Landscape Ecol Eng (2007) 3:1–13
DOI 10.1007/s11355-006-0018-4

REVIEW

Degraded ecosystems in China: status, causes, and restoration efforts

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Received: 28 July 2006 / Revised: 6 November 2006 / Accepted: 15 November 2006 / Published online: 9 January 2007
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Abstract The total area of China is about 9.6 million km^2. Among the terrestrial ecosystems, cropland area is about 1.33 billion ha, 78% of which is degraded land; forestland area is about 1.75 billion ha, 72% of which is forest deterioration; grassland area is 3.99 billion ha, 90% of which has already degraded. Derelict mining land area is about 6 million ha, which is increasing by 12,000 ha/year. So far, only 8% of the total derelict mining land area has been reclaimed. A total lake area of 1.3 million ha has been lost since 1950; 50% of the coastal wetlands has been reclaimed. The mangrove area has declined from 40,000 ha in 1957 to 18,841.7 ha in 1986. With a total of 0.18 billion ha of water area, over 50% of it has been polluted to type III–V in terms of the Chinese Water Quality Standard Classification System. Oceanic area is about 4.73 billion ha, over 1.6% of which is also polluted. Environmental pollution is very severe in China, especially the environmental problems in rural and agricultural areas. Water resource is severely lacking and most river ecosystems are facing deterioration. The oceanic environmental problem is still fearful. Water and soil eroded areas have been increasing year after year and have become the most severe environmental issue in China. In addition, land desertification, prairie deterioration, and land salination have been increasing at an accelerating rate. Forest function has weakened and the current environment in derelict mining land areas are headachy. Biodiversity has been destroyed badly. The reasons for the deterioration of China's environment are diverse, such as the pressure of a large population, industrialization, and its markets. The deterioration of the ecological index has already affected the current economic index and prospective economic growth directly and obviously.

Keywords Cropland · Ecosystem degradation · Forest · Grassland · Restoration

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Introduction

Ecosystem degradation is a natural process, along with the abduction and acceleration of human activities, such as the inappropriate employment and management of agricultural land, forest destruction, over grazing, poverty, legal frameworks, government policies, and institutional structures. Ecosystem degradation is one of the most prominent global environmental problems. So far, there has been 20 billion ha of land deterioration in the world, which takes up 22% of the area of farmland, prairie, and forest. About 5 million ha of cropland cannot produce crops because of the deterioration in the world every year. At this speed, one third of the arable land will be lost in the next 20 years around world. The large decline in land productivity has resulted from ecosystem degradation. In the past 50 years, global agricultural production has declined by about 11.9–13.4% because of ecosystem degradation (FAO 1979, 1994; Daily 1995; Middleton and Thomas 1997). In addition, land degradation has resulted in many environmental problems, such as the filling up of rivers and lakes, changes in the soil organic carbon reserve, the disappearance of special habitats, and the loss of biodiversity, which greatly threaten human survival and sustainable development. Therefore, to keep food safe and sustain a healthy environment, preventing land from degrading, restoring and reconstructing degraded ecosystems, and taking effective actions to make the sustainable use of land resources come true are the hot spots concerning government organizations, non-government organizations, scientific communities, and the public alike.

Recently, the Chinese government has paid much attention to the protection of natural ecosystems and the restoration of degraded ecosystems. According to the State Environmental Protection Administration of China (SEPAC, 2003), in 2004, there were about 2,194 natural reserves in China, including 226 national natural reserves, which total 14.8% of the country's area. Those natural reserves play an important role in protecting wild animals and plants, wetlands, culture, and landscape, improving the environment, and prompting socially sustainable development in practice (Li and Zhao 2004). However, China is one of the nations having the most severe problems with land degradation and hungriness, and land degradation has already greatly influenced the sustainable development of society and the economy. Therefore, recently, the Chinese government brought forward to establish a ''harmonious society'' from only the recognition of economic development, but ignoring the protection of the environment in the past, and strengthen the construction of harmony between humans and nature. This paper will report on the spatial and temporal distribution patterns and restoration status of degraded ecosystems in China and discuss the strategies and techniques that have been employed.

Ecosystem types and their spatial distribution

The total area of China is about 9.6 million km^2, which makes it the third largest in the world. Its latitudes range from 4°N (tropical zone) to 53°N (cold-temperate zone), it is 5,500 km long from the south to the north, including nine climate zones, and 5,200 km wide from the east to west, spanning 62° longitude. The topography is very variable and complicated, with high mountains, basins of different sizes, undulating plateaus and hills, and flat and fertile plains, 46 types of soil, 29 vegetative types, and 48 types of land use types. In addition, the coastline of the mainland is about 18,000 km long and its oceanic area is 4.73×10^9 ha (Sun 1995; Shen 2001).

For the terrestrial ecosystems, over two thirds of the total area is mountains and hills, and only one third of which is relatively flat. The cropland area is about 1.33×10^9 ha, forestland 1.75×10^9 ha, and grassland 3.99×10^9 ha; the summation of these three parts is about 70%. Among the above land use types, first-class cropland only accounts for 40%, 13% of the first-class grassland, and 65% of the first-class forestland. Over 90% of the cropland is distributed in the eastern wet and semi-wet areas with an annual rainfall >400 mm (He 1996).

In general, China has a large land area, abundant resources, and diverse ecosystem types (See Fig. 1), but its per capita land resource is small. The relative lack of natural resources and the small survival space makes China a country with intensive resource restriction. The average amount of cropland, forestland, and grassland per capita in China is only one third, one fifth, and a quarter, respectively, of the average amount of each person in the world (WRI 1998; Peng 2003). The land which is of poor quality amounts to a large proportion, and resources are distributed lopsidedly and combined improperly. The intensity of resource exploitation is great, but the resources support is generally absent (Table 1).

