats: the scientific ecological description for “wetlands”. In terraqueous habitats, the decomposition of accumulating organic matter is primarily a bacterial process. Bacterial soil types typically develop in wetlands, such as bog-flush meadows and seepage swales, where terraqueous conditions inhibit fungal communities.

Wetland terrains were once much more widespread on the Qinghai–Tibet rangelands (Gao et al. 2013). Before succumbing to the cumulative impacts of hard-hoofed grazing animals, which destroy critical cryptogam bioseals regulating the release of aquifer springs and groundwater mounds, most grassland meadows were terraqueous not terrestrial habitats. The widespread occurrence of relict black soils rich in organic materials, so commonplace on terraqueous footslopes and river floodplains is an ecological indicator of prior terraqueous habitats in which bacteria dominated plant-soil nutrient cycles.

By comparison, the nutrient cycles of woody plant communities such as shrubs, trees and forests depend on soils dominated by fungal mycorrhiza. The widespread occurrence of fungal soils occupying terrestrial habitats in the Huang He headwaters region points to an ecological heritage of woody plant communities. Because the prevalence of fungal habitats is usually considered detrimental to the health of grazing livestock, in the Qinghai–Tibet rangelands woody weeds and fungal soils are ranked among the main “pastoral problems”. From an ecological perspective, fungi and their mycorrhizal communities are ecological indicators of prior shrublands, woodlands and forests.

In valley depressions kept free of grazing livestock, terrains are more inclined to be dominated by terraqueous habitats that generate organic soils and wetland meadows. Trees and forests do not regenerate readily in these depressions because wetland habitats tend to favour bacterial rather than fungal soils required by woody communities. The exception to this is the elevated river formed floodplain levees, which are able to support hardy willow communities in areas such as the Zoige Basin (Brierley et al. 2016b, Chap. 3; Yu et al. 2014). Wherever wetlands are grazed, slowly but surely they are drained, degraded and dehydrated into terrestrial habitats, increasing the likelihood of “permafrost” conditions. This aggravated permafrost predicament is now characteristic of many low-lying valley and intermontane basin terrains.

Wherever soil and vegetation biomass are reduced and degraded, and aquifers and wetlands are dehydrated, the normal heat/water energy cycles that moderate microclimatic conditions are severely disrupted and rendered dysfunctional. Consequently, the ground heats up excessively during the day and cools down excessively at night, leading to human-induced permafrost conditions. The prevalence of permafrost conditions in lower lying terrains (below 4000 m asl) is more likely than not an ecological indicator of severely degraded valley floodplains and intermontane basins.

As a result of freezing cold air drainage, radiant frosts and frost hollow effects, riverine habitats in higher-altitude floodplains of the Qinghai–Tibet rangelands (above 4000 m asl) are commonly subjected to subalpine microclimate conditions that support wetland communities such as bog-flush meadows, chains-of-ponds, distributary channels and floodplain swales with herbs and grasses. Dwarfed shrubs and willow trees are only likely on more elevated sites.

Below 4000 m, the floodplain basins and river valleys contain a tattered tapestry of remnant wetlands among severely degraded pastures with planted trees showing browse and graze damage. These relationships occur even where attempts have been made to fence out grazing animals.

13.4.5 Animal Resource Ecography of Grazing Flocks and Herds

Pastoral communities in the Huang He headwaters graze herds and flocks of yak, sheep, goats, horses and cows. These hard-hoofed animals have been bred and grazed in flocks and herds for so long and so extensively that they have induced short, tough “golf course” grasslands throughout the headwaters region (Miehe et al. 2009, 2014). Shown in Fig. 13.5, there are also many areas where selective browsing and grazing habits have induced a wide range of unpalatable poisonous and thorny plant communities.

The biology, ecology, habitat and husbandry of yak, as well as its place in Tibetan culture, are well reported by Weiner et al. (2003/06). Arguably the yak is the hardiest, toughest, very agile and most versatile of all hard-hoofed, browsing and grazing animals. It is unsurpassed for its ability to access and browse, graze, track, trample, muck and pug, climb and swim to access all sorts of edible vegetation. Only the most poisonous of plants repel the yak. They can access virtually all areas. They plough up terrace edges with their horns, wallow in wetlands and congregate in herds at critical aquifer discharge zones. They are truly remarkable rangeland engineers, albeit lacking ecological foresight of the damage they generate.

By comparison, Mongolian communities in the Huang He headwaters are readily identified by prominent statues of their distinctive, dramatic “fire” horses ~ super horses able to traverse hundreds of kilometres in a day carrying a heavy load ~ notably a mounted warrior with armour and sword. Shown with sun symbols displayed prominently, these “fire horses” were the horses ridden by their

Fig. 13.5 Golf course pastures in the headwaters region are being gradually invaded in many places by poisonous plants and thorny shrubs



greatest warrior kings. Horse and pony pastures were once connected by an intricate network of hoof-hardened trails and roads.

As the totemic icons of Tibetan and Mongolian cultures, the hardy yak and fire horse are revered in ways that can only be fully appreciated by traditional

Shamanist cultures (Fig. 13.6). On the other hand, minority Islamic communities in the headwaters region follow the Old Testament edict that only those who sacrifice sheep or goat to God are welcome in Heaven. Islamic communities graze flocks of sheep and goats wherever they can, including in their towns and villages. The landscapes of Islamic communities are readily recognised by the intricate criss-cross patterned tapestry of sheep and goat trails carved into the soils.

13.4.6 Habitat Indicators: Water Birds, Amphibian Reptiles and Raptors

Remnant and relic aquatic and amphibian fauna in the headwaters indicate that wetlands and water bodies were once more plentiful. In remoter areas of the headwaters, in terraqueous discharge seeps in thermal zone footslopes, amphibians such as frogs and geckos are still common.

Water birds were observed in relatively lower numbers than expected for healthy high country watersheds with arrays of aquatic and terraqueous habitats. Geese, herons and crested grebes are locally common, though not numerous in summer. Water fowl relying on riparian ecotones and other wetlands have been seriously impacted by hard-hoofed livestock pugging, tracking and trampling their nesting and feeding habitats. The grebe's floating nest has helped it survive better than most (Fig. 13.7). Water birds and pasture birds are predators of insect pests. Their droppings provide biologically active fertiliser. Birds and insects play crucial roles in nutrient transfer processes particularly between high-nutrient riparian zones and low-nutrient slopes, spurs and ridges. Healthy populations of birds and insects redistribute significant loads of nutrient on lands they occupy and range over.

Raptors such as eagles and falcons are sacred birds in Shamanist cultures. Falcons were once used for hunting game birds, hares and rabbits, though this is now rare. Eagles are top predators. They perform multiple ecological functions from predating small mammals such as pika, vole and rabbit, scavenging livestock carcasses, to devouring human bodies dissected on hilltops near Tibetan towns. Given their role, eagles have unique spiritual status.

There are still abundant eagle populations present in the upper headwaters region near Maduo. Old telegraph poles retaining their crossbars have been adapted by eagles to make their nests and roosts. In recent years, government authorities have re-erected old telegraph poles in deforested districts to increase nesting habitats for eagles. This action reflects as much as anything the loss of trees and forests for eagle nesting habitats. Before the trees and forests were consumed, the bodies of deceased Tibetans were burnt on funeral pyres of stacked logs in much the same way as their Nepali neighbours further south. Today their cairn-like pyres have much smaller fires intended for other social and spiritual purposes.

Fig. 13.6 Yak and fire horse statues at historic sites and headwaters towns: Latticed landscapes from sheep/goat grazing present a stark contrast to nescient romantic notions of pristine natural landscapes in the Qinghai–Tibet region cared for and tended by a spiritual people living in harmony with Nature. The animal resource ecology of grazing flocks and herds over millennia has transformed the watershed ecosystems of the Huang He headwaters into anthropocentric landscapes bearing little resemblance to original ecosystems



Lead author at the Yak Monument at Zhaling Lake



Fire horse in Henan



Fire horse at Maqen

Fig. 13.7 Grebe nests at Shining Star Lake Maduo. Gazelles browse the shoreline edges. Browsing and tugging at roots of plants erodes the riparian edge habitat, simultaneously piercing the algae/cryptogam seals that cover the silty mud which controls the release rates of ground water from nearby soils and aquifers. Piercing of ecohydraulic bioseals controls the release of water supplies stored in aquifers and soils. It results in the demise of aquifers, springs and streams. The riparian ecotone ends up desiccated, degraded and derelict



Geese grazing



Gazelle grazed lake edges



Grebe nest at Shining Star lake, near Maduo

13.4.7 Predatory Bears, Wolves, Foxes, Weasels and Snow Leopards

Tibetan and Mongolian pastoralists are keen hunters of livestock predators and edible game, often carrying guns and ammunition with them on their daily rounds. Tibetan stores in headwaters towns sometimes display guns and ammunition for sale. Wolves and foxes are prime targets for pastoral people because they predate their grazing livestock. To protect grazing livestock from predatory animals, they are guarded by aggressive, large wolf-like dogs. At night, Tibetan graziers often corral their flocks and herds in secure barns and yards for safety.

Greatly reduced numbers of predators such as bears, wolves, foxes and snow leopards means livestock can be grazed most everywhere without too much worry. And they do, from the very mountaintops, to the islands in the middle of lakes, as yak are all terrain ungulates. While this may be a fortunate situation for pastoralists, the consequences for the health of riverine ecosystems are not good, as healthy populations of predatory animals are usually necessary to maintain the health of rangeland and riparian ecosystems.

Predator–prey relationships are important for maintaining resilience and stability in rangeland ecosystems. Whether it is bears, wolves, foxes or snow leopards, flocks and herds of grazing animals are kept on the move by the presence of predators. Sick animals, careless offspring wandering away from the herd, or those lagging behind the rest are prime targets for predators. Grasslands evolving under grazing regimes where predators have been eliminated or their numbers greatly reduced should be considered as human-induced ecosystems.

13.4.8 Animals of Ecosystem Disturbances—Animals of Ecosystem Restoration

Domestic herds of hard-hoofed grazing yaks, sheep and goats are agents of radical geomorphological and ecological change, degrading and transforming ecosystems (Tane 2009; Trimble and Mendel 1995). They can be major drivers of pastoral desertification (FAO 2006; UNESCO 2009; UNEP 2010). Contrary to some people's beliefs, the social and ecological behaviour of feral ungulates, contrasts starkly with the behaviour of wild populations (Muir 1977).

Antelope, ass, deer, donkeys, gazelle, goats, sheep, yak and their close companions pika, vole, marmot, hares and rabbits are the dominant animal communities in the Huang He headwaters. While domesticated communities of hard and soft footed animals are ubiquitous, wild free-ranging populations of these companion communities are not uncommon.

