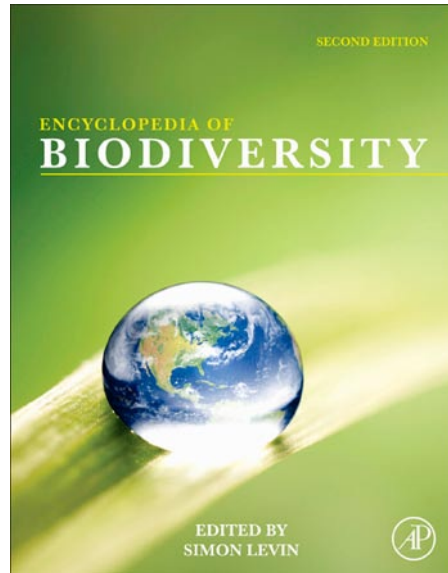


**Provided for non-commercial research and educational use only.
Not for reproduction, distribution or commercial use.**

This article was originally published in the *Encyclopedia of Biodiversity, second edition*, the copy attached is provided by Elsevier for the author's benefit and for the benefit of the author's institution, for non-commercial research and educational use. This includes without limitation use in instruction at your institution, distribution to specific colleagues, and providing a copy to your institution's administrator.



All other uses, reproduction and distribution, including without limitation commercial reprints, selling or licensing copies or access, or posting on open internet sites, your personal or institution's website or repository, are prohibited. For exceptions, permission may be sought for such use through Elsevier's permissions site at:

<http://www.elsevier.com/locate/permissionusematerial>

Liu Jianguo, Ouyang Zhiyun, Yang Wu, Xu Weihua, and Li Shuxin (2013) Evaluation of Ecosystem Service Policies from Biophysical and Social Perspectives: The Case of China. In: Levin S.A. (ed.) Encyclopedia of Biodiversity, second edition, Volume 3, pp. 372-384. Waltham, MA: Academic Press.

© 2013 Elsevier Inc. All rights reserved.

Evaluation of Ecosystem Service Policies from Biophysical and Social Perspectives: The Case of China

Jianguo Liu, Michigan State University, East Lansing, MI, USA
Zhiyun Ouyang, Chinese Academy of Sciences, Beijing, China
Wu Yang, Michigan State University, East Lansing, MI, USA
Weihua Xu, Chinese Academy of Sciences, Beijing, China
Shuxin Li, Michigan State University, East Lansing, MI, USA

© 2013 Elsevier Inc. All rights reserved.

Glossary

Cost-effectiveness analysis (CEA) A kind of economic analysis that allows comparison of the relative effects and costs of two or more actions. Typically the CEA is expressed as the ratio of effects to costs. The effects in CEA do not need to be in monetary values, which is the distinction from cost-benefit analysis (CBA) in which the benefits are assigned with monetary values.

Coupled human and natural systems (CHANS) Integrated systems in which human components interact with natural components.

Ecosystem services Also referred as environmental services, ecological services, or ecosystem goods and services, ecosystem services are the benefits obtained directly and

indirectly from nature, ranging from freshwater, timber, non-timber forest products, through carbon sequestration, water and soil conservation, to tourism and nutrient cycling.

Interactive effect Refers to the effect of an interaction term in statistical analysis, a situation in which the simultaneous effect of two variables on a third one is not additive. In other words, the effect of one variable on another variable depends on a third variable.

Payments for ecosystem services (PES) Also known as payments for environmental services or benefits, PES is a kind of conservation practice that offer incentives (e.g., cash, grain) to participants (e.g., farmers) in exchange for their forgone economic benefits or management efforts to protect one or many types of ecosystem service.

Introduction

China is endowed with immense reserves of natural capital and ecosystem services that flow from it (Ouyang, 2007; Task Force for Eco-Compensation Mechanisms and Polices in China, 2007). Unfortunately, natural capital in many areas has been degraded or lost due to a variety of reasons, such as rapid economic development (Task Force for Eco-Compensation Mechanisms and Polices in China, 2007), increasing human population size (Liu and Diamond, 2005), even faster household proliferation (Liu *et al.*, 2003a), and inappropriate governance (Liu and Diamond, 2008; Liu and Raven, 2010). The resulting degradation and loss of ecosystem services have contributed to large disasters, such as massive flooding in 1998, and other huge impacts on human well-being (e.g., economic losses and harm to human health) (Millennium Ecosystem Assessment, 2005). Having realized these problems, China has developed and implemented a series of large-scale policies to protect and restore natural capital and ecosystem services.