Degradation and restoration of typical ecosystems

A degraded ecosystem refers to a beyond-nature system that is formed under natural or human disturbances. Compared to natural ecosystems, the component, community, or system structure of a degraded ecosystem has changed, biodiversity decreased, biological productivity reduced, soil and microenvironment deteriorated, and relationships between organisms changed (Ren and Peng 2001). A degraded ecosystem includes all kinds of soil degradation, the blight of water resource produced by human activities, the destruction of forest vegetation, and the decrease of grassland productivity, etc. Ecosystem degradation mostly represents the reductions in both quantities and qualities of ecosystem services (FAO 1994; Liu 2000; Wu and Wang 2003). The following discussion in this section describes the condition of typical ecosystem degradation and restoration in China.

Cropland ecosystem degradation

China's cropland area was 1.12 billion ha in 1957 and the average amount per capita was 0.19 ha. Since then, although there have been some reclaimed croplands, the total cropland area has declined by 5.4 million ha and the resultant crop production drop was 25 billion kg/year between 1981 and 1995 (Zeng 1998; Peng

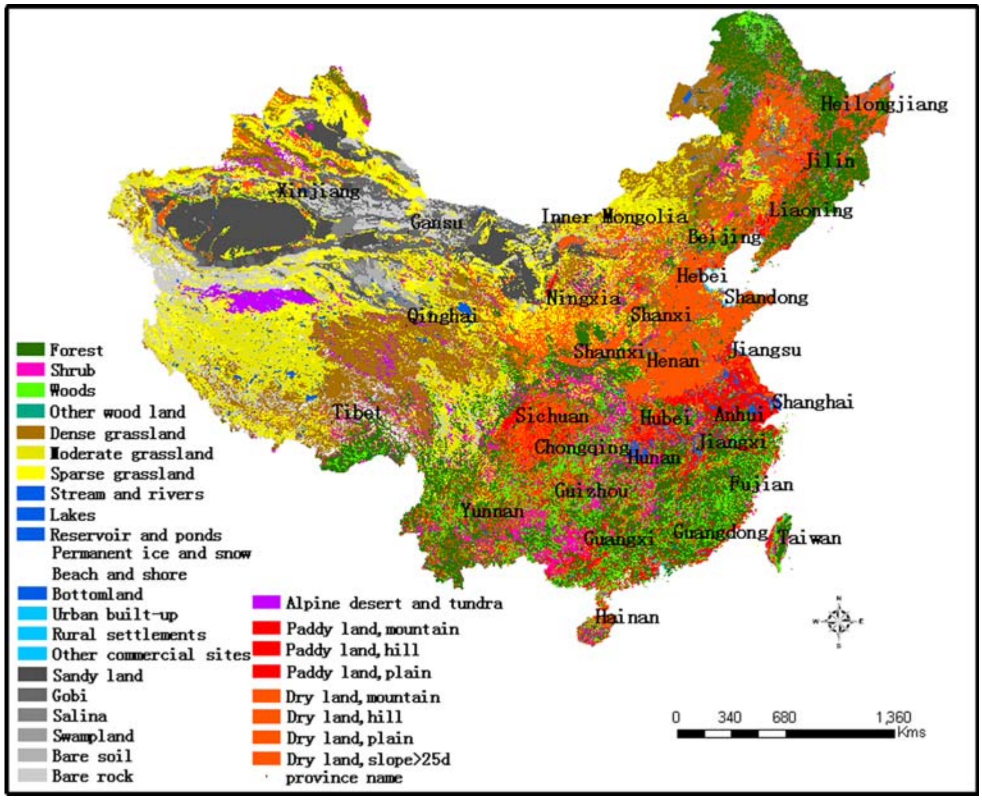

Fig. 1 Spatial distribution of the natural resources of China (TM image 2003). The labels show the rough location of China's provinces

Table 1 Area composition of the major land cover types in China

Type	Total area (10^9 ha)	Proportion of country area (%)	Source (in 2004)
Cropland	1.33	13.90	National Land Resource Department
Forestland	1.75	18.21	Forest checking of the National Forestry Department
Grassland	3.99	41.55	Grassland investigation of the Ministry of Agriculture of China
Inland water area	0.18	1.85	National Agriculture Department
Gobi, quicksand, and barren terra	1.85	19.27	National Land Resource Department
Town, residential area, mine, traffic area	0.25	2.62	National Land Resource Department
Glacier	0.06	0.61	National Land Resource Department
Others	0.19	1.99	National Land Resource Department
Summation	9.60	100	
Ocean	4.73	100	National Ocean Bureau

2001). The present cropland area is about 1.33 billion ha, but the average amount per capita is only 0.11 ha; that is, less than half of the average of the rest of the world. However, different types of degraded land reached 78% among those croplands (Table 2). The reasons for cropland degradation are the following: only considering the utilization of the cropland but ignoring the maintenance; the improper using of fertilizer (too small an amount of organic fertilizer, too large an amount of inorganic fertilizer), which results in the unbalance of nitrogen (N), phosphorus (P), and potassium (K), the overuse of K; and secondary salination resulting from flooding. The massive employment of fertilizers and pesticides contributed to the acidification of soil, the pollution of underground water, and the erosion and hardness of the soil (Shen and Cao 2003).

