Chapter 6
Ecological Protection and Restoration in Sanjiangyuan National Nature Reserve, Qinghai Province, China

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Abstract Historical data and published results are reviewed to assess the rationale and design criteria used to establish the Sanjiangyuan (Three Source Region) National Nature Reserve in Qinghai Province, China. This area, which comprises the headwaters of the Yellow, Yangtze and Mekong Rivers, has been described as the 'Third Pole' or the 'Roof of the Earth'. Key drivers for the designation of this ecological reserve include concerns for sustainable water resources management and biodiversity management, especially the protection of endangered flora and fauna. These issues are placed in context of prevailing and prospective threats, namely climate change, environmental degradation associated with overgrazing and burrowing mammals, and human-induced pressures (population growth and various land use practices). Ecological protection and restoration measures being applied in the Sanjiangyuan region are reviewed. The approach to environmental conservation and management parallels initiatives applied in many other parts of the world, with 18 core areas, connected and/or surrounded by buffer areas, with experimental areas beyond. Adopted measures are framed primarily in relation to wetland functions, striving to protect water resources and the precious but fragile ecosystems in this region. Water resources planning strategies and landscape ecology programmes link lake and river ecosystems to grassland, forest and wetland management strategies at the landscape scale.

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> The preservation of the full range of biodiversity and of physical features is an essential element in the selection of mountain protected areas. As an integral part of planning, provision should be made for the protection of large examples of natural ecosystems and of populations of plant and animal species, together with sites illustrating the principal geological and physiographic features and the processes at work in the landscape. These should be supplemented by the protection of a larger number of small areas representing the full local variety of species and ecosystems, including intra-specific genotypic variation (Hamilton and Macmillan 2004, p. 14).

6.1 Introduction

Ecosystems provide essential goods and services, contributing substantially to social and economic development. Societal wellbeing is dependent upon the maintenance of biodiversity and the capacity of species and ecosystems to survive, evolve and adapt to environmental change. The extent and impact of human disturbance upon 'natural' ecosystems across the world is no longer in dispute (Millennium Ecosystem Assessment 2005). Environmental damage brought about by population pressure, land use intensification and climate change, among many factors, has been accompanied by progressive depletion of natural resources. In response to these concerns, genuine commitment to environmental protection has become a core element of sustainable management programmes. Although protected areas now cover over 12% of the Earth's land surface (Chape et al. 2005), conservation activities in their own right are unable to maintain the inherent diversity of genes and ecosystems. An ecosystem approach to environmental management promotes recovery and enhancement of the self-sustaining properties of 'natural' systems, recognizing implicitly that there are too many species to save them one at a time.

Because of their history, isolation, and great variability of habitat, mountain regions are treasures of high biodiversity and are rich in endemic species (Hamilton and Macmillan 2004). These reservoirs of biodiversity contain rich assemblages of species (and their genotypes). Distinctive ecosystems have developed in response to the pronounced altitudinal belts and local variability in physical conditions in these areas. However, these steep, high altitude terrains are especially susceptible to human-induced damage, and many elements of these fragile environments are vulnerable to accelerated rates of climate change.

In global terms, concerns for environmental conditions in the face of population pressures and the demands for economic development are nowhere more evident than in China. In the 11th Five Year Plan, explicit recognition is given to the need to enhance and expand approaches to environmental protection (Xiao 2006). One of the most important initiatives is efforts to protect the headwater zone of the Yellow, Yangtze and Mekong Rivers in the high altitude country of the Qinghai-Tibetan Plateau (see Fig. 6.1). This area in Qinghai Province is known as the

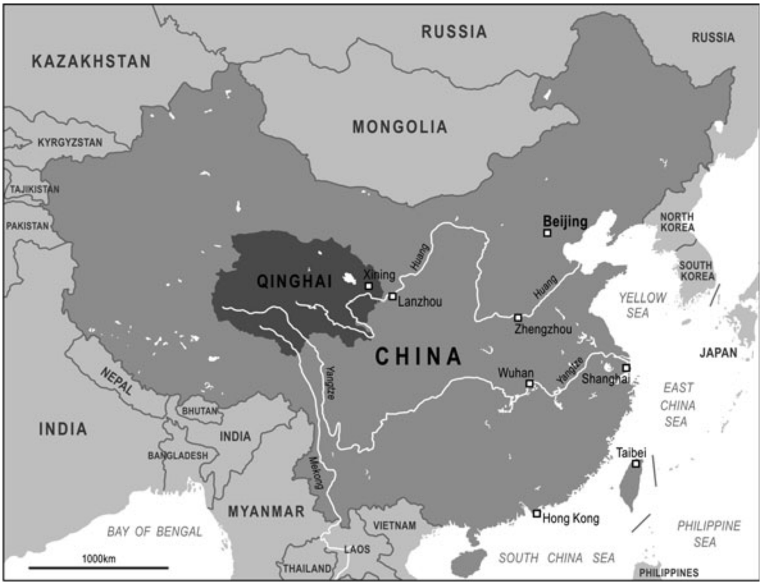

Fig. 6.1 Qinghai province, western China. The headwater zone of the Yellow, Yangtze and Mekong rivers lies in the high altitude country of the Qinghai-Tibetan Plateau

Sanjiangyuan (the source zone of the Three Rivers), and is often referred to as 'The Third Pole' or 'The Roof of the World'. The Sanjiangyuan region is the highest (average elevation above 4000 m) and largest wetland ecosystem in the world (Li 2007). Indeed, this region is also known as the 'kidney of the earth', the 'cradle of living forms' and 'the water tower of China'. Key functions of these fragile and complex wetland ecosystems include their capacity to retain water, reduce surface runoff, store flood-water to mitigate flood events, reduce pollution, maintain biodiversity, supply water for human services, regulate climate, etc. Annual water supply from these three rivers to downstream areas is as much as 60 billion m^3, supplying 49% of total water to the Yellow River, 25% to the Yangtze and 15% to the Mekong (Li 2007; Ma 2007; Zhou and Yie 2007). Although the drainage areas of the Yellow and Yangtze Rivers make up 24% of the total land area of the country, they comprise 50% of the total population of the country and make up 50% of the total Gross Domestic Product (Chen et al. 2002). Protection of water resources is integral to China's economic and environmental security (see Cannon 2006).