Feral and domesticated animals usually keep clear of each other. The much smaller feral flocks tend to move through the terrain quickly in pulses, grazing along the way in areas free of faeces. By comparison, their domesticated counterparts slowly graze the meadow to the ground while eating through their own faeces, before moving on to repeat the ecological offence time and time again (Fig. 13.8).



Grazing deforestation erosion



Accelerated drainage from grazing



Pugging from tracking and treading



Close up of pugging from treading



Pugging riparian ecotones



Pastoral land degradation



Pastoral desertification



Pastoral desertification

Fig. 13.8 Hard hoof flocks, herds, horses and ponies are classic examples of animal-induced ecosystem disturbances. Tracks and yards become compressed hard from years of traffic. Riparian habitats and terrace edges are exposed by horns and hooves to make soil baths, as they roll around in the soil and mud. Tibetan ponies ridden by locals compress the ground along ancient mountain trails to such a degree that the trails resemble “hard surface” roads. Tracking and treading compress some soils so hard they can serve as a road without any further materials

Hard-hoofed animals are renowned road makers. A characteristic feature of Roman road construction in ancient times involved flocks of sheep compressing the road foundations. Today they have been replaced by large sheep-foot rollers towed by tractors. Softer, finer wet silty soils tend to go muddy from continuous hard hoof traffic. However, below the surface muck, hard hoofs compact *B* and *C* horizons, inhibiting aquifer recharge. Hard surfaces also accelerate rainfall runoff eroding soils and generating flash flooding (Tane 2009).

13.5 Part 2: Cultural Ecology of Pastoral Rangelands

Chinese culture evolved from animist views of the world, which hold that everything is an integral part of open living systems sustained by living water. In China, this is expressed by the term “Dao”. The fundamental nature of Chinese culture enshrining its character and disposition is expressed in the Dao de Jing, the leading text of Chinese “Dao” culture. Dao culture is the traditional animist culture of the first Chinese farmers from the time of Huang Di to modern times. Dao culture survives and thrives in Chinese communities honouring the water dragon above the hard-hoofed animals, and practicing traditional terrace farming and paddy pond terraquacultures.

Since the Legendary Kings Period around 5000 years ago, Chinese Dao cultures have recognised that pastoral grazing diminishes and destroys the watershed ecosystems on which their water-based farming system depends. From this perspective, when “*pastoral barbarians in the western regions*” destroyed the forests and woodlands of their rivers’ headwaters, watershed ecosystems were so extensively and seriously damaged, they inadvertently created a legacy of flash floods and prolonged droughts (Tane 2012). Since the times of the Legendary Kings, China has opted for the cooperative watershed farming approach of village farmers operating zero-grazing systems. No fences, gates or similar structures were needed to protect crops in gardens and farms because livestock were barn raised, and there were no grazing animals to threaten them.

The cultural intelligence of Neolithic watershed communities forged in China’s cultural heartlands produced archetypes for some of the most productive farming systems in the world (Bellwood 2005; Ruddle and Zong 1988; Tane 2009). While these systems were copied by farming communities throughout Asia and transported to the Americas and Oceania over 4000 years ago (Carter 1961), they were most unwelcome in regions where pastoral religions such as Shamanism and Lamaism prevailed, such as in the heartlands of Mongolia-Tibet. After nearly 10,000 years of open-range pastoral grazing, the resistance to Asia’s zero-grazing farming systems remains as strong as ever among pastoral cultures who revere the yak (Tibetans), horse (Mongolians), or sheep and goats (Muslim).

Tibetan, Mongolian and Muslim herders have rarely adopted barn farming with zero-grazing practices developed in the Middle Kingdom realm of China (Chang et al. 2012). Perhaps for religious reasons and preferred lifestyles, traditional pastoral communities failed to learn (or refused to adopt) the crucial lessons of rangeland ecosystems and their resource economies ~ that the productivity of pastures and the health of livestock are superior when they are confined to enclosed barns and sheltered yards, and their fodder harvested and fed to them, well clear of their faeces and urine.

The high country of central Asia is often referred to as an alpine zone climatically unsuited to arable farming with pastoralism the only realistic option (Harris 2010; Weiner et al. 2003/06). Yet Tibetans farm barley, their staple cereal, and harvest a range of feral foods and medicines which could be cultivated in their wetlands, shrublands and remnant forests. In recent years, Tibetans and other pastoral communities have turned to cultivating extensive areas for hay production. Perhaps the reasons for preferring pastoralism are more cultural than climatic.

In the collective cultural heritage and memory of grazing communities in the headwaters region, there still can be found numerous artefacts, ceremonies, rituals and recollections from early times when there were extensive habitats and terrains of terraqueous habitats, tall grasslands, shrublands, woodlands and forests. Many are carefully recorded and displayed in the Qinghai Museum, and other museums located in and around Xining. For example, the Mongolian Cultural History Museum in Henan County has a particularly valuable resource of artefacts and displays revealing how extensively rangeland habitats and ecosystems in the Huang He headwaters districts have been transformed since the Yuan Dynasty, less than 1000 years ago. A growing body of palaeo-ecological research corroborates the dramatic transformation of ecosystems on the Qinghai–Tibet rangelands by these pastoral cultures (Miehe et al. 2007, 2008, 2009, 2014; Opgenoorth et al. 2010). Older Lamaseries and sacred sites retain further evidence of the close connections between Tibetan culture and wooded ecosystems (as noted by Miehe et al. (2003) in their paper entitled “*Sacred Forests of Tibet*”).

13.5.1 Cultural Ecology of Pastoral Peoples

The cultural heritage and spiritual practices of human communities are often key factors in the ecogenesis of cultural habitats and ecosystems (Proshansky et al. 1970; Tane 2009). Cultural ecology is the study of human cultures and their communities. It entails the following: (a) mapping and describing human interactions with their home habitats (Bardon 1991; Sveiby and Skuthorpe 2006), (b) modelling ecological processes creating and evolving cultural ecosystems (Tane and Wang 2007) and (c) explaining impacts and adaptations to their watersheds and broader territories (Tane 2010; Tane et al. 2014).

The evolution of Tibetan and Mongolian pastoral cultures occupying high country rangelands in central Asia covers more than 10,000 years (Aldenderfer et al 2011;

Chang et al. 2012; Mieke et al. 2009, 2014; Opendoorth et al. 2010). From cultural iconography and symbolism displayed on their temple architecture, sacred sites and pastoral accessories, Tibetans and Mongolians have adapted and practised a special blend of traditional Palaeolithic Shamanism characteristic of central and northern Asia. As a result of their contacts with Han Chinese, during Neolithic times they incorporated an unusual blend of Dao Animist symbology, including the *tai'ji dao* symbol seen at Kumbum Lamasery and elsewhere. Subsequently, in more recent times, Tibetans incorporated their version of Buddhist liturgies and rituals delivered locally in special blends, depending on historic community and regional affinities.

As warriors with highly developed hunting and fighting skills, Tibetans and Mongolians have a reputation for disputes with their neighbours, particularly over grazing lands. As hunter/pastoralists with limited options for fresh vegetable foods, they are confirmed eaters of animal meat. From these perspectives, it is clear Tibetans are not Buddhists. They refer to themselves as Lamas and their religion as Lamaism. Until recent times, Lamaseries such as Kumbum Lamasery near Xining were educational academies and professional institutes, as well as spiritual temples. Among pastoral religions such as Lamaism and Islam, religiously proscribed pastoralism is not a farming system based on scientific knowledge. Like Mongolian Shamanism, Tibetan Lamaism and Islamic Monotheism, pastoral religions require a high degree of conformity and compliance with traditional beliefs, religious rituals and cultural values among their communities.

13.5.2 Palaeolithic Cultural Impacts—Qinghai Tibet Rangelands

The earliest recorded human occupation on the Qinghai–Tibet rangelands occurred during the last glacial maximum when cool-temperature forests and woodlands of juniper (*Juniperus genus*), fir (*Picea genus*), willow (*Salix genus*) and birch (*Betula genus*) were common on sunny hillslopes up to 3500 m asl (Han et al. 2016, Chap. 12; Mieke et al. 2003, 2007; Opendoorth et al. 2010). Post-Ice Age warming has pushed the forest tree line more than 1000 m higher, with remnants of juniper forests evident at 4900 m asl (Mieke et al. 2007). Disappearance of these woodlands and forests most likely reflects the impacts of human occupations, including the clearing of trees and forests to increase grazing areas (Aldenerfer 2011; Mieke et al. 2009; Opendoorth et al. 2010).

Archaeology of the Qinghai–Tibet rangelands places the earliest occupations in the northern extents at the Lesser Qaidam (33,000 years ago), though recent reassessments of the site suggest it may be more recent (see Han et al. 2016, Chap. 12). In the south of the Qinghai–Tibet rangelands at Chusang, the earliest occupations are dated between 28 and 32,000 years ago; a date confirmed by recent cross-checks (Aldenerfer 2011). In the north-east sector of the Qinghai–Tibet rangelands, which includes the headwaters of the Huang He, the dates are more recent. The Qinghai Lake district records human impacts from around 15,000 years ago.

*La Jia Forest**Remnant juniper trees*

Fig. 13.9 Photographs of La Jia Forest and woodland. Fire is still being used as a tool for clearing trees and scrub and any other unwanted vegetation, particularly from dry warm sites, such as sunny hillslopes, thermal belts, solar basins and sheltered gorges where fire flourishes and spreads readily in dry weather

While cultural, ecological and museum evidence points to early Palaeolithic settlements on the Qinghai–Tibet rangelands, scientific archaeology, genetics and palaeo-geography only recently confirmed from field evidence that the Plateau was occupied in the Late Pleistocene perhaps as early as 25–33,000 years ago (Aldenerfer 2011; Mieke et al. 2009, 2014; Opgenoorth et al. 2010).

While anthropocentric fire may have played a lesser role in deforestation of the Qinghai–Tibet rangelands than in other rangelands globally, considerable evidence found in buried subsoil strata reveals burnt tree stumps and woody debris (Mieke et al. 2009). Evidence for fire includes fire cairns found near villages and at sacred sites and pastoral camps, the widespread occurrence of burnt tree trunks in places where trees and forests survive, and the sight of Tibetan yak herders gathering around their bonfires in the evening. These all attest to a pastoral culture that embraced fires for many social, cultural and economic purposes, not just fuel and warmth (Fig. 13.9).

13.5.3 Mesolithic and Neolithic Cultures

The evolutionary pathways of ecosystems in mountain rangelands occupied by pastoral peoples are not only remarkable case studies in cultural ecology, they reveal the ecological dynamics of converting small populations of wild ungulates migrating over extensive territories to much larger flocks and herds of domesticated ungulates constrained by grazing boundaries. As the numbers of grazing livestock increase and competition for grazing land grows, watershed habitats, underlying ecostructures and rangeland ecosystems are slowly but surely modified and transformed into terrestrial biomes that are no longer able to serve essential functions of watershed ecosystems (Tane 2009).