Before the early 1960s, China's main agriculture type was traditional organic agriculture. Organic fertilizer and green fertilizer were mainly used for maintaining soil fertility, but the soil nutrition was unbalanced in most croplands and caused severe deg-

Table 2 Evaluation of cropland quality in China

	First class[a] (%)	Second class (%)	Third class (%)	Fourth class (%)
South China	30.07	47.22	21.85	0.86
Sichuan basin—down the Yangtze River area	48.24	31.54	19.01	1.21
Yunnan—Guizhou plateau	23.45	47.77	23.74	5.04
North China—southern Liaoning	37.70	40.59	18.92	2.80
Loess plateau	26.50	16.66	43.89	12.95
North-east area	65.20	31.07	3.19	0.54
Semi-drought area of Inner Mongolia	19.89	44.26	21.45	14.39
Drought area of the north-west	47.40	31.60	18.36	2.64
Qinghai–Tibet plateau	16.88	24.54	52.46	5.81
Whole country	41.33	34.55	20.47	3.65

[a] The cropland quality classification is mainly based on nutrient content in the soil, with nutrient-rich for the first class (total N content > 2.0 g/kg, available K > 20 mg/kg, and exchangeable K > 100 mg/kg), slightly poor for the second class (total N content = 1.5–2.0 g/kg, available K = 15–20 mg/kg, and exchangeable K = 80–100 mg/kg), moderately poor for the third class (total N content = 0.5–2.0 g/kg, available K = 5–20 mg/kg, and exchangeable K = 40–80 mg/kg), and severely poor for the fourth class that is basically non-arable (total N content < 0.5 g/kg, available K = < 5 mg/kg, and exchangeable K < 40 mg/kg)

radation. From the mid-1960s to the early 1970s, with the development of industrialized fertilizers, about 80% of N and P were gained from inorganic fertilizers, 20% of it was from depleting soil, and South China began using K fertilizer. N and P became basically balanced when the whole nation began using K fertilizer in the mid-1970s. From the late 1970s to the present day, the amount of fertilizer being used almost doubled. Considering the whole country, about two thirds of the total cropland belonged to middle-to-low productivity classes (only 3–5 t/ha.a), 59.1% of croplands lacked N and P, and 22.9% lacked K, and about 10.6% of cropland had less than 6 g/kg of organic substance in its soil. About 50% of the cropland bears 5–20 g/kg of organic substances in the whole nation (Zhang and Gong 2003).

There were about 60 million ha of farmland polluted by organic substances and chemical material in China. About 36 million ha of farmland was polluted by organic contaminants (such as pesticides, petroleum hydrocarbons, and PAHs), and, among them, 16 million ha was polluted from agricultural contamination. The amount of pesticide in the main farm products exceeded the standard by about 16–20%. Due to the extensive use of fertilizers, about 10 million t N/year were transformed into contaminants and entered the surrounding environment. About 7.8 million ha of land were polluted by agro-film, 25 million ha of farmland were polluted by heavy metals, and 12 million t of foodstuff were polluted by heavy metals every year. Brutes and aquatic bird breedings produced dejecta 17.3 billion t/a, which was 2.7 times that of industrial solid trash. About 400 million ha of cropland were polluted by industrial wastewater, waste gas, and waste solids, 1.867 million ha by villages and town industry, 13 million ha by pesticides, and 2.667 million ha by acid rain. The agricultural environment was badly polluted (Desertification Prevention and Cure Office of China 2003; Zhou and Song 2004).

China has 0.99×10^8-ha of salted alkali land, which are mainly distributed in the north-west dry region and the north-east moist region. Among them, the salted alkali cropland area of North China reached 313.75 ha, which was about 41.10% of the salted and alkalized cropland area of China (Zhang 1999; Zhang et al 2000). Currently, 35% of the cropland in the Xinjiang, Gansu, and Ningxia provinces has been threatened from the soil being salted and alkalized, and 50% of the cropland of Inner Mongolia have been salted and alkalized (Gong and Shi 1991).

According to the estimations, about 40,000 ha of land was taken up by the basic construction of industry and town development every year. The construction itself does not have the largest impact on land degradation, but it impacts on the land which has not been used; for example, mining in the open air destroyed land surface and vegetation and acid elements, alkali elements, or heavy metals in the mine trash resulted in soil pollution and was abandoned through runoff and floating dust. Due to randomly poured useless soil, stone, and slag, a lot of the agricultural lands have been taken up.

In order to prevent further degradation, the government should pay attention to providing employment opportunities and increase farmers' income, control agricultural production pollution, make use of traditional organic farming knowledge, improve the conservation of all kinds of varieties of crop, and train young farmers to decrease soil erosion and chemical pollution.

Forest ecosystem degradation and restoration

The State Forestry Administration of China (SEPAC) has organized six forest surveys in the past few decades(see Table 3). The sixth forest survey data indicated that there were about 2.58 billion ha of forest stand (shrub land+forest stand) and only 1.75 billion ha of cover forest, with a coverage of 18.21%, but the natural forest (mainly original forest or some original forest with less human disturbance) area was less than 5%. The forest timber volume was 124.56 billion m^3. The plantation area was 0.53 billion ha, which was the largest in the world, and the timber volume was 15.05 billion m^3. China's forest coverage was only 61.52% of the average amount in the whole world and was ranked 130th in the world. The forest timber volume per capita was only 9.421 m^3 and ranked 122nd in the world, and was less than one sixth of the average of the whole world. China's forests were distributed unevenly; the forest coverage in eastern China was 34.27%; in middle China, it was only 12.54%; but the forest coverage in the five northwest provinces that occupy 32.19% of the country area was only 5.86% (State Forestry Administration of China 2003, 2004).