The high elevation and dry, cold climate of the Qinghai-Tibetan Plateau foster the unique fauna and flora (alpine germplasm) of the Sanjiangyuan region (see Fig. 6.2). Spatial distributions of many living forms have been marginalized in this area. The fragility of ecosystems is locally threatened by increases in human population and uncontrolled production activities (Ma et al. 2000; Zhou et al. 2003b; Du et al. 2004; cf., Harris 2010). Removal of natural vegetation has reduced the water-retention capacity of the region and lowered the capacity of the environment to cope and recover in periods of stress (Li 2007). Natural disasters such as floods, droughts and

Fig. 6.2 Distinctive topographic, faunal and floral attributes of the Sanjiangyuan region

dust storms occur more frequently, and erosion has become more serious. Overgrazing has caused the degradation of grassland, seriously affecting living condition of herders (Ma et al. 2001, 2002; Zhou et al. 2003a, b; Wang et al. 2004; Shi et al. 2005). Desertification is growing as uncontrolled harvesting of wood, gathering of materials for herbal medicines (especially caterpillar fungus (*Cordyceps sinensis*); see Winkler 2009)) and mining activities degrade grassland and forest vegetation (Chen et al. 2002). Deterioration and fragmentation of habitat is decreasing the regional biodiversity (Chen et al. 2007).

Implementing the policy of 'the Great Development of the West' is an important strategy laid out by the Chinese Government (see Economy 1999, Goodman 2004, Xin 2008). An inspection team was sent by the 'Jiu San Society' to examine the eco-environment of the Sanjiangyuan region (Chen et al. 2007). With support from

Fig. 6.3 The Sanjiangyuan region makes up the southern half of Qinghai province in western China. The region is divided into 17 administrative districts

relevant departments of central government, the People's Government of Qinghai province has prepared a programme for ecology-based protection and construction in the area, including the formation of the Sanjiangyuan National Nature Reserve. A comprehensive, integrated and balanced approach to protection and construction strives to ensure that economic development continuously enhances the living standards of local people (Chen et al. 2007). To achieve this, the distribution and livelihood of human beings is being adjusted, encouraging herders to develop more advanced approaches to livestock production within an ecology-oriented economy. Alternatively, many are being asked to abandon livestock production.

In this manuscript we review the natural features and ecological values of the Sanjiangyuan region, appraise the pressures and stressors that bring about ecological degradation, and highlight measures that are being taken to address these issues through the creation of the Sanjiangyuan National Nature Reserve. The design criteria applied in the derivation of the reserve and suggested measures for ecological protection and restoration are discussed in relation to large scale conservation initiatives elsewhere in the world.

6.2 Regional Features and Ecological Conditions of the Sanjiangyuan Region

The Sanjiangyuan region lies at the heart of the Qinghai-Tibetan Plateau in the southern part of Qinghai province (latitude 31°39′–36°12′ N, longitude 89°45′–102°23′ E) (see Figs. 6.1 and 6.3). It covers a total area of 363,000 km^2,

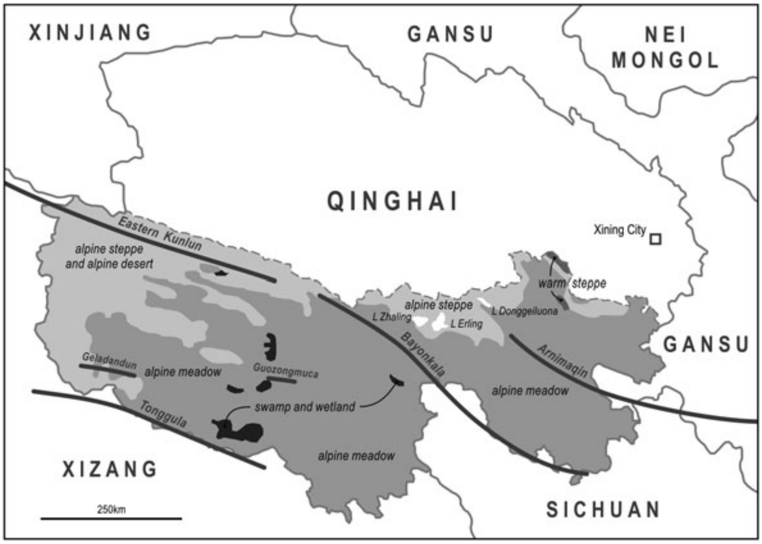

Fig. 6.4 Vegetation map of Qinghai province (Liu et al. 2004)

accounting for 50.4% of the total area of Qinghai province. The major mountainous areas such as the eastern Kunlun, Arnimaqin, Bayankala and Tanggula Mountains range in elevation from 3335 to 6564 m, typically between 4000 and 5800 m (see Fig. 6.4; Sun and Zheng 1996; Chen et al. 2002). Snow-covered mountains cover a total area of 2,400 km^2, with 1,812 km^2 covered by continental mountain glaciers. Glaciers are retreating at a rate of 30–50 m/year (Zheng 1996; Chen et al. 2002). Wetlands account for 20.3% of the total land area (73,300 km^2) (Zhou and Yie 2007). The Sanjiangyuan region has more than 16,500 lakes, of which around 190 have an area > 0.5 km^2, and there are extensive groundwater reserves (Chen et al. 2002; Zhou and Yie 2007). Numerous lakes and swamps are included on the List of Important Wetlands in China.

The alpine continental climate is characterized by clear separation of dry and wet seasons but small annual temperature differences, large diurnal and seasonal temperature differences, long sunshine hours and strong radiation (Zhang et al. 1999). Mean annual temperature across the region ranges from −5.6 to 3.8°C while mean annual precipitation ranges from 262 to 773 mm. The cold season, which lasts for 7 months, is controlled by high pressure systems. Given the high altitude and very thin air, the growing period is short and there is no absolute frost-free period.

Primary vegetation classes in the region include coniferous forest, broad-leaf forest, needle-leaf and broad-leaf mixed forest, shrub, meadow, steppe, swamp and aquatic vegetation, cushion plants, and zones of sparse vegetation (Table 6.1). Forests comprise 1.22 million ha in the Sanjiangyuan region (3.27% of the land area). Grasslands account for 59% of the total land area (21.4 million ha, of which 19.27 million ha is utilizable grassland). Alpine meadow (82.6%) and alpine steppe (12.1%) are the main grassland types (see Fig. 6.4). Alpine meadow is

Table 6.1 Land utilization in the Sanjiangyuan region (Statistical Bureau of Qinghai Province 2003)

Prefecture	Total land area (10^4 km^2)	Grassland		Woodland area (10^4 ha)	Of total woodland		Tilled and ploughed land (10^4 ha)	Water area (10^4 ha)	Others (10^4 ha)
		Grassland area (10^4 ha)	Acceptable grassland area (10^4 ha)		Wood area (10^4 ha)	Shrub forest area (10^4 ha)			
Total	36.31	2141.80	1926.60	122.40	11.33	107.40	4.81	106.34	1255.65
Yushu (all counties)	19.79	1084.80	956.98	41.40	4.67	35.33	1.64	79.05	
Guoluo (all counties)	7.63	675.40	625.52	57.47	3.60	53.20	0.29	25.32	
Hainan (only Xinghai and Tongde county)	1.69	145.73	139.16	14.13	2.00	11.13	2.44	0.86	
Huangnan (only Zeku and Henan county)	1.31	125.69	119.92	9.40	1.07	7.73	0.44	1.11	
Haixi (only Tanggula town)	5.87	110.19	110.19						

Note Qumalai, Zhidou, Zhadou, Nangqian, Yushu and Chengdou counties are in Yushu prefecture and Madou, Dari, Gande, Maqin, Jiuzhi and Banma counties are in Guoluo prefecture mainly distributed on mountain slopes, or on top of mountains, terraces, or valley benches at elevations between 3200 and 4700 m. The vegetation comprises cold-tolerant perennial plants. The main grassland species include sedge (*Carex* spp., especially *Kobresia* spp.), needlegrass (*Stipa* spp.), saussure (*Saussurea* spp.), roegneria (*Roegneria* spp.), bluegrass (*Poa* spp.), wild ryegrass (*Elymus* spp.) and speargrass (*Achnatherum* spp.) (see Fig. 6.2c). The height of forage is low, ranging between 5 and 30 cm. Productivity is very low. Around 12.47 million ha (58.3% of the total grassland area) has been subjected to moderate to severe degradation (Chen et al. 2002; Wang et al. 2005; cf., Harris 2010; Li et al. 2011).