These policies include the Key Shelterbelt Construction Program, Beijing–Tianjin Sandstorm Control Program, Nature Reserve System (NRS) (Liu *et al.*, 2008; Ouyang, 2007), Forest Eco-Compensation Program, Grassland Eco-Compensation Program, Wetland Restoration Program, Natural Forest Conservation Program (NFCP; also known as Natural Forest Protection Program), Grain-to-Green Program (GTGP; also known as the Farm-to-Forest Program or the Sloping Land Conversion Program) (Liu *et al.*, 2008; Ouyang, 2007; Xu *et al.*, 2006a), and Ecosystem Function Zones (EFZs) (Ministry of Environmental Protection and Chinese Academy of

Sciences, 2008). These programs have generated important biophysical effects (e.g., biodiversity conservation; and mitigation of climate change, desertification, droughts, floods, soil erosion, and water runoff) and socioeconomic effects (e.g., poverty alleviation and economic development) (Liu and Diamond, 2005; Liu *et al.*, 2008; Xu *et al.*, 2006a). They also have provided significant benefits, such as carbon sequestration, at the global level (Liu and Diamond, 2005; Liu *et al.*, 2008).

The purpose of this article is to evaluate three major programs – NRS, NFCP, and GTGP – from biophysical and social perspectives. These programs are national in scope and have significant global implications. For example, NFCP and GTGP are among the biggest payments for ecosystem service programs in the world (Liu *et al.*, 2008). For each program, this article offers an overview of background and goals, illustrates their biophysical and socioeconomic effects, and discusses future opportunities, challenges, and needs. The programs are presented in the order of their inception times (1956, 1998, and 1999, for NRS, NFCP, and GTGP, respectively).

NRS

Background and Goal

China is among the world's most biodiverse countries, probably behind only Brazil, Colombia, and Indonesia (Liu and Raven, 2010). In the temperate Northern Hemisphere, China has the richest assemblage of biodiversity. For instance, it

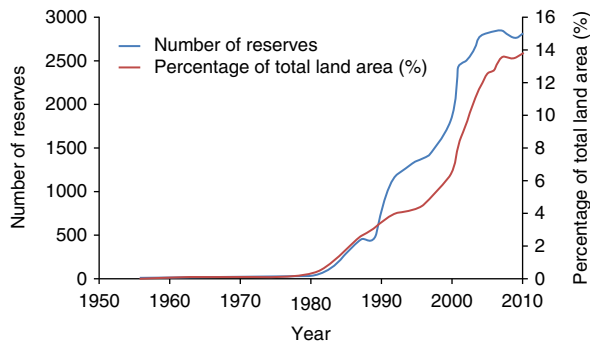


Figure 1 Growth of nature reserves in China. Reproduced from Liu J and Diamond J (2005) China's environment in a globalizing world. *Nature* 435: 1179–1186; Ministry of Environmental Protection (2011) *Bulletin of China's Environmental Status 2010*, and National Bureau of Statistics of China (1985–2010) *China Statistical Yearbooks*. Beijing: China Statistics Press.

contains 16 main biomes according to plant functional types (Liu and Raven, 2010). China has almost 10% of terrestrial vertebrate species (at least 2340 species out of ~25,000 named species worldwide) and ~9% of known vascular plant species (~31,500 out of 350,000 total worldwide) (Liu and Raven, 2010). So far, only a small proportion of species have been recorded. For the eukaryotic species, China may have ~1 million species (out of a global estimate at >12 million (Liu and Raven, 2010)), but <150,000 are actually recorded (Liu and Raven, 2010). However, much of China's biodiversity is under severe threat, such as habitat destruction, environmental pollution, poaching, global climate change, and invasive species (Liu *et al.*, 2003b; Liu and Raven, 2010). For instance, although the number of endangered wild giant pandas is small (~1600) (Viña *et al.*, 2008), the number of remaining wild tigers in China is tiny (~50) ("WWF News," <http://www.worldwildlife.org>).