Recent reviews of palaeo-ecological evidence suggest the onset of pastoralism on the Qinghai–Tibet rangelands began by the onset of Mesolithic times 10,000 years ago (Miehe et al. 2009, 2014). Evidence of Palaeolithic occupations has been largely obliterated over extensive areas by storm and tempest, episodic floods and cycles of erosion. As a result of widespread erosion, there are few sites where the aggradational history of soil terrains remains sufficiently intact to provide a chronological story. As a result, archaeological evidence cannot be relied upon for a complete picture of pastoral impacts, as the evidence has been compromised, disturbed and dispersed by episodic events and widespread erosion. The alternative is to compile the presence of human communities from surrogate sources such as ecologic and geomorphic indicators, palaeo-ecology and Quaternary research and ecographic mapping and modelling. Taken together they reveal consistent evidence of human activities and their impacts (Kaiser et al. 2007; Aldenerfer 2011; Miehe et al. 2009, 2014). By the onset of the Neolithic Age 5000 years ago, pastoralists had already induced profound ecological changes to Huang He watersheds, their habitats, regoliths, vegetation and wildlife communities.

More consistent, reliable and widespread evidence has been found of Mesolithic and Neolithic people's impacts on the headwaters region from 10,000 to 3000 years BP (Miehe et al. 2014). Mesolithic communities began clearing forests and woodlands, to expand grazing areas to accommodate their growing numbers of livestock, ponies and horses. Neolithic people's impacts included clearing woodlands and forests; burning trees, scrublands and grasslands; draining wetlands; grazing domesticated herds in critical watershed habitats; hunting wildlife; and eliminating predators. Together, these activities amounted to a major assault on the watershed ecosystems of the headwaters region.

As the Mesolithic peoples cleared and expanded their grazing lands, they came into conflict with other pastoral tribes doing the same. By the time Neolithic peoples were adapting and evolving their communities more than 5000 years ago, they were forging closer settlements in the Huang He headwaters. Competition for grazing lands in rangelands commonly grows into territorial conflicts, forging the arts and technologies of warfare between neighbouring tribes. By Neolithic times, intertribal warfare was commonplace, revealing a level of competition for grazing territory that resulted in a wave of extensive environmental impacts that transformed watershed ecosystems over large areas. Weaponry artefacts in the Qinghai Museum reveal intertribal wars were common at this time. Fatal conflicts between neighbouring communities likely reflected territorial conflicts for grazing lands. By the Tang Dynasty (618–906), the King of Tibet had amassed a large, well-equipped horseback fighting force that defeated the Tang Emperors Armies in 763 AD, taking control of the Huang He headwaters as far east as Chang'an in Shaanxi. A similar pattern of fighting activity and weapons manufacturing is presented in the Mongolian Cultural Heritage Museum at Henan County as recently as 1000 years ago, when the Yuan Dynasty was flourishing. These conflicts are reflected by increases in erosion rates from relatively low rates in the early Holocene to relatively high rates of erosion during Neolithic times through to the present (Miehe et al. 2014).

Territorial conflicts between pastoral communities indicate increasing pressure on essential resources for sustaining livelihoods: woodlands for fuel and timber, and grasslands for grazing lands. Across the world, pastoralists have displaced hunter-gatherers, followed by pastoralists fighting pastoralists and pastoralists fighting farmers over the use of key resources (Bellwood 2005). In this respect, the history of traditional watershed farming in China is a salutary lesson in human survival, for Chinese sedentary watershed farming communities were continually faced with hostile invasion by pastoral people including the Jin, Tibetans, Mongolians and Manchurians (Tane 2009; Tane et al. 2014).

In the heartland of China, a long, lamentable legacy of devastating wars between farmers and herders attests to the fact that Asia is home to both farming and pastoral cultures. Since the beginning of Neolithic China, represented by the first three “Legendary Kings” (Fu Xi, Shen Nong and Huang Di) around 5000 years ago, conflicts between pastoral and farming cultures in China have been resolved by the simple expedient of separating them by enforcing natural boundaries and building high earthen walls. Wherever possible, pastoral tribes were relocated to the western mountain regions outside the walls. This made fenced fields and gates unnecessary for Chinese farmlands.

In China’s traditional watershed farming cultures, livestock are barn raised. Zero-grazing systems were adopted and enforced. The outcomes were mutually beneficial for both cropping farmers and livestock farmers remaining within China, with both groups achieving higher production and more profit for their efforts. When Huang Di and his contemporaries came to this realisation around 5000 years ago, they undertook the pre-emptive step of separating the two conflicting cultures by expelling the pastoral communities to the far western regions and building huge walls to keep them there. It took another 3000 years of repeated conflicts between farmers and herders before the walls were expanded and linked into a series of Great Walls protecting China from invasion by pastoral grazing cultures.

From the perspectives of pastoral cultures, the ecological impacts of grazing animals are the natural and necessary consequences of land use systems proscribed by their pastoral religions. Vedic and Shamanist religions worship cows and other “power animals”, at the same time persecuting and vilifying those who cherish non-pastoral farming pathways. Ever since Biblical and Vedic times (post-4000 years BP), pastoral religious myths and dogmas have distracted from closer, objective observations of the ecological consequences of pastoral grazing in rangeland watersheds (Tane 2009; UNESCO 2009).

13.5.4 Prevailing Grazing Cultures

While Tibetans, Mongolians and Muslim minorities practise a range of spiritual and religious beliefs, they are all God fearing, meat eating pastoral farming communities. Tibetans and Mongolians practise a unique type of Shaman–Lamaism

that is intricately tied to their hunting and grazing activities. Islamic communities follow the Abrahamic religious edict, grazing sheep and goats everywhere they can.

When Tibetans and Mongolians were nomads, they followed the migratory patterns of feral ungulates and moved on with their flocks and herds before too much damage was inflicted on critical watershed ecosystems. The ecological impacts of domestic herds of grazing animals became more serious when they settled down and simply rotated their herds on the same land year after year (Weiner et al. 2003/06). This revelation is confirmed by Li et al. (2010) who commented that: “*Since the 1950’s the human population of the region has trebled, and livestock numbers have doubled. Grassland overgrazing is most pronounced in spring. It results in sparse, low and degraded cover and enhanced growth of plants toxic to livestock*”.

13.5.5 Tree and Timber Dependency of Tibetan Culture

As nomadic pastoral people with seasonal patterns of rangeland grazing, yak herders used a traditional round felt covered structure called a yurt. The traditional home of Tibetans, the yurt is a remarkable example of design and construction requiring specialty timbers. The roof cover is supported by a radial array of light and springy timber beams held in place by a circular wooden frame into which the beams are slotted. The walls are a lattice structure of crosslaced timber slats and supports. A wooden frame and door complete the yurt. To warm the yurt, an iron stove takes central place, with the chimney poking through the roof cover. Once the stove burnt fragrant juniper boughs, the knotty birch and clean burning willow wands. Now these trees are gone, the Tibetan pastoralist are forced to burn yak dung, collected, dried and stacked by Tibetan women wearing face masks to safeguard themselves from cold air and respiratory infections. Their colourful clothing embellished with amber and turquoise necklaces is strikingly beautiful. Amber is particularly cherished by Tibetans ~ derived from tree resin, amber is a cultural treasure.

Tibetan culture is reliant on trees and timber for a wide range of everyday items, from their yurt timber slat structures to spiritual flag poles which they raise annually on outstanding peaks, mountain passes and river gorges (Fig. 13.10). Wooden pegs are essential tools used for securing dogs, tethering yaks and dogs and pegging down yurts. Tibetan Lamaseries are traditionally built of timber with internal fittings and furniture made of wood. Traditional Tibetan prayer wheels are made of wood. Their spiritual altars, cairns and campsite fire pits are constructed to burn wood. In the markets and shops of Tibetan towns, there are still many traditional farming implements made of wood. At local markets, bunches of juniper boughs are sold as incense. These are not items produced by treeless grasslands. While modern truck transport now provides ready access to imported wood and timber supplies in the past Tibetans relied on local woodlands and forests for their needs.



Tent poles, wood stove, amber beads



Wooden structure (frame) of a yurt



Ceremonial flag poles



Ceremonial spears

Fig. 13.10 Photographs of Tibetan women wearing amber beads, preparing food in their wooden frame yurt. Spiritual poles, wooden implements and cairns for burning juniper are Tibetan cultural icons

13.5.6 Rangeland Deforestation

From the perspective of the cultural ecology of pastoral peoples in the Qinghai–Tibet rangelands, clearing and felling of trees and forests were traditional activities for Tibetan and Mongolian herders engaged in forging pastoral grasslands since the earliest days. This entailed using wood for fires, wooden slats for their yurts and huge timbers for their bridges and temples. Expanding their home grazing areas to their present territories was a major accomplishment. It took at least 8000 years.

The destruction of woodlands and forest ecosystems was paralleled by draining and grazing of wetland meadows and other terraqueous habitats to expand terrestrial habitats more suited as grazing areas. Incessant grazing prevented regrowth of woody communities, with the exception of unpalatable poisonous and thorny species. Today, remnants of the once widespread montane forests of fir and juniper, and woodland communities of birch, willow and buckthorn (*Sarchi*) are only found in the most remote steep hill slope and inaccessible gorges (Miehe et al.

2009, 2012). Exploitation of vegetation since ancient times has not only generated severe erosion processes, it removed forests, woodlands and shrublands from extensive areas suited to tree growth (Aldenderfer 2011; Miede et al. 2007, 2008, 2009, 2014; Opengoorth et al. 2010).

13.5.7 Transforming Vegetation Communities

Watershed habitats suiting trees, woodlands and forests have been transformed into grassland disclimax communities by combinations of dynamic activities. This includes clearing trees and forests, burning regrowth, draining wetlands and regular grazing by hard-hoofed livestock. When combined strategically, burning, grazing, taking timber and collecting woody fuel offer very effective activities for hindering woody regeneration, drying out wetlands and dehydrating watersheds (Muir 1977; Tane 2009; Tane et al. 2014).

The dehydration of terraqueous habitats and destruction of their wetland communities is particularly damaging to watershed ecosystems for they are critical surficial reservoirs for aquifers and ecostructures (Tane 2009). Once very common, intact suites of chain-of-ponds typical of healthy rangeland ecosystems are now very rare (Fig. 13.11).