Fauna in the Sanjiangyuan region comprise 93 species of mammals belonging to 22 families of 8 classes; 255 species of birds belonging to 41 families of 16 classes; and 18 species of amphibians and reptiles belonging to 10 families (Chen et al. 2007). Among the mammals and birds, 69 species are on the list of "protected wildlife of national importance", of which 16 animals are 'first class' protected species (e.g. Tibetan antelope (*Pantholops hodgsoni*), wild yak (*Bos grunniens*) and snow leopard (*Uncia uncia*)) and 53 animals are 'second class' protected species (e.g. blue sheep (*Pseudois nayaur*) and Tibetan gazelle (*Procapra picticaudata*)).

The Sanjiangyuan region is a vast area with very low population density. Of the total regional population of 590,000, 408,900 are herders (69.3%) (Table 6.2). Tibetan families account for 90% of the herding families, with small number of other nationalities such as Mongolian. Livestock grazing is the main component of the regional economy, with over 22 million sheep in the region. Since 1990, herders have rented land from the local government over 50–100 year lease periods. Under this arrangement, herders can use and manage the land tax free under laws such as the grassland law and the land utilization law, in programmes co-ordinated by the grassland supervision station.

6.3 Key Mechanisms and Stressors that Bring About Environmental Damage

Establishment of the Sanjiangyuan National Nature Reserve is a coordinated response to many social and environmental pressures in this fragile region. Prior to assessing criteria used in the design and implementation of the ecological reserve, the primary stressors that induce environmental damage in the region are outlined.

6.3.1 Climate Change

Global climate change is the fundamental natural factor causing the deterioration of ecological environments in the Sanjiangyuan region (Zhang et al. 1998, 1999). Fragile ecosystems have been destabilized, reducing their capacity for self-restoration.

Table 6.2 Socio-economic statistics for the Sanjiangyuan region (Statistical Bureau of Qinghai Province 2003)

Prefecture	Total population (10^4 persons)	Population of pastoral area (10^4 persons)	Households of pastoral area	Annual income per capita (Yuan)	Livestock number (10^4 Cattle/sheep)	Equivalent sheep units (10^4 sheep units)
Total	59	40.89	83,531	1549.69	1038.93	2224.03
Yushu(all counties)	26.3	17.04	34,664	1432.5	278	748.81
Guoluo(all counties)	13.54	9.20	20,732	1588.97	232.2	759.90
Hainan (only Xinghai and Tongde county)	10.67	6.54	13,476	2043.83	316.4	291.52
Huangnan (only Zeku and Henan county)	8.40	8.01	16,165	1355.49	201.4	409.07
Haixi (Only Tanggula town)	0.10	0.10	314	1730.23	10.63	14.73

Global warming and intensified evaporation have promoted reverse succession. Wang et al. (2000, 2001) attribute the large-scale degradation of alpine meadow and steppe vegetation to the warming of the regional climate over the last 40 years, largely associated with the degradation of previously frozen land. Similarly, Chen et al. (1998) suggest that global warming has induced desertification that has degraded grassland areas. This warming trend has impacted upon plant growth, yield and community structure in alpine meadow ecosystems (Li et al. 2004). Extreme weather and climate disasters in the 1990s intensified grassland degradation.

Figure 6.5a shows significant increases in average annual temperature in the Sanjiangyuan region from 1961 to 2004 (Li et al. 2006; Wang 2007). This increase was especially marked in the 1980s and 1990s. Mean annual temperature was −2.36°C in the 1960s, −2.19°C in the 1970s, −2.04°C in the 1980s, and −1.78°C in the 1990s. Mean annual temperature in 2003 was the highest on record, 1.4°C higher than the average for the previous 30 years. As temperature adjustments are most marked in autumn and winter, the annual variation of temperature has decreased year by year (Li et al. 2006; Fu et al. 2007b; Chen et al. 2007). This has induced glacier retreat, ascending snow lines, drying up of wetlands, and degradation of alpine permafrost.

Mean annual precipitation in the Sanjiangyuan region from 1961 to 2004 is shown in Fig. 6.5b (Li et al. 2006; Wang 2007). While the 1980s were characterized by slightly above average precipitation, this trend was reversed in the 1990s. Seasonal changes have varied across the region (Chen et al. 2007). Major snowstorms occurred in the Sanjiangyuan region during winters of the late 1990s and in the spring early in the twenty first century.

Mean annual evaporation in the Sanjiangyuan region increased slightly from 1961 to 2004, with an average increase of 0.13 mm a^{-1} (Fig. 6.5c). Mean annual evaporation was notably lower through the 1980s, but increased in the 1990s (Wang 2007; Chen et al. 2007). To some degree, climate warming has reduced the inhibiting effect of low temperatures upon plant growth in alpine meadows, but evaporation of ground surface and evapotranspiration from vegetation has increased faster than precipitation, such that water availability is the primary limiting factor for plant growth (Li et al. 2000). Intriguing debates are emerging about the relative impacts of climate change and human impacts on the vegetation structure and function atop the Qinghai-Tibetan Plateau (cf., Klein et al. 2007; Miehe et al. 2008, 2011).