Forestland that was suitable for plantation but remained abandoned accounted for only half of the forest stand area, which was more than 1 billion ha. There were 1.85×10^7 ha of sparse forest and 3.04×10^7 ha of shrub forest in existence. The forest resources were distributed asymmetrically, mainly in the southwest and northeast regions. The structure of the forest resources was also inappropriate. The proportion of timber forest area and volume accounted for three quarters of the whole forest resource. The proportion of shelter forest and other uses of forest resource were small. The area ratio of young forest, middle-aged forest, and mature forest were 4:4:2 (State Forestry Administration of China 2003). The area of coniferous forest was equal to the area of broad-leaved forest. The amount of timber that can be harvested was small. The general increase of forest resource was close to the consumption, which was already observed in China, but the general trend of the forest resource changes are as follows: forest coverage began rising, and forest area and timber volume carried on increasing, but the forest resource quality remained decreasing; the amount of timber volume per unit area was decreasing; and especially, the volume and area of the near-mature forest, the mature forest, and the over-mature forest was greatly decreasing (Zhou 1999; Zhang and Yuan 1999; Zhang 2002; State Forestry Administration of China 2003; Li 2004). In addition, the age structure of the forests was unreasonable, the management of the plantation was at a low level, a great deal of the established artificial forests with mono-species resulted in the lacking of biodiversity and stableness, non-native species had been widely imported and planted, features required by healthy ecosystems such as heterogeneity were ignored, the mutual biotic interaction among different species were ignored, rare and endangered species of climax had seldom been considered in forestation, and the ecological function of vegetation was neglected in town virescence and the landscape.

As a country with limited forest resources, China has recently made a great effort in developing its forestland; especially, the forest area and the volume of plantation have greatly increased. Few other countries around the world could be compared with China. Since 1949, its plantation area had increased by 42.6%, which was closely related to the rapid development of the construction of shelter forest at the upstream Yangtze River and the ''Three North (north, northwest, northeast) Shelter'' put forward by the country. When China's forestry benefitted from massive afforestation, the destruction of natural forest was getting worse, which resulted in the dropping of forest quality under the conditions of the enlargement of the total forest area. China's forest degradation showed the features of region and structure (Li and Li 1996). The main types of reforestation are as follows: exotics species (*Poplar deltoids*) was broadly planted in north China by monocultures (about 6 million ha and 19% of the total area of plantations); coniferous native species (*Pinus massoniana*) and coniferous exotics species (*Pinus*

Table 3 Changes in China's forest resources

Time (year)	Woodland (10^4 ha)	Forest area (10^4 ha)	Forest coverage (%)	Timber volume (10^8 m^3)	Plantation area (10^8 ha)	Coniferous forest area proportion (%)
1950	–	82.8	8.6	–	–	–
1973–1976	261.24	121.86	12.7	95.3	20.21	49.82
1977–1981	263.52	115.28	12	102.6	27.81	45.93
1984–1988	267.42	124.65	12.98	105.7	31.01	42.14
1989–1993	256.77	133.7	13.92	107.85	33.78	42.82
1994–1998	263.3	158.94	16.55	112.7	46.67	43.95
1999–2003	258.32	175.01	18.21	124.56	53.12	44.58

elliotii) in central and south China (about 59% of the total area of plantations); and exotics species (*Eucalyptus*) in south China. The structural changes in China's forest resource embodied the decrease of mature and over-mature forests. Regional forest degradation mainly happened at the southwest and northeast forested areas of China.

As seen from the above discussion, only 68% of the forest stand was covered by forest or plantation, but only 28% of those forests were natural forest. So, forest area that was not degraded only accounts for 28% of the total forest area. The forest degradation issue has been ignored for a long time. The result of forest degradation represented the water/soil erosion problem and the loss of biodiversity. Forest degradation was considered to be the major reason for the Yangtze River and Songhuajiang River floodings in 1998. Because of the unreasonable inspiriting mechanism, the lack of market reform, the deficiency of management, the pressure of population increases, and increasing market demands sped up forest degradation. Market reform of the Chinese Forestry Department lagged behind other reforms. The elements of reform in current industrial and agricultural departments have not been put into practice in forest departments. Leaders of forest departments have rejected the non-collectivizing of forest stand property rights and the contract management of national and collective forest stand. In addition, forest departments strongly resisted against the market reform in the collective forestland. The investment of large projects greatly depended on governmental planning and financial support. Increased government investment only reproduces the old mechanism that has been improved to result in forest degradation if there is no management system reform under the economic system.

Several lessons can be learned from the Chinese government: the conservation and management of natural forest resources (for example, the Chinese government established the National Forest Conservation Programme in 1998), the control of forest fires and the protection of forests from pests and insects, rational felling and regeneration, strengthening the development of protective shelterbelts in the key environmental fragile regions, the conservation of biodiversity and the establishment of nature reserves, afforestation and mandatory conservation of marginal farmland to forestlands, reform forestry policy, and strengthening forestry research and training (Li 2004).

Several problems should be pointed out during the forest restoration in China: a large amount of the established artificial forests with mono-species result in the lack of biodiversity and stableness; non-native species have been widely imported and planted; features required by a healthy ecosystem, such as heterogeneity, are ignored; the mutual biotic interaction among different species are ignored; rare and endangered species of climax are seldom considered in forestation; and the ecological function of vegetation is neglected in town virescence and landscape.

Grassland ecosystem degradation

There is about 3.99 billion ha of natural grassland in China, which only accounts for 41.6% of the country's area and ranks second in the world (Australia ranks first). However, there is only 0.33 ha of grassland per capita, which is only half of the average level of the world. There is about 19.32 billion ha of grassland in pasturing areas, 5.9 billion ha of grassland in half-agriculture and half-pasturing areas, 12.11 billion ha of grassland in agriculture and forest stand areas, 2 billion ha of grassland in lake, river, and coastal belts, which account for 49.2%, 14.9%, 30.8%, and 5.1% of the total national grassland area, respectively. Grassland quality is low in China. Low-productivity grassland accounts for 61.6% and 20.9% in middle-productivity grassland. The proportion of overused grassland is higher, which accounts for 5.57% of the total grassland area. The productivity of grassland in China is about 7.02 livestock product units, which is only 1/10th of Australia, 1/20th of America, and 1/80th of New Zealand (grassland investigation of the Ministry of Agriculture of China (2004)).