Burning of rangelands is largely restricted to habitats where following a dry period, the vegetation dries out sufficiently to carry fire. This can be any time of the year in some localities, like the La Jia Gorge. Some vegetation communities maintain high moisture levels in all seasons, limiting their susceptibility to wildfire hazards and “burning off”. Open intermontane basins with extensive floodplain wetlands and water bodies may have resisted fires for long periods, until soil moisture was depleted. It is likely that habitats carrying fire most readily were the well-drained sunny hillslopes, terrestrial woodlands and temperate zone thermal belts and solar basins that once supported woodlands and forests. These were favoured camp sites for livestock, particularly in cold weather.

Selective browsing and grazing, coupled with regular tracking, trampling and treading are ecological impacts with serious long-term consequences. Typically, watershed ecosystems respond in three ways when the ecological impacts of pastoral grazing accumulate. Over time, the most palatable floras are eliminated, leaving the thorniest and most unpalatable plants. As vegetation cover is depleted and the ground compressed, Nature sends in small mammals such as pika or rabbit to remedy the ecological and hydrological damage. If grazing is allowed to continue, communities of these soft footed mammals continue to grow, eventually reaching pest proportions. Allowing grazing to continue, stimulates invasions of poisonous plants and thorny scrubland and before long, degraded and eroding soils become commonplace (Li et al. 2010, 2016, Chap. 7).

Pastoral agricultures are recognised by UN agencies such as UNESCO and FAO for their radical ecological impacts on rangeland watersheds. Pastoral grazing systems have converted whole biomes from wetlands and woody vegetation to

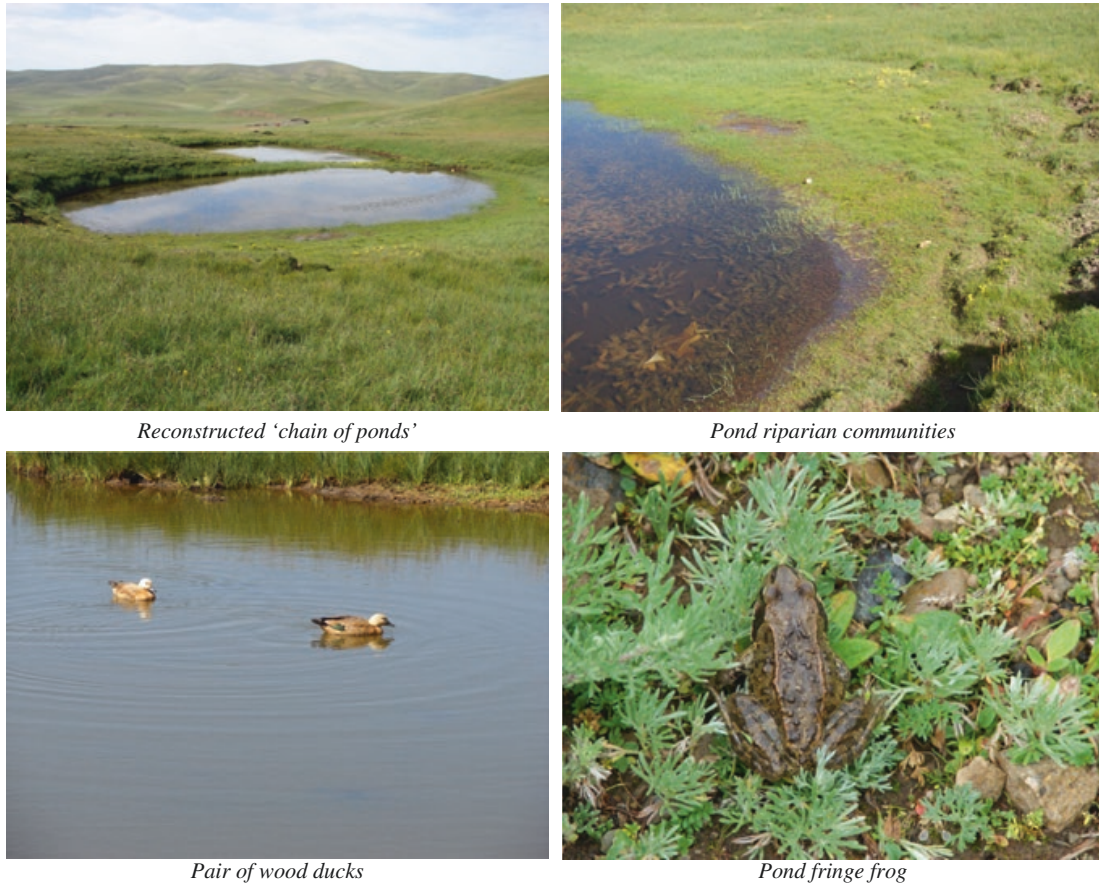


Fig. 13.11 Intact floodplain ponds are now very rare along the Upper Yellow River; they are effectively restricted to spring–pond–stream sequences in mountain rangelands. The remote rangeland saddle site east of Maduo (one of the few remaining examples) sustains a pair of resident wood ducks and relict amphibian communities. This site was partially reconstructed by a Tibetan yak farmer to help ensure winter fodder and water supplies for his livestock

dry lands with grassy vegetation, as a prelude to more serious ecological problems (FAO 2006; UNESCO 2009). From ecological perspectives, pastoral agricultures generate profound impacts with long lasting consequences for watershed habitats and rangeland ecosystems. Arguably, the most serious consequences are soil sun-burn, eroded and gullied terrains, dryland salinity and pastoral desertification.

13.5.8 Aggravating Atmospheric Aridity and Climate Extremes

Clearing trees and forests usually means habitats and their vegetation communities are transformed to much lower levels of total biomass. This in turn corresponds with greater temperature extremes above and below ground level (Geiger 1950), decreased atmospheric humidity and declining aquifer water storage (Tane 2009). In pastoral rangelands dominated by grasslands, devoid of woodlands and forests,

typically the average humidity is reduced over summer months from 50–60 % in forest and woodland habitats, to around 20–30 % for grasslands and bare ground (Geiger 1950; Tane 2009). The consequences of radical biomass reduction are severe disruptions to the heat/water balance with an increase in climatic extremes such as atmospheric aridity and climate chaos (Geiger 1950; Kravcik et al. 2007; Tane 2009). There are also serious impacts upon soil and water ecosystems.

13.5.9 Soil Indicators of Pastoral Desertification

Soils are complex living organisms that import, export and transform matter and energy. They are dynamic open ecosystems with spatial discontinuities, time lags and feedback mechanisms that generate ecological potential. Most soils are poly-genetic, meaning they adapted and evolved over time under changing circumstances. In this respect, soil systems can contain various sources of information about historic conditions including changing climatic and ecological conditions, prior communities and how they were transformed.

Atop the Qinghai–Tibet Plateau, many areas are characterised by prior terraqueous habitats and relic wetland soil ecosystems. Indicators include black humic soils rich in organic materials with gley substrate commonly associated with wetland meadows. Gley subsoils are indicators of anaerobic processes occurring during subsoil formation. They are typical in wetlands with impeded drainage.

In glaciated mountains, montane basins, river valleys and rangeland regions with deserts, transported materials, atmospheric dust and soil nutrient cycles are closely related. Alluvial, colluvial and aeolian deposits contribute to aggradational soils, building and creating new terrain layers, sometimes burying old ones completely. In eroding rangelands such as the Huang He headwaters, the Quaternary history of soil ecosystems is continually being lost to the forces of land degradation. As few areas retain near-complete soil sequences, evidence for palaeo-environmental conditions must be gleaned from other indicators of ecosystem potential.

13.5.9.1 Soil Sunburn

Soil sunburn is a serious hazard in rangeland ecosystems, as reduced vegetation biomass allows solar radiation to burn organic matter and oxidise the topsoil. The gradual reduction in the height and density of pastoral grasslands in the Qinghai–Tibet region has elevated sunburn risks and hazards to serious levels.

When organic soils are exposed to direct sunlight, their fragile organic compounds oxidise and volatilise leaving a residual mineral dust that is prone to wind and water erosion. Sunburnt, mineralised soils are a conspicuous feature of the headwaters region (Fig. 13.12). This feature of rangeland soils is sometimes wrongly blamed on climate change, when in fact it is more often a coincident

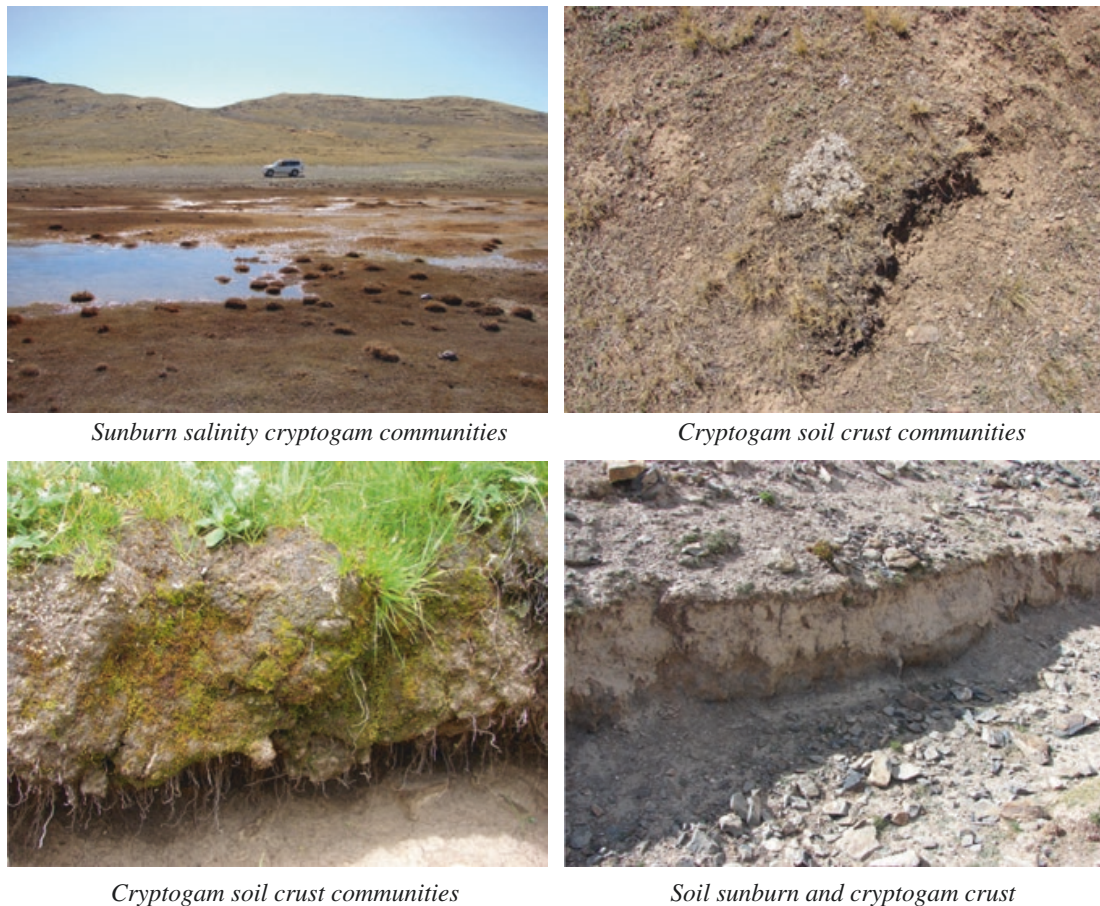


Fig. 13.12 Indicators of soil sunburn: cryptogam communities on mineralised soils near Maduo

symptom of human-induced land degradation and pastoral desertification (Tane 2009). High-altitude rangelands are exposed to some of the highest levels of solar radiation on the planet. Sunburn times for exposed human skin are measured in minutes; and so it is for exposed habitats grazed down to short swards and bare ground. Ecological indicators of severe sunburn in the Huang He headwaters region include plants with growing leaves and stems turning red and purple as a safeguard against excess solar radiation, scabby burnt bark on the sunny side of Rosaceae, scalded soils with cushion plants, very low levels of soil organic matter, mineralised topsoils and bare ground held together by cryptogam communities (Eldridge and Tozer 1997).