6.3.2 Grassland Degradation and Desertification

The influence of global warming, intensified human activity, overgrazing, and frequent natural disasters have degraded almost 90% of natural grassland areas in Qinghai province in recent decades (Department of Animal Husbandry and Veterinary 1996; Fu et al. 2007a; cf., Harris 2010, Li et al. 2011). This has markedly decreased the primary productivity associated with animal husbandry in

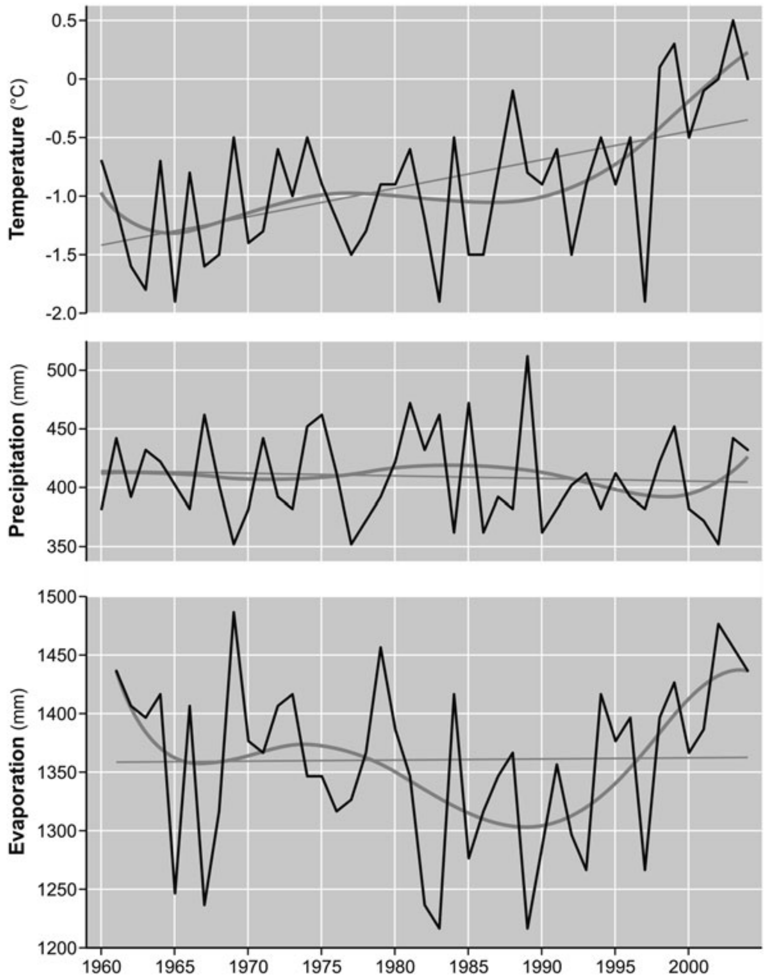

Fig. 6.5 Variability in mean annual temperature (**a**, *upper graph*), precipitation (**b**, *middle graph*) and evaporation (**c**, *lower graph*) in the Sanjiangyuan region (1961–2004; data from Li et al. 2006; Fu et al. 2007a, b; Chen et al. 2007; Wang 2007)

these areas, threatening people's livelihood. Remote sensing analysis indicates that the area of degraded grassland increased from 764×10^4 ha in the late 1970s—early 1990s (32.8% of the total region) to 841×10^4 ha in the period 1990s—2004 (36.11% of the total region) (Table 6.3, Liu 2008). Moderately degraded grasslands now extend across around 6.9 million ha, which is 36% of the total utilizable grassland (Chen et al. 2007). Compared to 1950, the yield per unit area of grassland has decreased by 33%, the percentage of elite forage species has decreased by 25% and vegetation cover has decreased by 20%, while the percentage of toxic plants has increased by 75%, the height of dominant plants has decreased by 40%, and the height of grasses has decreased by 20% (Fu et al. 2007a). Ecological

Table 6.3 Changing extent of grassland degradation in the Sanjiangyuan region (Liu et al. 2008)

Grassland degree	Late 1970s–early 1990s		Early 1990s–2004	
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)
Slight	5,328,317	22.88	5,572,405	23.93
Middle	2,212,216	9.50	2,734,779	11.74
Severe	103,957	0.45	103,082	0.44
Total	7,644,490	32.83	8,410,266	36.11

landscapes associated with alpine meadow and alpine steppe are progressively being destroyed and fragmented. Many grassland areas are characterized by reverse succession from alpine meadow to degraded alpine meadow to desert (Table 6.4; Fu et al. 2007b; cf., Miehe et al. 2008, 2011). Disruption of the ecological balance of alpine eco-systems has also seriously affected production and living conditions of herders in the region.

6.3.3 Soil Erosion

Given its harsh natural conditions and fragile ecological environment, the Sanjiangyuan region has serious problems of wind erosion, water erosion and freeze–thaw processes. A remote sensing survey in 2000 indicated that areas with moderate extent of erosion extend over 95,000 km^2, making up 26.2% of the region (Chen et al. 2007). Intensified soil erosion, along with frequent drought and flood conditions, seriously restricts prospects for industrial and agricultural development, and threatens the ecological safety of the area.

6.3.4 Rodent Damage to Grassland

Although the plateau pika (*Ochotona curzoniae*), plateau zokor (*Myospalax baileyi*) and plateau vole (*Pitymys irene*) are native mammals, they are referred to as '*rodents*' of the Qinghai–Tibetan Plateau. Grasslands are severely impacted by their burrowing and gnawing behavior (Zhou et al. 2003a, b, 2005). Their activities accelerate erosion and degradation rates by loosening the Kobresia sod and killing its roots (Limbach et al. 2000; Zhou et al. 2005). The area affected by these burrowing animals in the Sanjiangyuan region is 6.4 million ha (Chen et al. 2007). This makes up 17% of the total area of the region, and 33% of the total utilizable grassland. As many as 374 pikas/ha have been recorded in some areas (Ma et al. 2000), with up to 1335 burrows/ha (Zhou et al. 2005). Natural enemies for burrowing animals have been greatly reduced since the 1980s because of illegal hunting (especially eagles), impacting greatly upon the food chain. The 'degradational' role of these burrowing mammals remains contentious. Indeed, some argue that some of

Table 6.4 Increase in desertification area in the Sanjiangyuan region (1949–1998) (Fu et al. 2007a)

Year	Yellow river (km^2)			Yangtze river (km^2)			Data source
	Area	Increased area	Annual average increased area	Area	Increased area	Annual average increased area	
1949	1961.00			7430.60			
1959	2208.90	247.90	24.79	8369.94	939.34	93.93	Aerial photographs supplied by the Sand control team of Qinghai
1977	2923.00	714.10	39.67	11075.80	2705.86	150.33	Aerial photographs supplied by the Forest investigative team of Qinghai
1986	3540.90	617.90	68.66	13417.14	2341.34	260.15	Fu et al. 2007a
1994	4636.10	1095.20	136.90	17567.06	4149.92	518.74	Satellite data
1998	5357.60	721.50	180.38	20300.96	2733.90	683.48	Satellite data

Table 6.5 Average annual river runoff in the Sanjiangyuan region the late twentieth century ($\times$ 10^8 m^3; Han 2004)

Region	1956–2000	1991–2000
Yellow source	204.9	174.8
Yangtze source	122.1	112.0
Mekong source	43.5	42.9
Sanjiangyuan region	370.2	329.7

these species, especially plateau pika, are critical ecosystem engineers in this region (see Smith and Foggin 1999).