To protect biodiversity, China has taken a series of actions (Liu *et al.*, 2003b), including both *ex situ* and *in situ* conservation actions. The former include colony relocation (e.g., National Nature Reserves for Milu (*Elaphurus davidianus*) in Shishou City of Hubei Province and in Dafeng City of Jiangsu Province), botanical gardens, zoos, gene banks, germplasm banks, and breeding facilities (e.g., the Breeding Center for Giant Pandas (*Ailuropoda melanoleuca*) in Wolong Nature Reserve in Sichuan Province). The first germplasm bank in China was established in 2007 at the Institute of Botany of the Chinese Academy of Sciences in Kunming. Plans include the collection of 6450 species of plants by the end of 2012 and 19,000 by the end of 2022 ("China Germplasm Bank of Wild Species," <http://www.genobank.org>).

The *in situ* conservation actions include policies prohibiting poaching and gathering, restricting economic development, and establishing the NRS. The NRS is particularly impressive. In the half-century since the first reserve, Dinghushan Nature Reserve, was created in 1956 in Guangdong Province, China has designated 2588 nature reserves (through 2010) (Figure 1). These nature reserves account for 1.49 million km², or ~15% of China's territory (Ministry of Environmental Protection, 2011). The goal of the NRS is to protect biodiversity of all major forms in China.

Distribution

The nature reserves are distributed across the country (Figure 2), but the majority of the land area (~56%) is in western China, concentrated in Qinghai Province as well as Tibet and Xinjiang Autonomous Regions, although the numbers in these regions are relatively small (Wu *et al.*, 2011). The nature reserves vary greatly in size, ranging from 0.01 to 298,000 km². The largest one is Qiangtang Nature Reserve in Tibet, established in 1993 primarily for the protection of Tibetan antelope (*Pantholops hodgsonii*), wild yaks (*Bos mutus*), and their habitat of desert highlands.

Nature reserves are managed at different institutional levels (i.e., national, provincial, city, and county levels). At the national level, there were 319 nature reserves covering 926,756 km² in 2010 (Ministry of Environmental Protection, 2011). These national nature reserves are managed by national government agencies. The majority of them (237) are managed by the State Forestry Administration. The remaining are managed by the Ministry of Environmental Protection (46), State Oceanic Administration (12), Ministry of Agriculture (9), Ministry of Land and Resources (11), Ministry of Water Resources (3), and Chinese Academy of Sciences (1) (Ministry of Environmental Protection, 2010).

Most nature reserves are managed by provincial and county governments. Compared to national nature reserves, provincial and local reserves usually receive less support and are less known. For these reasons, many provincial and local governments have put forth much effort to elevate their reserves to the national level (Xu and Melick, 2007).

Although the vast majority of nature reserves are within a particular administrative or political boundary, some cross those boundaries. At the national level, a number of nature reserves cross country boundaries. For example, China and Russia jointly established the Khanka Lake International Nature Reserve for red-crowned crane (*Grus japonensis*) in 1992. China, Russia, and Mongolia cocreated the Dauria International Nature Reserve in 1994. China and Russia are also considering the establishment of more cross-boundary nature reserves to enhance the conservation of the Siberian tiger (*Panthera tigris*), Amur leopard (*Panthera pardus*), and other rare and endangered species ("Xinhua News," <http://news.xinhuanet.com>).

Biophysical Effects

NRS includes areas for the protection of a variety of geological and paleontological relics, ecosystems, floras, faunas, natural scenery, and natural coastal environments and resources (Ministry of Environmental Protection, 2010). Protected ecosystems include forests, grasslands, desert highlands, inland wetlands, and marine and coastal areas. These ecosystems provide a variety of services such as food and water supply, water and air purification, carbon sequestration, flood and drought regulation, ecotourism and recreation, and refuges for endangered species. Of the total 53 ecoregions represented in China, 29 have more than 10% of their land areas within the current NRS (Wu *et al.*, 2011). Of 502 important bird areas in China, 340 are within the current NRS (Wu *et al.*, 2011). Approximately 81% of China's natural vegetation communities are within at least one nature reserve (Wu *et al.*, 2011).