13.5.9.2 Soil Erosion

When intense rainfall events rake sunburnt soils with flash floods, they induce widespread soil erosion, often in association with slips, slumps and stream gullying (refer Hu et al. 2016, Chap. 5). Topsoils are stripped away, leaving skeletal subsoils with low nutrient levels. These destructive events inhibit the functionality

of watershed aquifers by removing their eco-hydraulic bioseals that regulate water flows through ecostructures and soils. As a result, aquifers drain dry instead of storing water for drier times (Tane 2009).

The incremental impacts of continuous hard hoof tracking, treading and pugging, combined with pathogenic pollution from incessant excrement, go largely unnoticed by local pastoral communities until the situation becomes perilous and soil erosion is widespread. By this time, however, greatly enlarged populations of soft footed mammals are helping to restore critical aquifer recharge/discharge dysfunctions by digging holes through the compacted ground and loading the entrance with their nutrient loaded pellets (Tane 2012). Rainwater washes the pellets into the warrens to recharge soil water and aquifers; instead of running off overland to generate flash floods loaded with nutrients. In seeping and filtering through regolith strata, recharge water is cleansed of nutrients, pathogens, salts and sediments by (a) deep rooting plants (b) ecological communities of microbiota and (c) integration into senescent clay layers (Hancock et al. 2005; Goonan et al. 2015; Tane and Williams 1999). When aquifers are recharged, they overflow, pushing fresh clean water continuously through seeps and soils, springs and streams. These elements and interactions are linked together by riparian ecostructures, thereby providing perennial water supplies to soil and plant ecosystems (Tane 1996, 2009; Tane et al. 2014).

13.5.9.3 Soil Salinity

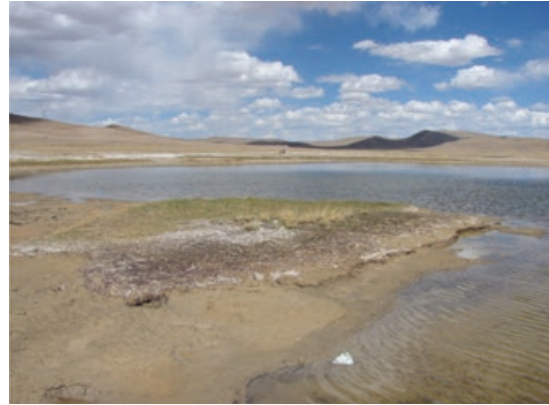
With soil erosion and severe gulying, subsoil clays are quickly desiccated. Prone to shrinking and cracking as they progressively dry out, this predicament enables water to flow through their substrata, flushing and leaching out salty wastes stored in senescent clay layers over millennia. In drier seasons, the saline solutions rise through capillaries spreading across the surface where they quickly evaporate, leaving behind white crusts of salt. These salt crusts dissolve in the next significant rainfall event to be conveyed into streams, rivers and lakes, where they accumulate to create saline water bodies. These soil salinity processes begin within a few decades of pastoral degradation and are exacerbated as grazing continues. Salinity has already reached calamitous levels in the Huang He headwaters near Maduo and elsewhere (Fig. 13.13).

Soil salinity is like cancer. It spreads unseen within the terrain until it reaches serious levels when it breaks out and spreads across the surface, leaving a trail of dysfunctional habitats and dying communities in its wake. When it reaches elevated levels, salinity kills soil and vegetation communities and pollutes waterways making them unfit for essential fresh water purposes.

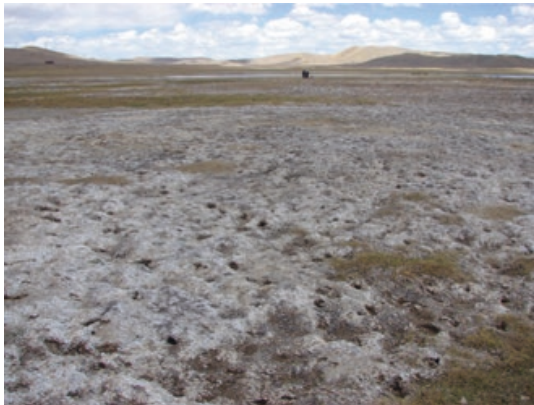
Rehydrating the terrain is the traditional proven solution to salinity management, because intact saturated clay layers effectively lock up excess salts (Tane 1996). Removing grazing animals and rehydrating the floodplain greatly reduces salinity as floodplain aquifers are recharged, soil moisture levels are enhanced, and springs and streams start running again (Tane 1996; Tane and Andrews 1998; Tane and Williams 1999; Andrews 2006).



Salinity problems in the headwaters of the Yellow River



Rangeland salinity at lake margins in the headwaters of the Yellow River



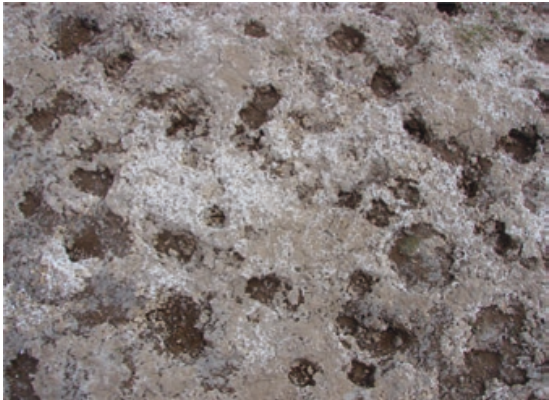
Floodplain salinity in the headwaters of the Yellow River



Riparian zone salinity in the headwaters of the Yellow River



Saline soil discharge



Salty soil crusts

Fig. 13.13 Soil salinity in the Maduo district

The Maduo district, including Zhaling and Eling lakes and the Huang He downstream, is affected by serious salinity levels. Viewed from prominent hills overlooking the lakes, historic evidence of old salt harvesting structures are evident in shallow bays. Is it possible both Zhaling and Eling were fresh water lakes in Palaeolithic times, before gradually becoming saltier and saltier as their watershed systems were desiccated and degraded by pastoral desertification?

Sunburn, soil erosion and salinity are key ecological indicators of watersheds suffering from severe pastoral desertification in degraded rangeland watersheds with a history of pastoral grazing (Tane 2009; Tane et al. 2014). Impacts of grazing, sunburn, soil erosion and salinity over hundreds of years inevitably result in extreme pastoral desertification. The consequences for aquifer recharge, storage capacity and discharge volumes are severe to fatal.

13.5.10 Disrupting Aquifer Recharge—Accelerating Overland Run-off

Rates of rainfall run-off vary considerably, depending on the nature of land use and vegetation cover. Typically, habitats in healthy functioning floodplains achieve relatively high levels of rainfall recharge to surficial aquifers. Indeed, more than two-thirds of significant rainfall events are taken directly into aquifer storage in ecologically functional rangeland watersheds (Tane 2009). As a result of slow water transmission rates through riparian ecostructures and near-surface aquifers in healthy watersheds (transmission rates measured at $<1 \text{ m day}^{-1}$), time lags and net water flux over time eliminate the deleterious effects of seasonal droughts through spring discharges, increasing subsoil moisture and stream flows (Tane 1996; Tane and Andrews 1998).

Pastoral grazing of rangeland watersheds impacts aquifer recharge/discharge processes in several ways. Tracking and treading compacts the soil surface and subsurface layers inhibiting aquifer recharge and increasing overland run-off. Pastoral grazing gradually reverses the rainfall run-off ratio with more than two-thirds of significant rainfall events flowing overland in swales and runnels, streams and rivers. The consequence of accelerated rates of rainfall run-off is a substantial decline in the recharge rate of aquifers and increased surface erosion. With aquifers starved of their recharge waters, their storage gradually declines and over time such that they can fail completely (Tane et al. 2014).

The hard hooves of grazing livestock pierce the bioseals of aquifers and ecostructures. As a result, discharge rates of aquifers are accelerated, draining aquifers dry much more quickly (Tane 2004, 2009; Tane et al. 2014). The combined outcomes of impeded aquifer recharge and accelerated aquifer discharge bring about substantial declines in aquifer recharge, storage and discharge for rangeland ecosystems. This results in perennial streams from living watersheds becoming ephemeral storm drains for dying catchments (Tane 1996, 2004, 2009). As a result, springs, streams and rivers fail. Droughts alternate with flash floods to become serious hazards, limiting prospects for sustainable human communities, as farmland degradation is followed by food and water insecurity and entrenched poverty.

Pastoral desertification typically induces a ten-fold decline in the water stored in floodplain aquifers (Tane 1996, 2009; Tane and Andrews 1998). Proven methods for reversing soil salinity and pastoral desertification incorporate zero grazing

with barn farming of hard-hoofed livestock (Andrews 2006; Tane and Andrews 1998; Tane and Williams 1999; Tane et al. 2014). As outlined below, barn farming with zero grazing is already being implemented in some districts of the Huang He watershed (eg Ninxia, Shaanxi and Shanxi) with outstanding results.

13.6 Part 3: Adaptive Management of Rangeland Economies

The evolution of habitats and ecosystems are unstoppable, ongoing processes. Consequently, unless human communities adapt and change their resource economies to reflect changing ecological conditions, they will find themselves faced with intractable resource problems. This situation looms large in the headwaters region.

In an age of dynamic uncertainty, with chaotic climates, food and water insecurity, and entrenched rural poverty, adaptive management of watershed ecosystems and their resource economies is essential (Drucker 1959; Fulmer 2000). Proceeding from this perspective, we begin to outline the necessary processes for effective, equitable and efficient governance. This is not a linear process. At each stage, the outcomes must be related back to previous stages, to ensure they were completed correctly and properly aligned to over-arching objectives.