6.3.5 Declining Water Supply From Headwater Areas

Water production in headwater areas of Qinghai province has declined in recent years. Upper reaches of the Yellow River stopped flowing for the first time in recorded history in 1997 (Han 2004). Since 1990, water levels of Zhaling Lake and Eling Lake have declined by 2 m, and under extreme conditions flow between the lakes ceased. Around 1070 lakes in the Sanjiangyuan region have dried up in the last 20 years, of which 1040 were in the Yellow River source zone (Chen et al. 2007). From 1956 to 2000 average annual river runoff in Sanjiangyuan was 370.20×10^8 m^3, but it decreased to 329.70×10^8 m^3 in 1991–2000, a reduction of 10.90% (Table 6.5). The prolonged decline in discharge in the upper reaches not only constrains the sustainable development of herders living in the region itself, it also influences the livelihood of people downstream. The retreat of glaciers and shrinkage of lakes has caused a decrease in water level and degradation of wetlands in the region. Reduced runoff has brought about a water supply crisis in some settlements and towns. Herders have been forced into other areas in efforts to enhance their living standards, increasing grazing pressure and further degrading grassland areas (Chen et al. 2007).

6.3.6 Biodiversity Losses

Habitat fragmentation and isolation have brought about biodiversity losses in the region. Threatened species make up 18% of the total number of species, much higher than the world average of 13% (Chen et al. 2007). As many living forms on the plateau have special germplasm, the prospective disappearance of these species would reduce the gene pool that has adapted to the frigid alpine conditions. Habitat fragmentation and illegal hunting have reduced numbers of protected wildlife such as Tibetan antelope from a population of 10×10^4 in 1985 to 3×10^4 in 2002 (subsequent increases reflect tightening of regulations and anti-poaching efforts). Alpine musk deer (*Moschus sifanicus*) are almost extinct (Chen et al. 2007); these animals are highly sought for musk – a traditional medicine. There have also been declines in national first class protection animals such as white-lipped deer (*Cervus albirostris*), red deer (*Cervus elaphus*) and snow leopard.

Table 6.6 Population, livestock and pasture changes in Qinghai province (1949–2003) (Fu et al. 2007b)

Year	Population of pastoral area (10^4 persons)	Livestock number (10^4 Cattle/sheep)	Livestock number per capita (Cattle/sheep)	Grassland area per capita (ha)	Grassland area per livestock (ha)
1949	21.96	748.73	34.10	143.87	4.20
2003	70.00	2217.65	31.68	45.13	1.40

6.3.7 Human Induced Factors that Promote Ecological Degradation in the Sanjiangyuan Region

Socio-economic development in the Sanjiangyuan region relies largely upon grazing livestock, supplemented by activities such as illegal hunting, uncontrolled gathering and digging of herbal medicine, and mining. These harmful practices and ineffective management of resources have brought about numerous environmental problems. Population growth has increased the demands for animal husbandry in Qinghai, indirectly affecting grassland areas. Alongside climate warming and economic activities, severe ecological degradation in the region has resulted, in part, because of grassland property-rights, law regulation and cultural transformations (Ma 2007). Grassland property-rights in the Sanjiangyuan region have been transformed from an early tribe and temple (or monastery) possession system through a mutual cooperation system from 1949 to 1958, a community possession system from 1958 to 1978, and a family contract management responsibility system from 1978.

Bai et al. (2002) consider overgrazing to be the key reason for grassland degradation in Maduo County. Since the 1950s the human population of pastoral areas of Qinghai province has increased by 3 times, and the number of livestock has more than doubled (Table 6.6; Fu et al. 2007a). In response, grassland area per sheep unit has decreased from 4.20 ha in 1949 to 1.40 ha in 2000. This doubling of the stocking rate has forced herders to graze their livestock at even higher elevations, expanding the impact and damage of these activities (Wang and Cheng 2001; Zhou et al. 2003b, 2005). As shown on Fig. 6.6, stocking rates increased notably in the 1990s, reaching a peak in 1992 (Fu et al. 2007a). The theoretical capacity of stocking on natural grassland in Qinghai was 36,254,500 sheep units in the early 1980s (Fu et al. 2007a). Grassland degradation has reduced the current carrying capacity of grassland to 75% of that experienced in the 1980s (around 27,200,000 sheep units; Agricultural Resources Section Office of Qinghai Province 1999). Based on these numbers, the region was overstocked by about 6,330,000 sheep units from 1980 to 2003. This effect was most pronounced from 1990 to 1996, when the average rate of overload was 33.6% (Fig. 6.6). This is consistent with the accelerated rate of grassland degradation at this time (Fu et al. 2007a). Grassland overgrazing is most pronounced in winter and spring. It has brought about sparse, low and degraded cover and enhanced growth of poisonous plants, reducing the capacity for self-restoration. These consequences, in turn, provide good conditions for burrowing animals. Areas of alpine meadow have become extremely degraded as the vegetation community

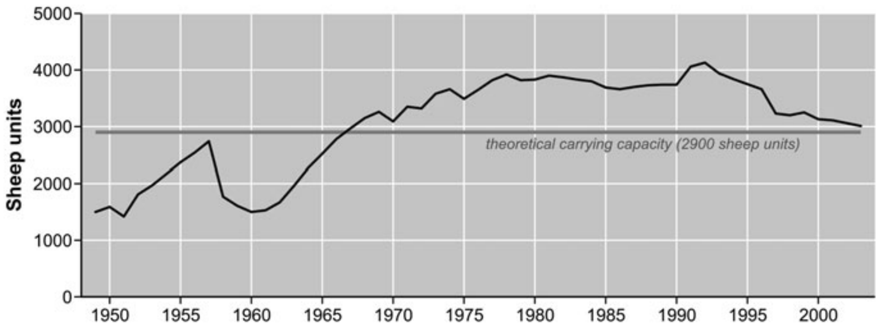

Fig. 6.6 Trend in sheep units (× 10^4) in the Sanjiangyuan region (1949–2004), showing the excess stocking rate since the 1970s (Fu et al. 2007b)

structure has been altered and soil fertility has been depleted. A vicious circle has been generated, characterized by overgrazing—vegetation degradation—harm by rodents and pests—grassland degradation—intensified mismatches between animal husbandry and management of grasslands.

Qinghai is a province rich in wildlife resources, with numerous unique wildlife of high economic value. Since the 1980s, illegal hunting has become a more and more serious problem (Wang et al. 2000; Zhou et al. 2005). More than 100,000 musk deer were killed in the 1980s, reducing their population by 90%. Snow leopards are increasingly rare. Illegal hunting resulted in the loss of 32,000 Tibetan antelope at the end of 1990s (Chen et al. 2007). The on-going illegal hunting of wild yak and wild ass (*Equus kiang*) has resulted in the rapid reduction of this rare and valuable wildlife.