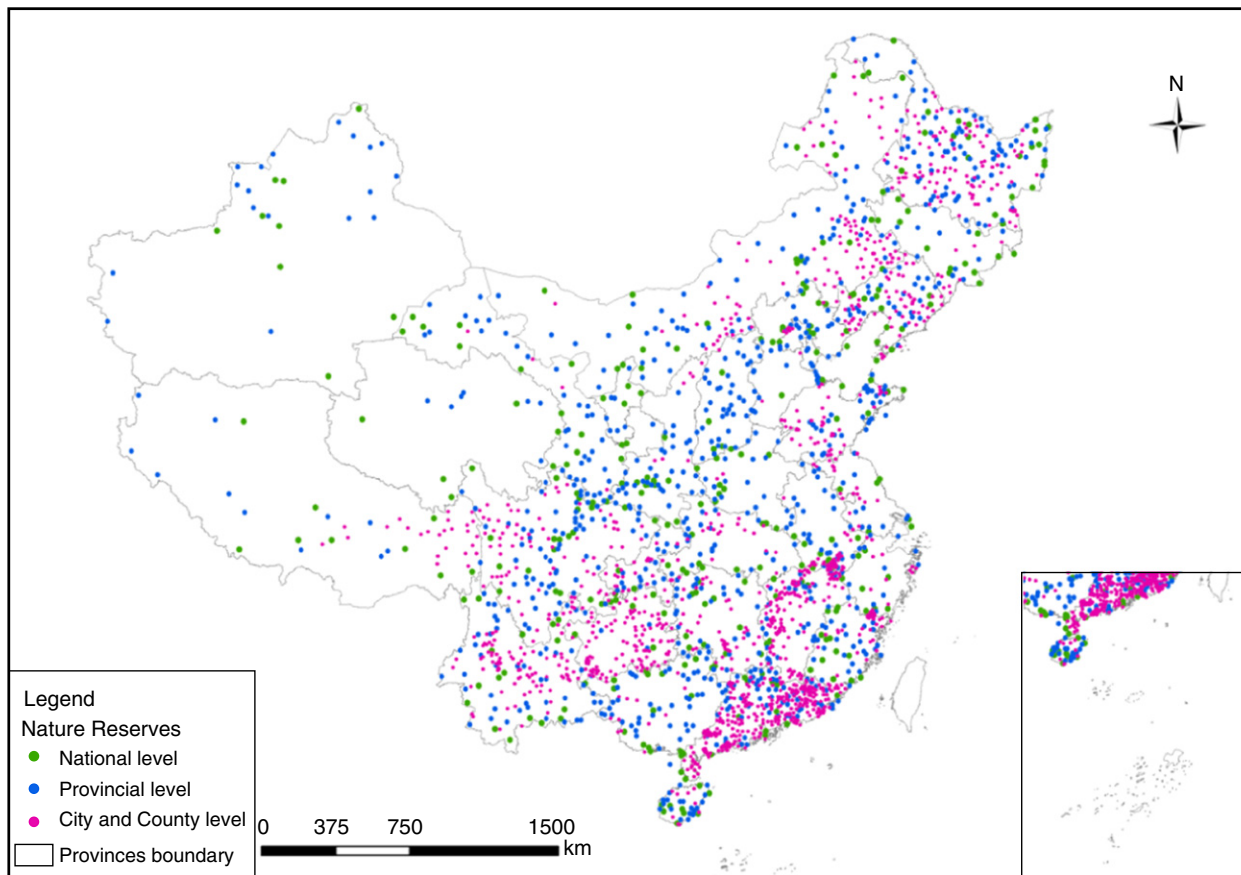


Figure 2 Spatial distribution of nature reserves in China. The map is provided by Nanjing Institute of Environmental Sciences, Ministry of Environmental Protection of China.