The key steps for good governance of and strategic planning for the Huang He headwaters can be summarised as follows:

- Formulate clear, unequivocal policy priorities and plain language policy guidelines
- Undertake a comprehensive geospatial inventory of watershed habitats, communities and ecosystems
- Complete an environmental health audit of watershed ecosystems and their resources
- Develop community and regional planning strategies for sustainable development through participatory watershed programmes involving all community stakeholders in each watershed
- Initiate practical and applied watershed models with watershed communities and
- Publicise and reward successful ecological restoration through sustainable development by rewarding successful “champion teams and communities”.

When these tasks have established the necessary policies, performance parameters and successful models for sustainable development and environmental protection, then it is appropriate to address the need for integrated landuse planning for resource economies, their development and management, with safeguards in place to protect essential life support systems for all watershed communities.

In the Huang He headwaters, pastoral farming communities are facing issues such as farmland degradation and food and water insecurity. Most are a consequence of “human induced” incremental degradation of watershed ecosystems from wide-ranging impacts that can be lumped together under the label “rangeland desertification”. This is a worldwide calamity. It arises from deforestation, unsustainable pastoral agriculture activities, destructive mining and engineering works and measures, and indiscriminate use of ecotoxic agrochemicals destroying the self-healing capabilities of communities and ecosystems (Tane 2009, 2010; UNEP 2010).

13.6.1 Reversing or Adapting to Climate Change

From ecological and geological perspectives, climate change is natural, normal and probably necessary to maintain homeostasis of key ecosystems on the planet. Climate change enables co-evolution of living communities within reasonably stable environs. As a complex open system surrounded by a bacterial biosphere, importing thousands of tonnes of cosmic ice laden with galactic dusts and viral materials every day, planet earth is much more than a physical entity (Consigli 2008). Referred to as a sentient living planet by leading astronauts (Kelley 1988), planet Earth is living, dynamic, complex organism capable of significant climatic oscillations in response to major calamities (such as volcanic activity). This situation is rarely fatal because there is inbuilt resilience in healthy watershed ecosystems. The planet’s ecocybernetic system can return regional climates to moderate conditions. However, the planet’s self organising ecosystems are being massively degraded and disrupted by human-induced desertification. The outcome is chaotic climate change: an avoidable calamity largely induced by human activities disrupting the planet’s meteorological systems, notably the heat/water balance of watersheds at local and regional levels (Geiger 1950; Kravcik et al. 2007; Tane 2009). From this perspective, the primary solutions include reforesting steep lands, reviving river floodplains and restoring watershed ecosystems and ecostructures (Tane 2009; Tane and Andrews 1998).

Human-induced desertification and resulting chaotic climate changes are impacting the headwaters region in ways that are already compromising essential life support systems that sustain human ecosystems. The situation is increasingly viewed as perilous by community and spiritual leaders in the headwaters region.

Drivers of grassland degradation atop the Qinghai–Tibet rangelands are highly contested (Harris 2010; Gao et al. 2013; Li et al. 2016, Chap. 7). Qiao and Wang (2010) concluded that while the headwaters region has experienced severe ecosystem deterioration in recent decades “*there are no obvious trends for either precipitation or evaporation over the past 50 years*”. Average annual temperatures have risen by only a small fraction of a degree Celsius corresponding perhaps with the slight increase in sunshine hours. The authors concluded with the statement “*Human activities were found to be the leading causes of vegetation degradation in the region*”.

Contrary to the position taken by closed system rangeland scientists like Harris (2010), drivers and generators of rangeland degradation cannot be reduced to simple “causes”, primarily because watersheds are complex open systems with a multitude of dynamic factors acting in concert. Because these factors are changing daily and seasonally, their dynamic behaviour, time lags and spatial discontinuities prevent cause-and-effect analysis. For these reasons, objective heuristic experiments using complex open system geosciences are required to diagnose ecosystem dysfunctions and ecological strategies for correcting them (Tane 2009; Tane et al. 2014).

13.6.2 Predominant Functions of Rangeland Watersheds

Mountain–river–lake watersheds provide essential life support functions in the Sanjiangyuan region. They are relied on to sustain communities with hundreds of millions of people in the Chinese heartlands and South-east Asia. These headwaters regions are required to provide reliable supplies of fresh living water free of unnecessary risks and hazards. This poses challenges for equitable and efficient governance in the headwaters region (Ci 2004).

From the perspective of pastoral communities inhabiting the upper reaches of the Huang He, the overriding purpose of the watersheds is grazing their domestic herds of ponies, yak, sheep, goats and cattle. To support them in this endeavour, they evoke gods and deities using a formidable blend of religious proscriptions, spiritual practises and cultural forces. It has worked that way for millennia. Reconciling cultural cognitive dissonance without hostile conflicts will be difficult if not intractable, without participatory watershed programmes building cooperative community approaches.

Arguably, long proven cultural strategies empowering traditional cultural intelligence of a united China provides the only safe way forward (Fig. 13.14). History has demonstrated time and again, that reconciling the two cultures is only feasible or possible by following the central theme of Chinese, Mongolian and Tibetan cultures: by *living in harmony with Nature*. Inscribed for posterity by Lao Zi in the Dao de Jing (circa 2500 Years BP), the way of living in harmony with nature is represented by elevating the water dragon representing living water (huo shui) over the hard hoof fire horse (Qilin) representing dead and dying water. The alternative is bleak and depressing; involving endless hostilities over grazing rights and privileges, with dying rivers and dysfunctional watersheds draining catchments of dead water (shi shui) (Tane 2009).

In pursuing sustainable development through adaptive management of resource economies in the headwaters, maintaining and protecting the integrity of watershed systems is fundamental for:

- Amplifying and protecting watershed ecosystems for storing, cleansing and supplying abundant fresh clean water distributed through watershed aquifers and ecostructures operating sustainably for free.



Fig. 13.14 In the seventh century when the King of Tibet's cavalry forces invaded China, soundly defeating the Tang Emperor's armies, he won the Emperor's beautiful princess for his wife. They were married on the shores of Zhaling Lake. At Dari, in the centre of the headwaters region, impressive monuments have been erected showing Tibetans rule the mountains, and Chinese rule the rivers

- Maintaining the integrity of meteorological systems and stability of local and regional heat/water cycles by helping reverse pastoral desertification by preventing sunburn, soil erosion and salinity.
- Developing effective strategies for reducing risks and hazards from floods, droughts, seismic stress, high intensity storms and regional food and water security.

Policies defining constraints and opportunities are needed urgently to provide the guiding framework for planning and development. At present, mainstream research is overly focussed on pastoral grassland problems. This “pastoral problem mindset” is distracting attention from discovering and developing sustainable farming systems, while indirectly perpetuating dysfunctional activities and unsustainable grazing systems in the headwaters region. New programmes are needed to address the collapse of watershed ecosystems threatening the future of water supplies from the Huang He.

Restoring the functionality of watershed ecosystems in the headwaters region requires a range of initiatives and programmes including initiating *Participatory Community and Regional Watershed Programs* for the following:

- Rehydrating degraded floodplains
- Restoring desertified rangelands with strategic reforestation
- Reviving springs, streams, rivers and lakes
- Alleviating soil hazards ~ sunburn, salinity, soil erosion

- Appraising weeds as ecological resurrection floras for restoring degraded habitats
- Researching pests as ecological indicators of dysfunctional/unsustainable land use systems
- Modelling the community ecology of grazing animals/soft footed burrowing mammals
- Developing sustainable pasture systems for zero-grazing watersheds with barn farming
- Engaging local schools in measuring, monitoring and evaluating environmental health and
- Establishing joint venture research in partnership with pastoral communities.

Is there a sustainable farming system, one that can enhance rather than degrade the watershed ecosystems of the Huang He headwaters? Based on successess reviving mountain rangelands in other Chinese Provinces as well as other countries, the answer is an unequivocal “yes”. Before this issue can be addressed successfully in Xinghai-Tibet rangelands however; it is first necessary to resolve dilemmas distracting attention from critical matters.

13.6.3 Overcoming Cultural Cognitive Dissonance

Cultural heritage is central to the principles of sustainable development and environmental protection in UN Agenda 21’s key principles. Following formal adoption as the Rio Accord in 1992, culminating a process began by UNESCO and global science fraternities in 1968, more than two-thirds of countries globally have become cosignatories (UNEP 2010; UNEP and FAO 1997, 1999). As a result, the 27 key principles of UN Agenda 21 have been elevated to de facto international law through their formal adoption in many international treaties and conventions. However, such principles provide little guidance on how to resolve seemingly intractable watershed conflicts exemplified in the headwaters region of the Huang He.

Standoffs between farmers and pastoralists are classic case studies in cultural cognitive dissonance. The dilemma arising out of cultural cognitive dissonance revolves around differing beliefs, antagonistic attitudes and conflicting perceptions. They lead to opposing parties being unable to see things the same way or agree on basic premises. This predicament renders them disagreeable on the most basic aspects of any issue.

Cultural perceptions of mountain rangelands are varied and divergent. With the benefit of historical hindsight recorded over millennia, it is apparent that many pastoral communities continue relentlessly with their destructive deforestation and grazing practices until their rangeland ecosystems are completely derelict (Hillel 1991; Tane 2009). This human predicament is widespread in cultures which view wetlands as water-logged wastelands, unpalatable floras as noxious weeds and normal flooding as “natural hazards”. There are however; several successful



Reforesting rangelands in La Jia



Reforested river valleys



Reforested dunes compromised by grazing



Juniper replanting at higher altitudes



Reforested eroding rangelands



Tree planting for fuel and shelter

Fig. 13.15 Examples of reforestation in the headwaters of the Huang He

examples of progressive attitudes to reforestation in the headwaters region that deserve closer attention (Fig. 13.15). These ecological restoration strategies and practices await acceptance by local pastoral communities. In this respect, a broader range of sustainable land use activities need to be identified, proven and promulgated through participatory watershed planning and development programmes (Tane 2009).

13.6.4 *Transcending the Natural Versus Cultural Dichotomy*

In cultural ecography and watershed ecology, there is no fundamental difference between native and exotic, natural and artificial. These are subjective, anthropocentric concepts reflecting the compartmental mindsets of taxonomists and biologists, not the co-evolutionary processes of symbiotic communities, the ecogenesis of ecosystems, or the ecogenesis of watershed ecosystems. As noted by UNESCO in their Man and the Biosphere Program (1970):

To the ecologist, there is no fundamental difference between natural, wild or modified, semi-natural or developed, domesticated or purely artificial vegetations. The laws governing these ecosystems are identical.