Economic interests have encouraged more than 200,000 outsiders to move into the Sanjiangyuan region seasonally for gold mining or gathering of herbal medicines. This has resulted in serious damage to vegetation. In Autumn–Spring 2000, around 200 ha/day of shrub grassland was damaged and 7–8 m^2/day of grassland sod was destroyed adjacent to herders dwellings (Chen et al. 2002). Local herders use livestock manure and roots and stems of plants as a fuel, damaging grassland. In addition, gold mining disturbed 1.07 million ha of grassland in the 1980s, of which 33,000 ha was thoroughly destroyed (Zhou et al. 2005). Similar rangeland management issues are being addressed in the North-West of China (Squires et al. 2010).

6.4 Programme to Protect and Restore Socio-Economic and Environmental Values in the Sanjiangyuan National Nature Reserve

Efforts to protect biodiversity while enhancing the regional economy and prospects for development prompted the establishment of the Sanjiangyuan National Nature Reserve. The reserve comprises an area of 152,300 km^2, making up 21% of the

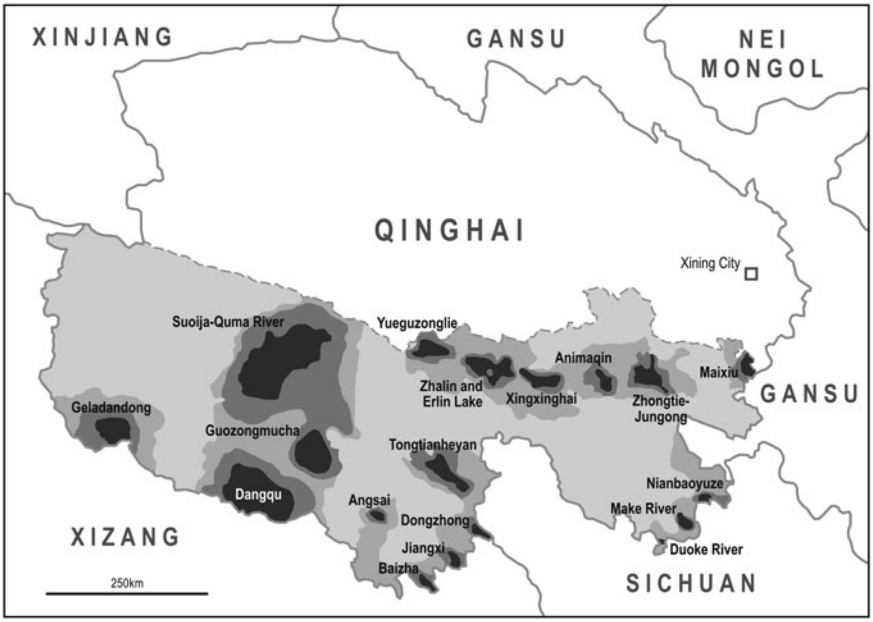

Fig. 6.7 Distribution of core (*dark tone*), buffer (*middle tone*) and experimental (*light tone*) areas in the Sanjiangyuan National Nature Reserve

total land area of Qinghai province and 42% of the Sanjiangyuan region (Chen et al. 2007). Protection and restoration of high altitude plateau ecosystems is a critical step in efforts to provide abundant, high quality water resources for the Yellow, Yangtze and Mekong Rivers. Large scale planning and design are required to reverse degradation trends in the region. This entails both protection on the one hand, and restoration of forest, grassland and wetland ecosystems on the other. The main protection targets are:

- Alpine wetland ecosystems, including glaciers and snow-covered mountains, swamps, and lakes;
- Protected wildlife and other species of national and provincial importance, including Tibetan antelope, wild yak, snow leopard, blue sheep, Tibetan gazelle, caterpillar fungus and orchids (*Orchidaceae* spp.);
- Sparse alpine forest ecosystems, such as Balffour spruce (*Picea likiangensis var.*) forest and Qilian savin (*Sabina przewalskii*) forest.

The functional area of the Sangjiangyuan Natural Reserve is divided into core, buffer and experimental areas (Fig. 6.7). Core areas are strictly protected areas; buffer areas are important protected areas; experimental areas are normal protected areas in which consideration is given to both protection and utilization. The 18 core areas take up 31,218 km^2, equivalent to 20.5% of the total land area of the reserve (Chen et al. 2007). The present human population within core areas is 43,566 people. Criteria used to design the core areas include:

- To protect typical natural ecosystems in the area, fostering growth and reproduction of targeted wildlife, plants and organisms and their habitats.
- To separate areas of environmental protection and restoration from human activities.

Landscape planning and GIS analysis used population viability analyses to designate the network of core zones and associated corridors (Tang 2003; Table 6.7). Three core areas, Suojia-Quma River, Jiangxi and Baizha, which take up 37% of the total core area, have been designated to protect wildlife. Seven core areas, Tongtianheyan, Dongzhong, Angsai, Zhongtie-Jungong, Duoke River, Maixiu and Make River, taking up 15% of the total core area, protect typical forest and shrubland. Finally, eight core areas, Animaqin, Xingxingha, Nianbaoyuze, Dangqu, Geladandong, Yueguzonglie, Erlin-Zalin Lake and Gouzongmucha, taking up 48% of the total core area, are used to protect wetland ecosystems (Chen et al. 2007). Core areas in the west typically focus on wildlife, core areas in the east focus on forest and shrubbery, and core areas in headwater areas and around lakes focus on wetland ecosystems. Protection measures include closing the area for strict protection, forbidding hunting, suspending grazing, stopping deforestation, and forbidding resource development activities.

Buffer areas surround core areas, or they connect core areas to assist in protecting targets (i.e. they address concerns for fragmentation; see Fig. 6.7). The principle tasks of the buffer areas are to control the impact of threatening factors/processes, and to restore and harness slightly degraded ecosystems. Buffer areas take up 39,242 km^2 (25.8% of the total land area of the reserve). The present human population in buffer areas is 54,254 people (Chen et al. 2007). Criteria used to design buffer areas include:

- To buffer main protection targets from influences outside the natural reserve.
- To link core areas to assist in the protection of wildlife.
- Separation from towns, factories and mining sites.

Measures taken in the buffer areas include reducing grazing livestock numbers to sustainable forage, controlling grazing intensity through rotational grazing, and closing some areas for restoration of forest and grassland vegetation.

Experimental areas outside core and buffer areas take up 81,882 km^2 (53.7% of the total land area of the reserve; Fig. 6.7). The present human population in experimental areas is 125,270 people (Chen et al. 2007). Criteria used to design experimental areas include:

- To aid the development and improvement of socio-economic conditions, production and living standards of herders, while promoting societal progress by adjusting industrial structures to optimize the disposition of resources and promote regional opportunities (e.g. eco-tourism).
- To assist the restoration and rebuilding of degraded ecosystems.
- To enhance the management of fragmented protection targets by providing a natural defence for core and buffer areas.