In the 1970s, the rate of grassland degradation was 15%. In the middle 1980s, badly degraded grassland area amounted to over 30% of the total grassland area. Nowadays, China's grassland has degraded severely; 90% of the grassland has already or is being degraded, among which, 1.3 billion ha of grassland has degraded at a mediate degree (including desertification and basification). Furthermore, it is increasing at a rate of 2 million ha/a. Degraded grassland in the northern and western areas reached 70 million ha, which accounted for 30% of the total pasturing area (Chen and Chen 1995). The grassland in Inner Mongolia's prairies and the Loess plateau suffered wind erosion and vegetation coverage was only 40%. The grassland in Yunnan Guizhou, Qinghai–Tibet plateau, faced severe water and soil erosion, and a palatable grass rate of only 36%. The grassland in the northwest had faced desertification. The reasons for grassland degradation were as follows: firstly, overgrazing and overusing for a long period of time; secondly, the dry climate caused grassland sandification in general; thirdly, human's chopping, overexcavating of medicinal materials, mining, excessive hunting, and the destruction of grassland vegetation resulted in grassland degradation (Wang 2004).

Arid ecosystem and its desertification

China is the country with the most deserts in the world. The total desert area is about 1.28 million km^2 and accounts for 13.3% of the country's area. The desert region is distributed in the northern latitudes of 37–50° and eastern longitudes 75–125°, including the Xinjiang, Qinghai, Gansu, Ningxia, Inner Mongolia, Shannxi, Liaoning, Jilin, and Heilongjiang provinces (Fig. 1), which forms a desert strap 600 km wide from south to north and 4,000 km long from east to west. Among them, the desert area was about 0.71 million km^2 and accounted for 7.4% of the country area. The Gobi desert area is 0.57 million km^2 and accounts for 5.9% of the country's area. The Takelamagan Desert, located in the Talimu Basin in the southern Xinjiang province, with an area of 33.76 km^2, is the largest desert in China and the second largest flowing desert in the world. The China government has invested a lot of resources to prevent and cure desertification, but the result was part-improvement the land desertification and sandification and the whole land was becoming worse (Zhu 1998). The most grim behavior was the increase of the desert area, which reached 5.20 km^2 from 1995 to 1999; the average rate of increase was 1.04×104 km^2/a. China's desert is still enlarging at a rate of 2,100 km^2/a, which is equal to the disappearance of the twice the land area of Hong Kong. According to the State, about 3.32 million km^2 of land was impacted by desertification in China, including about 1.53 million km^2 of sand hungriness land that accounts for 15.9% of the country's area. About 0.4 billion people, 15 million ha of cropland, 0.1 billion of grassland, hundreds of thousands of water conservancy engineers, and railways and transportation links were affected negatively by the desertification (Lu 2000; Yang 2004).

Derelict mining land

With the rapid economic development of China, its mining resource has been largely exploited. However, the ignorance of reclamation resulted in the existence of an abundance of derelict mining land. At present, China has more than 1,500 coal mines and the deposit reached 30 billion t in the past few years, which amassed to 6,670 ha of land area. About 25 billion t of disposed stone and gangue had been thrown away by non-coal mines in the past few years and has been still increasing by 3 billion t/a. At present, about 6 million ha of land was destroyed because of the mining and it is increasing at a rate of 12,000 ha/a (Wong 2003). Between 1989 and 1991, the National Land Resource Management Department restored 33,000 ha of land in ten provinces, including the Hebei, Gansu, and Jilin provinces, and 23 land reclamation spots as experimental units. So far, about 1 million ha of derelict mining land has been reclaimed, which only accounts for 8% of the total abandoned mining land area (Su 2000). However, the reclamation rate of mining land in China is increasing year after year. In the early 1980s, it was only 0.7–1%; 2% in the late 1980s; 6.67% in the early 1990s; 13.33% in 1994; and not more than 20% at present. If one ignores the quality, there is still a big difference from the 50% reclamation rate of the developed countries (Ma 2003).

Wetland ecosystem degradation

The lake area of China has dropped by 1.3 million ha compared to the early 1950s. More than 1,000 lakes disappeared because of mining. In the downstream region of the Yangtze River, mining resulted in the dropping of the lake area from 25,828 km^2 in 1949 to 10,493 km^2 at present, which accounted for 59.4% of the original lake area. Among them, the area of the Dongtinghu Lake, the largest lake in the past, has dropped to less than 2,270 km^2 at present from 4,300 km^2 in 1950. The Hubei province used to have more than 1,000 lakes, but now it has declined to 741 lakes and the water surface has declined to about three quarters. Wetland area has declined by over a half of the area in the past 56 years in order to build cropland for food (Guo 1990; State Forestry Administration of China 2000).

Coastal wetland was the most heavily destroyed area among all types of wetlands in China. Enclosing the sea and building cropland projects have been undertaken in China since 1950, mining in the coastal wetland reached 1.19 million ha by the end of the 1980s, 81% of which were converted into farmland and 19% of which was used for salt production. In addition, about 1 million ha of wetland was transformed into urban and industry land uses. The summation of those two items equaled 2.19 million ha, which is about 50% of the total coastal wetland area of China (State Forestry Administration of China 2004).

Because of the non-sustainable use and overexploitation of the aquatic produce and breeding fish, enclosing the sea to create farmland, denudation, and coastal mangroves decreased a large amount of the area. According to the investigations, the mangrove area in China dropped from 40,000 ha in 1957 to 18,841.7 ha in 1986 (Nu 2004).