Degradation of streams, soils and salinity, vegetation and wildlife communities and watershed ecosystems in the headwaters is a product of dynamic interactions between ecological processes and cultural impacts. The main drivers of degradation, however, are unsustainable human activities undermining the stability and resilience of ecosystems. Understanding how this occurs is hindered, if not prevented, by engaging in natural versus cultural debates. They are integral parts of the same complex open ecosystems which cannot be separated scientifically into biological compartments for closed system analysis (such as the analysis underpinning the yak farming versus pika “pests” debate (Tane 2012; see Li et al. Chap. 7; Fig. 13.16).

Resolving this dilemma is a straightforward matter of inventorying and auditing watersheds objectively, establishing the conditions of habitats and communities and the potential of their ecosystems (Tane and Nanninga 1992; UNESCO 1970, 2009). Without this watershed inventory and performance audit, policies and guidelines are unable to address the situation accurately and reliably. Problem-oriented management approaches cannot be conducted without bias or prejudice



Yak grazing and grooming has a wide range of impacts on landscapes and ecosystems. Physical impacts include destabilisation of edges/banks, compaction of soils, acceleration of runoff, depletion of aquifers and reductions to biomass.

Pika burrows aerate soils and accelerate aquifer recharge. This is especially important in areas where hard hooved animals have compacted soils.

Fig. 13.16 Animals of ecosystem disturbance—animals of ecological restoration

until a comprehensive inventory and objective audit of habitats and ecosystems are completed. Overarching policies relating to the whole watershed can be compiled and condensed during the audit. Promulgating watershed policies in plain and simple language with maps and illustrations that are easily understood by all members of the community is fundamental.

13.6.5 Watershed Hazards and Environmental Risk Management

Human activities and land use systems are drivers and generators of environmental risks and hazards, particularly where they are compromising critical functions supporting watershed ecosystems. A typical example from the headwaters is how pastoral desertification generates flash floods and more frequent incidences of severe droughts, while loading waterways with pathogen-laden nutrients, sediments and salts renders the water unfit for human uses (Tane 2009).

There are other human impacts to address as well. Ecotoxic agrochemicals and engineering infrastructure networks like roads, railways, towns and industrial areas have potential to severely disrupt watershed ecosystems. Environmental performance safeguards are required if they are to be used or operate successfully in rangeland ecosystems without exacerbating the destruction of watershed ecosystems, depletion of aquifer systems or generation of new hazards (Tane et al. 2014).

13.6.6 Adapting to the Dynamics of Change and Uncertainty

Pastoral grazing cultures worldwide tend to ignore or overlook the impacts of their grazing activities, blaming the inevitable consequences of grazing herds of hard-hoofed livestock on external “causes” over which they have no control (Hillel 1991). Typically, pastoral cultures blame pests and weeds, climate change or global warming for land degradation, viewing pastoral grazing as inherently natural, normal and necessary. As yet they have not learnt to adapt their farming systems to the sustainable development parameters or requirements of watershed ecosystems (Hillel 1991; Tane 2009).

More than 8000 years of pastoral adaptation in the Huang He headwaters has resulted in the slow but steady degradation of watershed ecosystems, in ways remarkably similar to the pastoral desertification of the Middle East under Abrahamic pastoral cultures; India’s rangeland degradation under Hinduism; and the human-induced desertification of Australian and New Zealand rangelands under pastoral Christianity (Fig. 13.17). In these global regions, blame for these calamities is often laid by pastoral leaders on global warming or an unreliable capricious Nature (Andrews 2006; Tane 2009).



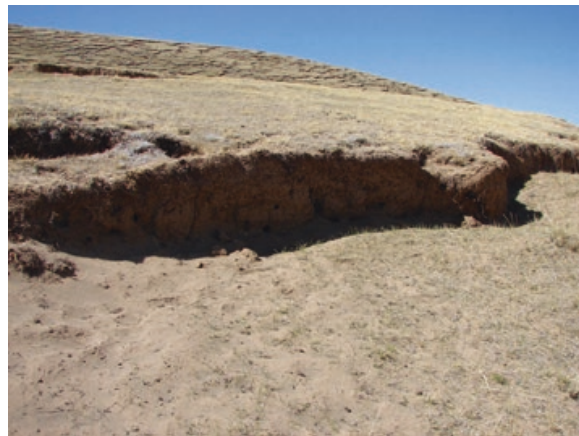
Grazing tracks accentuate hillslope erosion, creating terracettes with broken cryptogam bioseals.



Tracks from sheep and goats indicate a nearby Moslem village that supports arable farming and tree cropping in the upper Huang He valley



Terracettes produced by tracks and trails are ecological indicators of severe to extreme pastoral degradation of rangelands



Track and trail terracettes further drain dry moist soils, providing nesting habitat for burrowing mammals such as plateau pika

Fig. 13.17 Sheep and goat terracettes ~ incremental terrain degradation

As renowned river makers Rajendra Singh and Peter Andrews have demonstrated in Rajasthan and Australia, when provided with the right opportunity, riverine ecosystems can repair themselves through adaptive ecosynthesis (Andrews 2006; Tane 1996). Ecosynthesis is the co-evolutionary re-building of new ecosystems through progressive community adaptations integrating habitats and regoliths that forge watershed ecostructures.

As zoologist Monbiot (2013) records in his book *Feral*, some human communities are re-engaging with Nature to re-discover a traditional indigenous way of living sustainably and more productively. In adopting feral approaches, Nature is allowed freedom to find its own way without human interference, enabling ecological processes to repair essential life support systems. Monbiot describes this way as living in harmony with Nature. Aligning with traditional Dao culture and modern restoration ecologists, Monbiot recommends we restore degraded environs ecologically by allowing feral communities free range instead of grazing domestic ungulates. His advice paraphrases strategies implemented by Andrews (2006) and outlined in Lao Zi's *Dao de Jing*.

It is perhaps remarkable that there is still very little cultural awareness evident in the headwaters region of how free-range grazing of hard-hoofed livestock ~ yak, cows, horses, sheep and goats ~ are radical agents of geomorphic change and champions of ecological degradation. Ecogenesis of the Qinghai–Tibet rangelands indicates that formerly widespread shrublands, woodlands and forest communities have been replaced by habitats with eroding skeletal soils partially covered by tough grass mats, complete with pastoral pests and weeds. Over extensive areas, aquifer springs, discharge seeps, wetland meadows, bogs and flushes have collapsed into corrugated terrains characterised by erosion gullies and moving sands, shining white with salt.

The first step to address these perilous issues entails auditing the ecological status of watershed habitats and their land use communities of soils, vegetation, livestock and wildlife, including springs, streams, rivers and watershed ecosystems.

13.6.7 Auditing Rangeland Watersheds for Ecologically Sustainable Development

Compliance and performance audits of watershed ecosystems are increasingly necessary to diagnose their dysfunctions as a prelude to ecological restoration programmes (Tane and Nanninga 1992, 1995; Tane and Williams 1999). Similar methods were used for validating traditional methods for rehydrating degraded floodplains ecosystems (Tane and Andrews 1998). The methodology is called Eco³ Sustainability auditing (Tane and Yu 2002; Tane et al. 2014). Eco³ Sustainability is a function of integrating ecogeography.ecology.economy using geospatial sciences with image-based geospatial intelligence systems like watershed iGiS (Tane and Nanninga 1992; Tane and Yu 2002; Tane et al. 2014).

Mapping habitats and modelling ecosystems is called ecogeography: from *ecos* (home habitat) and *graphy* (to map, model or draw). When watershed habitats are accurately and reliably mapped and modelled, it is possible to diagnose their complex ecological relationships and evaluate their economic implications. Ecogeography is a traditional cultural practice in the Asia-Pacific region. It is commonly used to define a community's home territory, showing the distribution of habitats, resources and their assignment among members of the community (Tane 2009). In Mesolithic and Neolithic times, similar methods were used for recording the assignment of resources in the Qinghai–Tibet rangelands. A traditional Tibetan mandala woven in rugs on display in the Qinghai Museum was described by the Tibetan guide as representing the home territory of a community complete with resource rights of families. Much later, when Buddhists arrived from India, they adapted Tibetan mandalas to create spiritual maps of the cosmos.

Eco³ Sustainability audits of watershed ecosystems have been used in Australia, New Zealand, India and China to diagnose ecological dysfunctions of watersheds. They provide a platform for community and regional participatory watershed programmes (Tane and Yu 2002; Tane 2009; Tane et al. 2014). A similar methodology was used in reconnaissance field surveys for the present study.

13.6.8 Sustainable Watershed Systems

In mountain rangelands with heterogeneous terrains and climates, it is usual to find land use systems based on self-regenerating or planted forests. Self-regenerating forests and woodlands provide diverse habitats for wide-ranging food/fuel forest resources including medicinal herb and fungi, specialty timbers, renewable fuels, wildlife habitat and farming communities. They are also able to be adapted to recreation parks, wildlife conservation reserves and religious tourism resorts. When accompanied by ancillary activities such as goose and duck farming, freshwater aquaculture, and farming activities that enhance the performance of watershed systems (maintaining aquifers, riparian ecotones and their terraqueous ecostructures), they comply with the principles for ecologically sustainable development integrating ecosystem protection (UN Agenda 21).

Environmental health and animal welfare are closely intertwined. The health of animals reflects the quality of the water they drink, the food they consume and the habitats and ecosystems they occupy. Consequently, the health of grazing livestock is jeopardised by (a) water supplies contaminated with animal excrement and human faeces, (b) pastures contaminated with excreta, dangerous pathogens and poisonous plants and (c) habitats polluted with ecotoxic agrochemicals such as herbicides and pesticides. When food and water supplies are polluted with disease-laden pathogens and algae, and pastures are contaminated with faecal matter and ecotoxic agrochemicals, animal health and welfare suffers.

Viewed from the perspective of pastoral cultures, grazing is *believed* to be natural, normal and necessary. Viewed from the perspective of sustainable development of watershed ecosystems, pastoral grazing is a land use activity that is fundamentally incompatible with the primary functions of rangeland watersheds. Participatory watershed programmes are proven ways of providing a mechanism to assess this cultural dissonance and resolve it.

Tibetan and Mongolian farming systems previously involved a complicated resource assignment process involving clans and families, with kings and deities empowering and enabling pastoral grazing on accessible terrains. Under the contemporary household responsibility system, leasehold land tenures were introduced with exclusive family occupation blocks based on sedentary farming systems. Under this approach, open ranges are being fenced and subdivided into exclusive family parcels of private property able to be sold and traded. At the same time, more intensive pastoral grazing practices have emerged, unleashing dire consequences for watershed ecosystems.