Table 6.7 Protection aims in the 18 core areas of Sanjiangyuan National Nature Reserve (Tang 2003)

Core name	Protection targets	Location	Area (km^2)
Animaqin	Snow mountains and glaciers	North–West of Maqin county	507
Xingxinghai	Lakes and wetlands	In Madou county	984
Nianbaoyuze	Snow mountains, glaciers and lakes below	In Jiuzhi county	262
Dangqu	Wetlands and swamps	West of Zadou county	5,843
Geladandong	Glaciers and vegetation around	Tanggulashan town in Geermu city	1,952
Yueguzonglie	River, lakes and swamps	In Madou town of Qumalai county	963
Erlin–Zalin Lake	Lakes and swamps around	In Madou county	1,818
Gouzongmucha	Snow mountains river lakes and swamps	Between Zadou and Zhidou county	2,883
Soujia-Quma River	Tibetan antelopes wild yaks, monkeys etc. and swamps	Between Qumalai and Zhidou county	10,684
Jiangxi	Macaques etc. wild animals and their habitat	In Nangqian and Yushu county	337
Baizha	Golden leopards, snow leopards and clouded Leopards	In Nangqian county	419
Tongtianheyan	Cypress and shrub forests	In Yushu and Chendou county	1,355
Dongzhong	Spruce forests	In Yushu county	493
Angsai	Forests and shrubs	In Zadou county	356
Zhongtie–Jungong	Spruce forests	Between Maqin, Tongde and Xinghai county	1,341
Duoke River	Conifers	In Banma county	110
Maixiu	Forests	In Zeku county	544
Make River	Defoliate broadleaf, conifers and shrubs	In Banma county	367
Total			31,218

Projects planned for experimental areas include:

- In areas where human population is greater than the carrying capacity, herders will be resettled in aggregated locations. Prospectively, this ecological immigration policy will minimize pressure on the natural grassland, enhancing restoration efforts.
- To determine sustainable grazing livestock numbers given the quantity of available forage in the area, suspending grazing in some areas in efforts to restore grassland vegetation.
- To protect and rehabilitate forest and grassland vegetation, wetlands and wildlife.
- To construct water supply facilities and develop new energy for household needs.
- To set up research and monitoring bases.

Planning of the Sanjiangyuan National Nature Reserve considers ecology-based protection and construction in relation to herders production and lifestyle values while accelerating the development of the local economy. Proactive, preventative measures taken to improve ecological conditions include suspension of grazing to improve grassland vegetation, reverting crop land back to forest or grassland cover, and fencing off areas for restoration of grassland vegetation. This is accompanied by resettlement of ecological immigrants into small towns, rodent-disaster programmes and small-scale water and soil erosion measures in efforts to enhance livestock production and control the spread of desert and areas of degraded grassland (see Foggin 2008). These initiatives will assist efforts to promote water conservancy (Zhou and Yie 2007). However, experience shows that such programmes are not always effective (see Agrawal and Redford 2009; Dowie 2009; Blue 2010; Foggin 2011).

Measures taken to improve wetland conditions will include:

- enclosing wetland areas to promote self-regeneration of natural vegetation
- re-sowing wetlands that have been subjected to severe degradation
- reducing livestock numbers or stopping grazing adjacent to wetlands
- application of biological and ecological techniques to control rodents in areas where they have brought about severe damage.

Bans on fishing and wildlife management programmes protect animal resources in the region. Marked improvements in energy sources will improve herders' income and reduce dependencies upon remaining areas of forest and natural grassland. New technologies will be developed and trialed, such as rainfall generation (especially in the Yellow River source area) and engineering practices that will reduce the threat of desertification. International experience guards against undue expectations from such 'technofixes' (e.g. Higgs 2003). Hazard reduction management will include attempts to fire proof areas of forest and grassland. Ecological compensation mechanisms will be put into effect for those people affected by these environmental protection and restoration programmes (Li 2007).

Prospects for ecologically-linked industrial and societal developments in the Sanjiangyuan region are contingent upon protection of ecological values in the first instance. The main conflict between human and ecological values in the region relates to the protection/repair of ecosystem attributes in the face of increasing demands for land and water use brought about by population growth (Wang and Wang 2004). Of the 651,000 people in the region, 90% are Tibetan (Sheng 2006). Survival of herding traditions requires utilization and income generation from local resources in a manner that minimizes harm to the environment through overgrazing, soil erosion, desertification, and reduced water availability. Migration policies have been applied in light of these population pressures. These measures have been supplemented by assistance to develop more intensive industries, along with training programmes to improve labour skills (Sheng 2006). Steps taken include: modernization of the animal husbandry industry (including enhanced livestock processing; Zhang et al. 2005), development of regional grassland industries, production of new Chinese and Tibetan medicines, and promotion of ecotourism opportunities (Fang and Liu 2006; Wang et al. 2007). Animal husbandry production is a main component of economic development in the Sanjiangyuan region. As traditional practices applied in the farming of yak and Tibetan-sheep use no fertilizer, pesticide or other chemically synthesized materials, the Sanjiangyuan region is an ideal area to develop organic agriculture (Guo 2005; Shi 2006). These prospects promote a win–win 'green economy' for the plateau, protecting the environment while improving farmer's income. To assist these developments, adjustments to the service sector are underway, including infrastructure and governance arrangements, transportation, education and monitoring programmes (Chen et al. 2007).

The total investment for the Program on Ecology-based Protection and Construction of the Sanjiangyuan National Nature Reserve in Qinghai is estimated at 7.5 billion Yuan (RMB) (Chen et al. 2007). This includes:

- 4.92 billion Yuan for ecology-based protection and construction.
- 2.22 billion Yuan for construction of infrastructure to enhance living standards for herders.
- 0.36 billion Yuan for measures to support ecological protection.

6.5 Discussion

Efforts to address the 'big' questions, rather than becoming overwhelmed by the tyranny of small-scale thinking and approaches, have prompted the development of numerous large-scale conservation initiatives in differing parts of the world. These landscape-scale applications recognize that extensive reserves and/or protected areas are required to maintain and/or enhance the resilience of ecosystems. Reserve systems across the world comprise a biased sample of biodiversity as they are typically located in remote places and in areas that are relatively unsuitable for commercial activities (Pressey 1994). Having said this, mountain regions are not only treasures of high biodiversity that are rich in endemic species, they also provide a fundamental source of high quality water, other products (wood, minerals, game, food, traditional medicines, etc.), and recreational opportunities (Hamilton and Macmillan 2004). Unless these areas are protected as reserves, human exploitation of resources is likely to occur, and degradation will ensue. Reserves are required to support long-term survival of species (e.g. Soulé 1987). In most cases, conservation goals will not be met unless the ecological integrity of conservation targets is restored (Hargrove et al. 2002). Ecological restoration is expensive, costing an estimated 2–5 times more than conserving intact and viable examples of natural communities (The Nature Conservancy 2000). Conservation planning, as such, is a fundamental and cost-effective component of biodiversity management and sustainable development.