Aquatic ecosystem degradation

According to the State Environmental Protection Administration of China (SEPAC, 2003), in 2003, there was 0.18 billion ha of aquatic area in China. If it was based on the pollution standard of type III–V of water quality (SEPAC 1989, 2003), polluted water accounts for over 50%. The oceanic area was 4.73 billion ha and polluted water accounted for over 1.6% of this.

Based on the water quality measurements from 407 key monitoring transects that were set up in the seven large river systems of China, 38.1% of the measured transects met the water quality of type I–III, 32.2% belonged to type IV–V, and 29.7% belonged to type V. These five types of water quality are distinguished mainly based on chemical contents in the water; for example, type V water has BOD ≤ 6–10 mg/l, COD ≤ 30–40 mg/l, NH_4^+-N ≤ 1.5–2.0, total P ≤ 0.3–0.4 mg/l, Cu ≤ 1.0 mg/l, Zn ≤ 2.0 mg/l, Cd ≤ 0.01 mg/l, Pb ≤ 0.1 mg/l, and other metal species (see SEPAC 2002). The type IV and V water are only suitable for industrial and agricultural uses, not for drinking or as a habitat for most aquatic animals. From the heavily polluted to the slightly polluted, the water quality of the seven river systems followed the order of the Haihe River, Liaohe River, Huanghe River, Huaihe River, Songhuajiang River, Yangtze River, and the Pearl River. The Haihe River watershed was the most severely polluted, as 50% of it belonged to type V. The water quality of the Liaohe River was worse, 40.6% of which belonged to type V. The water quality of the Huanghe River water system was worse, whose tributaries were generally badly polluted. The water quality of the Pearl River, the major Yangtze River, and its first-class branch was good and mainly of type II nature.

In 2003, lakes with water quality types II, III, IV, V, and bad V among 28 key lakes accounted for 3.6%, 21.4%, 25.0%, 14.3%, and 35.7%, respectively. In 194 water level supervised cities and regions of major ground water, the water level of 61 cities and regions increased, which accounted for 31.4% of the total supervision. The water level of 60 cities declined, which accounted for 31.0%, and which was 19% less than last year. The water level of 73 cities and regions was basically balanced and accounted for 37.6%. In 2003, 460.0 billion t of living wastewater in the industry and towns of China was released, which increased 4.7% compared to the previous year. About 212.4 billion t of wastewater was from the industry and increased 2.5% compared to 2002; 247.6 billion t of living wastewater was from towns and increased 6.6% compared to the last year; 1.33 billion t of chemical oxygen demand (COD) was let in the wastewater and declined 2.4% compared to the last year; among them, 51.19 million t of COD in industrial wastewater was let in and declined 12.3% compared to the last year, 8.217 million t of COD in town living wastewater was let in and increased 5.0% compared to the last year. About 1.297 million t of ammonia nitrogen in wastewater was released and increased 0.7% compared to the last year; among them, 0.404 million t of ammonia nitrogen was from industrial waste water and declined 4.0% compared to the last year; 0.893 million t of ammonia nitrogen was from town living wastewater and increased 3.0% compared to the last year. According to the supervision of the State Environmental Protection Administration of China (2003), in 2003, type II seawater area was about 80,000 km^2 of the whole sea area and there was a decrease of 31,000 km^2 compared to the last year. Type III seawater area was about 22,000 km^2 and increased 3,000 km^2 compared to the last year. Type IV seawater area was about 15,000 km^2 and there was a decrease of 3,000 km^2 compared to the last year. Type bad IV seawater area was about 25,000 km^2 and decreased 1,000 km^2 compared to the last year. The remaining seawater was of type I. The whole trend of seawater pollution was dropping compared with the previous year.

In 2003, the quality of most of the close sea area was clean and that of the remote sea area remained good. Inorganic nitrogen, living phosphate, and lead were the major contaminations in the ocean. Badly polluted sea area was mainly distributed in the mouth of the Yalujiang River, East Liao Gulf, Bohai Gulf, Yangtze River mouth, Hangzhou Gulf, Pearl River mouth, and the parts of big cities which are close to the coast. In 237 supervising spots of close coast sea area, type I and II sea water proportion accounted for 50.2% and increased by 0.5% compared to the last year. Sea water proportion of type IV and bad IV accounted for 30.0% and dropped 5.9% compared to the last year. In all sea areas, 119 red tides occurred in 2003, whose total area was about 14,550 km^2. Red tides frequently occurred in provinces, including Zhejiang, Liaoning, Guangdong, Hebei, and Fujian. *Prorocentrum* is the major creature that caused red tide.

Problems of water and soil erosion

From the above discussion, we can see that water and soil erosion was the primary outcome in the land ecosystem degradation of China, which was closely related to the degradation of forest, farmland, grassland, and aquatic ecosystems. According to the second remote sensing investigation of water and soil erosion in China, the total area of water and soil was 3.56 million km^2 by the end of 1990. The total amount of soil loss reached 5 billion t/a, half of which (2.4 billion t) were contributed by the Yangtze River Basin. There was about 1.6 billion t of mud and sand eroded into the Yellow River every year (Water Conservancy Department 2002; Tang 2004).