Many nature reserves are established with the primary goal of conserving specific species. For example, there are 63 nature reserves whose primary goal is to conserve the endangered giant pandas (Viña *et al.*, 2010). Fifteen nature reserves have been established for Chinese dove tree (*Davidia involucrata*), seven for Chinese white dolphin (*Sousa chinensis*), and 34 for Chinese giant salamander (*Andrias davidianus*) (Ministry of Environmental Protection, 2010). Besides the focal species, many other species and associated ecosystems in these nature reserves also benefit (Viña *et al.*, 2010).

Since 1997, both biophysical and economic benefits of China's ecosystem services have been assessed (Ouyang and Wang, 1997; Ouyang *et al.*, 1999). However, relatively few rigorous ecosystem services assessments of nature reserves in China have been conducted, and many ecosystem services, such as carbon sequestration, are rarely quantified. An ecosystem service assessment of the Changbaishan Nature Reserve (total size 1965 km²) in Jilin Province, for example, found that annually a total of 105 million m³ of water were stored, 1.2 million tons of carbon were fixed, and 17,021 tons of nutrients were accumulated (Xue *et al.*, 1999).

Owing to inadequate management, the establishment of nature reserves also has caused some negative biophysical effects. In Nuozadu Nature Reserve of Yunnan Province, almost half of its forests were lost due to illegal extraction and open-

access farming with poor management (FCCDP, 1998). Similarly, in Wolong Nature Reserve of Sichuan Province, the panda habitats continued to be lost even after the establishment of the reserve due to rapid population growth and household proliferation, economic development inside the reserve, and extraction of timber and non-timber forest products (Liu *et al.*, 2001). Some studies have also recorded the adverse effects of tourism development (e.g., road construction and hiking) on vegetation, wildlife, and their habitats (Fan *et al.*, 2011; Li *et al.*, 2005; State Forestry Administration, 2006).

Socioeconomic Effects

Globally, the overall benefit–cost ratio of an effective wilderness conservation program is at least 100 (Balmford *et al.*, 2002). In China, taking the Yancheng Biosphere Reserve in Jiangsu Province as an example, a very conservative estimation suggests that the benefit–cost ratio of managing the reserve was 10 without considering the huge revenue from tourism development (Lu *et al.*, 2007). If the benefits of tourism development are taken into account, the benefit–cost ratio would be much larger than 100 for many reserves with tourism (e.g., Jiuzhaigou Nature Reserve in Sichuan Province and Zhangjiajie Nature Reserve in Hunan Province).

The average total annual investment for nature reserves from governments at different levels in China was ~ 200 million yuan over the past two decades (1 USD = 6.8 yuan as of 2010) (Yuan *et al.*, 2008). The total annual investment per square kilometer was approximately US\$53 in the early 2000s, compared to US\$2058 and US\$157 in developed and other developing countries, respectively (Yuan *et al.*, 2008). Moreover, this number continued to decrease with the rapid expansion of the NRS and relatively slow increase in investment. The gap of insufficient funding was filled through revenue-raising activities such as tourism development and the use of natural resources in the reserves (Ouyang *et al.*, 2002; Xu and Melick, 2007; Yuan *et al.*, 2008).

Since 1982, more than 80% of nature reserves in China have launched tourism development programs (Yuan *et al.*, 2008). These programs have produced socioeconomic impacts on local residents, companies, governments, and tourists inside and outside China. First, every year, tourism development produces billions of yuan in revenue for the government. For example, the Zhangjiajie Nature Reserve in Hunan Province received as many as 1.4 million tourists and created as much as 5.6 billion yuan in revenue in 2010 (Statistic Bureau of Zhangjiajie City, 2011). Of those tourists, 555,500 were from outside China. Second, local residents may also benefit from the nature reserves through government subsidies and participation in tourism activities. In Jiuzhaigou Natural Reserve of Sichuan Province, all of the local households have intensively participated in and benefited from tourism business, with the per capita income increasing by more than fourfold after the initiation of tourism (Li *et al.*, 2006b). However, studies have shown that in most reserves, local residents had received only a very small proportion of the produced economic benefits, with the major proportion divided by tourism-related companies and the government (He *et al.*, 2008; Xu and Melick, 2007; Yuan *et al.*, 2008). Besides direct economic benefits, tourism development has also dramatically improved the construction of infrastructure (e.g., roads, hospitals, and hotels), has produced job opportunities, and has changed the income structure of local households and governments (He *et al.*, 2008; Li *et al.*, 2006b; Xu and Melick, 2007; Yuan *et al.*, 2008).