Assuming that Tibetan, Mongolian and Moslem communities will persist with livestock farming as a central theme in their rangeland culture, there is an urgent need to find a way to accommodate hard hoofed livestock while protecting watershed ecosystems. A traditional farming system eminently suited to resolving this cultural dilemma is evident in Tibetan, Mongolian and Moslem rangeland land settlement systems. Pastoral farming settlements with high stone-walled yards and enclosed sheds where livestock are kept secure from predators at night provide an

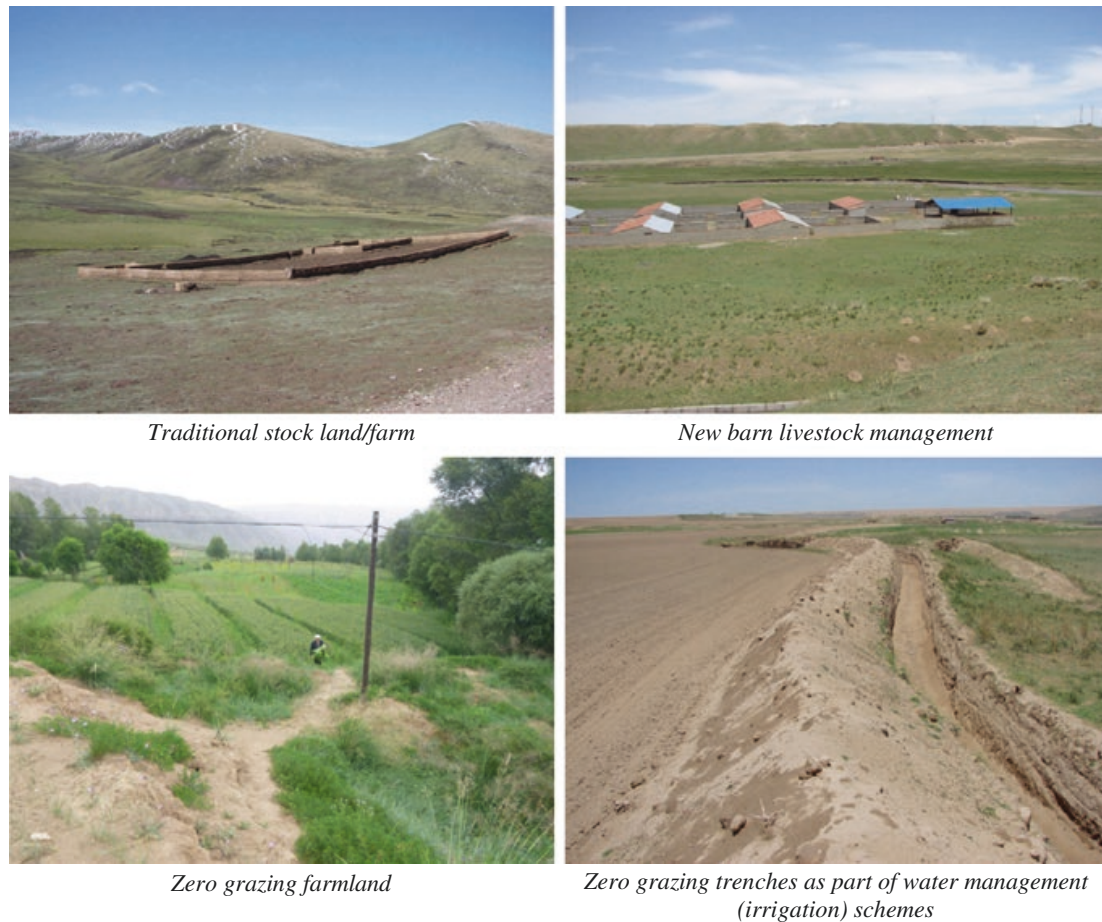


Fig. 13.18 Examples of zero-grazing farmlands

excellent start. These hamlets are usually surrounded by grasslands which would flourish and recover if they were unimpeded by trampling herds of hard-hoofed animals.

The solution may be closer than expected. In recent years, an advanced livestock farming method has been introduced to Qinghai, achieving higher levels of production with better stock health. It builds on traditional Tibetan practices of securing livestock in barns and yards overnight. Enclosed yards for securing flocks and herds against predators and thieves provide an important cultural connection leading directly to modern barn farming with zero grazing (Fig. 13.18).

In zero-grazing farming systems, all the food and fodder for livestock are harvested and taken to the animals kept in purpose-built barns complete with exercise yards (Muel et al. 2012). Livestock barns and their exercise yards have specific location and terrain requirements. Ideally, livestock barns and adjacent yards should be constructed in warmer thermal belt zones on hills and mountains, at sites where browsing and grazing animals typically congregate in cold weather. These elevated locations allow nutrient-rich effluents to be injected into mid slope recharge zones, to seep through aquifer networks and ecostructures, enabling effluents to fertilise and nourish the pastures lower down the slopes. With zero

grazing and nutrient flows re-established through near-surface aquifers, lowland meadows can recover more quickly, gradually returning to denser, taller grasslands. Sustained by wetter soil conditions, meadows will become more productive, with aquifer flows alleviating summer droughts while sustaining perennial springs and streams.

Barn farming with zero-grazing achieves superior animal health and welfare with higher productivity. Because all the fodder is kept clear of the ground on feeding racks, barn-fed livestock are able to consume their food, free of their faeces which drops into clean straw or wood chips. Straw spoiled with animal wastes is cleaned out regularly and fed to worm farms or applied as mulch to pastures well away from watercourses. By these simple expedient measures, animals no longer need to eat through their faeces, as they do in free-range grazing. As a result, pathogenic pathways in ruminant animals are interrupted and broken, effectively reducing animal infections and diseases. Nor are the livestock infecting water courses with their pathogens, or mucking and pugging riparian habitats. The outcomes are beneficial for water resources springs, streams and rivers.

13.6.9 Sick Rivers Can Be Saved

Eliminating grazing by hard-hoofed animals is a time-proven, commonly used solution to help regenerate sick streams, dying rivers and degraded watersheds. Although China is now a world leader in these methods, very few constraints on grazing are effective in the headwaters region. While domestic grazing impacts have been reduced (in some areas) in the headwaters district around Zhaling and Eling lakes, effective river restoration is still a long way off. The severity of degradation and erosion is so great in the headwaters district that drastic measures are necessary. It will be a challenging task, particularly in a predominantly pastoral district where conventional wisdom holds that everything that can be grazed should be grazed. There is also a need for ensuring continuing pressure from predators to prevent feral grazing animals from occupying critical riparian zones too frequently.

As noted in the recovery plans for the largest freshwater lake in China (Poyang Lake in Jiangxi Province), an integrated watershed strategy is required to alleviate and diminish the calamitous impacts of human activities like grazing and mining. A simple and effective strategy is needed which acknowledges and enhances the ecological and economic connectivity of mountain-river-lake regions:

To fix the lakes, first fix the rivers

To fix the rivers, reforest their watersheds

To reforest the watersheds, eliminate poverty

(by providing sustainable livelihoods)



Technology changes culture



Horse trails as hard as roads



Reservoir fish farms



Honey production



Forestry and tree crops



Tree farms and barn-raised livestock

Fig. 13.19 Farming futures for the headwaters

Dysfunctional watersheds can be restored and sick rivers can be saved. World-renowned “river makers” Rajendra Singh (Rajasthan) and Peter Andrews (Australia) have shown how the cultural intelligence of indigenous peoples can be adapted to revive dead streams and dying rivers (Tane 2003). By taking the pre-emptive step of removing all hard-hoof livestock, allowing pastoral weeds to flourish, and planting willows to repair floodplain headlands, re-establish aquifers, and restore ecostructures, these river makers liberated ecological processes to revive streams and rivers, and recover perennial stream flows and environmental health (Tane 2009). In the

absence of grazing animals, ecogenesis leads to ecosynthesis and the restoration of ecostructures. Ecostructures are fundamental to the health of watershed ecosystems for these ecologically linked suites of habitats and regoliths, function as self-regulating systems for harvesting, storing, cleansing, diffusing and releasing fresh clean water throughout floodplains and watersheds (Tane 2004, 2009).

The success of the twin policies (zero-grazing and rangeland reforestation) in restoring watersheds and rebuilding functional ecosystems provides a cost-effective pathway for reviving streams and rivers while reducing climate chaos. Destocking and reforestation allow the revival of terraqueous habitats and recovery of the heat/water balance. These actions remain the most effective strategies for reversing pastoral desertification (Tane et al. 2014) while providing opportunities for sustainable development of farming in the headwaters (Fig. 13.19).

In order to maintain the integrity of living watershed systems of the Huang He headwaters, hard-hoofed livestock should be secured in barns and yards and their feed taken to them. By this approach, practical farming of mountain rangelands may enhance watershed systems in an ecologically sustainable manner (Tane et al. 2014).

13.7 Conclusions

In this chapter, a transdisciplinary approach has been used to examine ecological relationships among habitats, regoliths and meteorological processes in the Huang He headwaters to reveal ecogenesis of watershed ecosystems their habitats and ecostructures. From information gathered over five years of fieldwork, ecological performance and dysfunctions were assessed. The assumptions and procedures are those of complex open system sciences: eclectic, integrative, and geospatial.

A strategic combination of reconnaissance surveys, site visits and literature reviews reveals how human-induced desertification was generated in repeated cycles over millennia by pastoral communities grazing flocks and herds of hard-hoofed animals everywhere possible. Urgent action is needed to halt and reverse human-induced desertification before salinity compromises the complete river system.

The Qinghai–Tibet rangelands are consistently ranked by UN agencies among the most severely degraded regions on the planet. How this occurred and what can be done about it requires engaging pastoral communities in the new sciences of cultural ecography, watershed ecology and resource economy. These geosciences do not rely on traditional alpha-numeric closed system analytical methods; nor do they focus on pastoral problems. They employ geospatial intelligence developed using complex open system ecosciences in efforts to revive ecological functions and restore resource prospects. They also build on the traditional cultural intelligence of indigenous cultures in ways that are more easily understood by local farming communities, using ecographic models and pictorial representations, rather than esoteric alpha-numeric research in languages foreign to local communities.

Summarising, the transdisciplinary geospatial approach applied in this chapter helped to:

- Assess hydrographical and meteorological processes connecting habitats and regoliths with their land use and vegetation communities
- Integrate disparate findings of separate disciplines and subjects using transdisciplinary research and development methods to provide a consistent evaluation of land degradation and desertification processes and
- Distinguish the cultural beliefs of different ethnicities and the subjective perceptions of specialist scientists from the objective ecological conditions prevailing in watersheds.

Our evaluation of watershed ecogenesis has confirmed how during Mesolithic and Neolithic times through to the heydays of the Tibetan Empire in the seventh century, and modern times, incremental deforestation combined with transformation of terraqueous wetlands to much drier terrestrial grassland pastures, amplified human impacts, until critical watershed systems in the headwaters region succumbed and failed. This calamitous predicament is known globally as pastoral desertification of rangeland watersheds.

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