According to the national investigation, the water erosion area was 1.5 million km^2 in 1950. The National Water Conservancy Department conducted two remote sensing investigations of soil erosion and employed TM images in 1985–1986 and 1995–1996. The results are shown in Tables 4 and 5, respectively. Comparing the results between the two investigations, we can see that the total area of water and soil erosion declined from 3.67 million km^2 at the end of the 1980s to 3.56 million km^2 at the end of the 1990s; the area of water erosion declined and the intensity reduced from 1.79 million km^2 at the end of the 1980s to 1.65 million km^2 at the end of the 1990s. The water erosion area of the middle degree reduced to 0.82 million km^2 from 0.88 million km^2. The water erosion area of the high degree declined to 0.11 million km^2. The wind erosion area increased slightly and its intensity went up. The wind erosion area increased to 30,000 km^2 from the end of the 1980s–1990s. The wind erosion area of the middle degree increased to 0.18 million km^2 and the high-degree wind erosion area increased to 0.21 million km^2. The range of increase and decrease was different in the eastern and central western parts of China. During the 10 years from 1980 and 1990, the water erosion area in the east reduced by 13% (from 0.13 million km^2 to 90,000 km^2). The water erosion area in the central west reduced by 21% (from 0.62 million km^2 to 0.49 million km^2). The water erosion area in the east increased by 3% (from 1.04 million km^2 to 1.07 million km^2) (Zhang 2002; Tang 2004).

Between 1950 and 2000, completely repaired water and soil erosion areas totaled about 0.895 million km^2, including 13.33 million ha of farmlands, 43.33 million ha of water and soil protection forest, 4.667 million ha of fruit forest, and 4.33 million ha of grasslands; all of these accounted for 0.6567 million km^2. At the same time, about 0.6 million km^2 of new water and soil erosion area was formed due to the destruction of forest and grassland. A total area of 2.667 million ha in farmland was destroyed because of water and soil

Table 4 Comparison of two remote sensing investigations on the soil erosion of China

Degree of erosion[a]	Period I (1985–1986)				Period II (1995–1996)			
	Water erosion		Wind erosion		Water erosion		Wind erosion	
	10,000 km^2	%	10,000 km^2	%	10,000 km^2	%	10,000 km^2	%
Slight	91.91	51.23	94.11	50.16	83.00	50.30	79.00	41.36
Moderate	49.78	27.74	27.87	14.86	55.00	33.33	25.00	13.09
Severe	24.46	13.36	23.17	12.35	18.00	10.91	25.00	13.09
Very severe	9.14	5.08	16.62	8.86	6.00	3.64	27.00	14.14
Acute	4.12	2.30	25.84	13.77	3.00	1.82	35.00	18.32
Total	179.41	100.00	187.61	100.00	165.00	100.00	191.00	100.00

slight<1.9 mm/year; *moderate* = 1.9–3.7 mm/year; *severe* = 3.7–5.9 mm/year; *very severe* = 5.9–11.1 mm/year; *acute* > 11.1 mm/year (MWRC 1997)

[a] The degree of soil erosion is classified based on the thickness of surface soil loss per year

Table 5 Areas with slight soil and wind erosion in the six major river basins of China (unit 10,000 km^2), remote sensing investigation of 1985–1986, TM images, open to public in 1992

River basin	Area	Water erosion	Percentage of basin area	Wind erosion	Percentage of basin area	Water erosion + wind erosion	Percentage of basin area
	10,000 km^2	10,000 km^2	%	10,000 km^2	%	10,000 km^2	%
Songliao	124.62	30.77	24.69	11.40	9.15	42.17	33.84
Hailuanhe	31.89	10.39	32.61	1.53	4.79	11.92	37.40
Yellow River	79.02	34.71	43.93	11.78	14.91	46.69	58.84
Huaihe River	26.68	5.60	21.00	0.34	1.27	5.94	22.27
Yangtze River	178.34	56.97	31.95	5.25	2.94	62.22	34.89
Pearl River	44.16	5.85	13.25			5.85	13.25

erosion, and the average was 66,700 ha/a. Desert land expanded by 1,500 km^2 every year between 1950 and 1970, and it reached a rate of 2,460 km^2 every year after 1980 (Chen 2002).

Biodiversity issues

China is one of the world's ''mega-biodiversity countries'' (Tang et al. 2006). The total recorded number of species in China is about 83,000, accounting for 7.5% of the world's species, of which, about 30,000 species are high plants, accounting for 10% of the world high plants and which ranks the third in the world. Terrestrial vertebrate species total about 2,340 and account for 10% of the world's terrestrial vertebrate. There are 2,804 fish species that account for 12% of the world's species. Algae number 5,000 species and account for 16% of the world's algae. There are 8,000 fungi species, accounting for 17% of the world fungi, and 500 bacteria species, accounting for 0.2% of the world's bacteria (Li and Zhao 2004).

Besides being rich in the number of species, the uniqueness of China's biodiversity is also high. It is estimated that China has about 15,000–18,000 unique plants, which accounts for 50–60% of the total amount of high plants, and 70–80% for some taxa. Because of the long history of geology and good natural geographical conditions, it is good for animal and plant existence and reproduction, especially during the fourth ice age; species were not directly destroyed by the ice coverage from the north continent. Therefore, China's flora and fauna are very old and contain a lot of special families and genera. According to the distribution analysis of unique plant genera in China, there are three unique centers, including east Sichuan–west Hubei, west Sichuan–northwest Yunnan, and southeast Yunnan–west Guangxi.

Because of ecosystem degradation, species nursed in ecosystems have been becoming extinct at an accelerating rate. It was estimated that about 10–15% of the plants are being endangered in the world, but the proportion of endangered plants in China reached 15–20% and endangered species reached 4,000–5,000 in total. Researches from the past 30 years showed that the distribution areas of precious wild animals, including high-nose antelopes, Yangtze river dolphin, wild elephants, bears, and northeast tigers, have clearly shrunk and that the populations have sharply reduced. Three hundred and twelve species and many varieties of rare and endangered wild animals belonged to unique species of China and are specially protected by the country. Three hundred and fifty-four plant species were listed in the National Endangered Plant Checklist. In addition, a lot of plant species had already disappeared. According to primary statistics, among the endangered plants on the checklist, about 5% of plant species have been close to extinction in the most recent 10 years (State Forestry Administration of China 2003).