Biological diversity is inextricably linked to the variety of landscapes in any ecoregion. Healthy ecosystems are self-sustaining and resilient–evolving systems that adapt and change over time. In fragmented landscapes populations can be prevented from reaching migration and dispersal destinations such that they are forced to live in habitats that are not large enough for their survival as they are unable to achieve genetic exchange. The steep environmental gradients and proximity of different altitudinal zones in mountainous regions present significant opportunities for biotic adaptation to environmental changes. Hence, large areas must be conserved to protect the adaptive capacity of these systems, giving species the opportunity to migrate to new habitats. The Sanjiangyuan National Nature Reserve is among the largest nature reserves in the world, with the highest and most extensive wetland protected area. The total area of the reserve is marginally greater than the land mass of England and Wales.

Water resources planning strategies and landscape ecology programmes in the Sanjiangyuan National Nature Reserve link lake and river ecosystems to grassland, forest and wetland management programmes at the landscape scale. The 18 core areas of the reserve have been framed in relation to water management strategies in wetlands, lakes and forests (Tang 2003; Chen et al. 2007; see Table 6.7). In this era of environmental repair, it is recognized explicitly that conservation programmes alone are not enough, and major efforts have been put in place to facilitate rehabilitation, promoting self-recovery mechanisms wherever possible (Brierley and Fryirs 2008). An ecosystem approach to environmental management has been adopted, wherein these applications strive to ‘work with nature’, emphasizing big-picture relationships at the ‘whole of system’ scale.

The approach to conservation planning adopted in the Sanjiangyuan National Nature Reserve mimics developments elsewhere in the world, emphasizing concerns for targeted species within process-based conservation and restoration plans. An umbrella species approach to conservation focuses upon keystone species, thereby facilitating the conservation of many other species with coincident, or a smaller range of, habitat needs. The approach to ecological protection and restoration in the Sanjiangyuan National Nature Reserve closely parallels the aspirations of the Pan-European Ecological Network (STRA-REP 2006) in that it aims to:

- Conserve a full range of ecosystems, habitats, species and landscapes in efforts to ensure the existence of healthy, intact and connected wildlife habitat.

- Ensure landscapes are large enough to conserve viable populations of keystone species.
- Reduce the impacts of fragmentation, providing sufficient opportunities for the dispersal and migration of species. This enables genetic exchange between different local populations and allows local populations to move away from degraded habitats.
- Restore damaged parts of key environmental systems, while securing the integrity of vital environmental processes.
- Buffer key environmental systems from potential threats.

Linked networks of core areas, corridors and buffer zones enhance resilience and mitigate against biodiversity loss and impairment of ecosystem services, promoting flexibility and adaptivity in light of environmental changes. Core areas with a variety of linkage zones are required to fulfill the vision of contiguous wildlife habitat (Bouwma et al. 2002). These areas act as reservoirs for biodiversity where evolution and reproductive processes can take place. A physical network of core areas, linked by corridors and supported by buffer zones, enables the dispersal and migration of species. Linkage zones are more than simple corridors: they are habitats with sufficient food and resources to support minimal wildlife populations and to accommodate the continual residence and movement of species between core areas (Bouwma et al. 2002). Corridors facilitate ecological connectivity and coherence, thereby enhancing the self-regulating capacity of ecosystems as species are able to disperse, migrate, forage and reproduce. Buffer zones provide protection from adverse external damages and disturbance, increasing the flexibility and adaptive capacity of core areas to respond to environmental changes. These areas may perform a corridor function or in themselves harbour valuable biodiversity, such as species populations that are dependent on traditional forms of agriculture (Bouwma et al. 2002). Sound management of human activities in these areas decreases the potential impacts and probability of isolation. Buffer areas that allow for approved manipulative research and low impact uses by residents surround well-protected core areas in the Sanjiangyuan National Nature Reserve.

Effective conservation programmes do not view ecological reserves as isolated landscape fragments. Rather, protected areas are linked to the wider region, providing a basis for the sustainable use of landscapes and natural resources. Precautionary measures provide sufficient ecological and landscape quality over as wide a range of territory as possible. This enhances the adaptive capacity of the system, enabling appropriate adjustments to be made in response to social and environmental changes. Many species within protected areas depend upon resources outside them. The transitional zone (experimental area) beyond the core/buffer areas in Sanjiangyuan National Nature Reserve has been established to promote collaboration and engagement with local residents in efforts to meet the conservation goals of the reserve (c.f., Smardon and Faust 2006).

Monitoring networks have been set up in the Sanjiangyuan region to support decision-making for further utilization and conservation and to adjust policies on the reserve are required. For example, GIS, remote sensing and modeling applications are being used to assess the rate and extent of damage by burrowing mammals, grassland degradation, desertification and the pattern/rate of erosion. Various experimental programmes have been established to trial new approaches to improve the management of wetlands, desertification, fish stocks in lakes, regeneration of grasslands, etc. Recent research has highlighted the success of these measures. There are increased numbers of wild animals such as blue sheep, wild ass, wolves (*Canis lupus*), golden eagle (*Aquila chrysaetos*), Tibetan antelopes and snowcocks (*Tetraogallua tibetanus*) (Ren 2008). Lakes that had dried up have water once more (Zhu and Dai 2008). Vegetation cover has reestablished in many areas of bare land (Zhu and Dai 2008). Critically, these elements work together to enhance ecosystem health. For example, recovered wild animals help to re-establish the food chain structure of the plateau ecosystem, as eagles and weasels limit undue degradational influences of burrowing mammals upon grassland (recognizing, in turn, that plateau pika are themselves key ecosystem engineers (see Smith and Foggin 1999)). Results from environmental monitoring programmes will be utilized to assess trends in ecosystem performance, identifying threatening processes that may compromise the integrity of ecosystems (cf. Margules and Pressey 2000).

Visions for an ecologically sustainable future integrate proactive biodiversity management programmes with coherent strategies that promote regional development and natural resource management. The quest for sustainability frames environmental condition in relation to socio-economic and cultural considerations—both now and into the future. Ecological degradation and biodiversity losses in the Sanjiangyuan region will continue unless human developments are managed appropriately (Foggin et al. 2006). Community engagement and education are required to unite conservation goals with sustainable development initiatives. Available resources in the Sanjiangyuan region are unable to meet the needs of the growing population, creating an imbalance between human development and environmental resources. Measures adopted to address this problem include migration policies (Sheng 2006; Chen et al. 2007), increasing local economies by developing ecotourism opportunities (Fang and Liu 2006; Wang et al. 2007), enhanced production of organic foods (Guo 2005; Shi 2006) and increasing high technology applications (Chen et al. 2007; Li 2007a, Zhang et al. 2005). Importantly, benefits from environmental conservation and rehabilitation measures extend well beyond the Sanjiangyuan region. Coherent approaches to management of water resources in headwater areas assist prospects for stable and sustained economic development downstream. Programmes that facilitate environmental protection and restoration in the Sanjiangyuan region promote ecological security for half of China.

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