Declination in habitat availability was the major cause of China's biodiversity loss. With the rapid growth of China's economy in the last two decades, China has experienced dramatic land use and land cover changes, which, as well as environmental pollution, resource overexploitation, large hydroelectric project construction, and other intensive human disturbances, have dramatically influenced the availability and quality of wildlife habitats, directly and indirectly caused by biodiversity loss (Fang et al. 2006). Facing the severe situation of biodiversity loss, China had established more than 2,000 national and local nature reserves by the end of 2004. These reserves cover approximately 1.7 million km^2 or 17.8% of the nation's territory, and most of them are located in mountainous regions, where several biodiversity hotspot regions were identified (Tang et al. 2006). The establishment of nature reserves and the restoration of some degraded ecosystems has restored habitats and biodiversity to some degree, but much more effort is still required to minimize negative human impacts, improve the functioning of the established nature reserves, and establish more wildlife habitats (Fang et al. 2006).

Social–economic causes and its consequences

Ecosystem degradation is a very comprehensive and complicated process which is dynamic in time, diverse in space, and is highly nonlinear. China is a country with wide dimensionality, complicated and multiple nature and social economic conditions, and obvious differences between regions. All regions face different types of resource and environment degradation problems during the process of agriculture and country development. Some problems coexisted in all regions; others are just unique for some special regions. As a whole, environmental pollution in the east resulted in severe degradation, and a lot of degradation problems in the west resulted from human agricultural activities. Environmental pollution severely and extensively spread throughout the country. The following are the environmental trends and problems faced by China:

1. The environment was polluted severely
2. Problems of the country and its agricultural environment were prominent

3. Good-quality water resources were lacking greatly
4. Some rivers and aquatic ecosystems were polluted
5. Environmental problems of the oceanic ecosystem were still severe
6. The area of water and soil erosion increased year after year
7. The land area of desertification continued enlarging
8. The area of grassland degradation, sandification, and basification increased year after year
9. The ecological function of forestland was reduced
10. Environmental status in mining was bad and geological disaster remained serious
11. Biodiversity was greatly lost

Ecosystem degradation and environmental pollution themselves formed economic loss and treasure expense. The depravation of the ecological index already directly and obviously impacted on the current economic index and expected economic growth. The reasons for the depravation of China's environment were diverse and complicated, and arose from three kinds of pressures:

– *Population pressure*: the population of China rapidly increased, which is the biggest obstacle of the modernizing process of China and the biggest pressure on China's environment. Humans destroyed forests to reclaim land, enclosed lakes to create farmland, picked disorderly and dug excessively, and destroyed vegetation. A lot of unreasonable human activities exceeded the payment capability, exporting capability, and bearing capability of the supporting system of nature.
– *Industrialization pressure*: China's industrialization was late, the starting point was low, and it faced a heavy task of overtaking developed countries, not only supporting rapid economic increase with high investment, but also obtaining economic prosperity in return for the high consumption of resources and at the high price of environmental degradation. Much thought was devoted to the short-term benefits for China, but not enough to long-term schemes, and too much thought emphasized on the economy but the environment was ignored. A short period of economic improvement behaviors brought abouta long period of degradation and accumulating problems for China's environment.
– *Market pressure*: China is in the process of transformation to improving market economy. The market economy itself produces a lot of exterior economic effects or exterior non-economic effects, such as environmental pollution. The environment is considered as a kind of common property, whose supply (such as clean water and good air environment) is good for all people and whose total cost would not be increased if more people enjoyed its benefits. However, if there was no such common property, all people's benefit would be destroyed. The features of the common property or common properties destroyed (such as polluted water and polluted air) has determined that the individual or market would not provide the expense and service for controlling environmental pollution. It is the government which is the only supplier of the common property. The larger the pressure from market economy, the bigger the responsibility of preventing and curing environmental pollution and repairing land resources by the government.

Future research perspectives

Future research of ecosystem degradation should include the comprehensive evaluation of the ecosystem and the rebuilding and restoration research of major degradation types from wider and deeper levels. Details include the following: the evaluation index system of ecosystem degradation; the supervision and forecast of ecosystem degradation; the process, mechanism, and influential factors of ecosystem degradation; the dynamic supervision and dynamic database and its management information system of ecosystem degradation at a national scale; the relationship between ecosystem degradation and global change, including ecosystem degradation, water system neutralization, ground water pollution, and greenhouse gas release etc.; the theories and technologies of all kinds of ecosystem restoration; the influence of productivity and its economic analysis caused by ecosystem degradation, assisting the government to establish rules which are good for sustainable use of the land, preventing and curing soil degradation; and the popularization of restoration ecology. The development of restoration ecology needs the cooperation of scientists, the government, and common people to restore the degraded ecosystem rapidly via the processes of exchanging information, methods, and experience.

Acknowledgments We are grateful to Dr. Paul Dowling and Dr. Charlie Huang for the improvement of the language in this paper and the anonymous reviewers for their valuable comments on the early version of the manuscript. The support from the National Natural Science Foundation of China (grant nos. 30200035 and 30670370 to HR and grant no. 30570274 to WS), the Project of the Chinese Academy of Sciences (grant no. KSCX2-SW-132), and the Guangdong Sci-Tech Planning Project (grant no. 2005B33302012) is gratefully acknowledged. Although the research described in this review article has been funded in part by the above-mentioned agencies, it has not been subjected

to the agencies' required peer and policy review, and, therefore, does not necessarily reflect the views of the agencies and no official endorsement should be inferred.

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