The establishment and management of nature reserves also have some negative socioeconomic consequences such as conflicts over land use, tourism resources, and restrictions of natural resource use between the administrative bureaus of reserves and local residents as well as local governments. For instance, the establishment of many reserves incorporates land that had been allocated to local households or communities under the Contract Responsibility System in the early 1980s; however, many reserves were delimited on maps before determining the property rights and compensation measures for land and associated resources (e.g., forests), which unavoidably triggers conflicts over the use and management of land and associated resources (Miao and West, 2004). In the core zone of Wolong Nature Reserve of Sichuan Province, local residents were prohibited from collecting bamboo shoots and Chinese herbal medicines, which were traditional practices before the establishment of the reserve and constituted a large proportion of their income (Liu *et al.*, 1999).

Future Opportunities, Challenges, and Needs

China continues to expand the NRS. By the end of 2010, China had already achieved its designed goal for 2050 in terms of the number of nature reserves (2500), but had not yet met the goal for 2010 in terms of the percentage of total land area (16.1%, 16.8%, and 18.0% as planned for 2010, 2030, and 2050, respectively) (State Forestry Administration, 2001). Although the rapid increase in quantity is impressive, the total cover area and performance of nature reserves in protecting biodiversity are what really matter. Future expansion efforts should pay special attention to areas rich in endemic biodiversity, areas vulnerable to human activities and climate change, and connections between some existing nature reserves.

Although expansion efforts are needed, it is crucial to invest more resources in existing nature reserves to enhance their management. The current nature reserves are managed by different administrations at different institutional levels, of which the functions and responsibilities are often ambiguous or conflicting. Many reserves are listed only on paper because they are not effectively managed due to the lack of sufficient funding and low engagement of stakeholders (e.g., local residents). Some of these reserves are even "empty" because conservation targets have become extinct since the establishment of the reserves (Li *et al.*, 2010). For example, in Jiuzhaigou Nature Reserve of Sichuan Province, there is no recent evidence of giant pandas, probably due to the skyrocketing number of tourists (State Forestry Administration, 2006). To improve the effectiveness and efficiency of the NRS, it is necessary to rethink its goal, reevaluate and redefine current nature reserves, and establish an integrated administration.

To make the management of nature reserves most effective, it is critical to improve the well-being of local residents. Although tourism has generated much revenue, local residents receive only a small proportion of the economic benefits (He *et al.*, 2008). Thus, economic benefits should be more fairly distributed to local residents in order to provide incentives for local residents to cooperate for effective nature reserve management.

Another aspect for consideration is the potential impacts of global climate change. Although there has been discussion of the potential impacts of global climate change on biodiversity in general, little quantitative work has been conducted in China. Such quantitative research is a foundation to inform the development and implementation of effective climate adaptation strategies.

Information on the biophysical and socioeconomic effects of nature reserves has been largely fragmented so far. Much information (e.g., detailed environmental monitoring and financial data) is held by government agencies and is inaccessible to the public. Thus, systematic and integrated studies as well as timely and transparent information disclosure are needed to better conserve China's biodiversity and secure the provision of ecosystem services.

NFCP

Background and Goal

From the 1950s to 1990s, China's natural forests declined in area by 70% and stocking of natural forests per unit area



Figure 3 Spatial distribution of NFCP and GTGP. Reproduced from Liu J, Li S, Ouyang Z, Tam C, and Chen X (2008) Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences USA* 105: 9477–9482.

declined by 32% (Zhang *et al.*, 2000). The decline of natural forests was mainly due to the population explosion and soaring demand for timber. Human population in forested areas increased fivefold and timber harvests increased threefold (Zhang *et al.*, 2000). The dramatic decline in the quantity and quality of natural forests resulted in extensive desertification, soil erosion, floods, droughts, carbon emission, and damage to wildlife habitat, and so forth (Liu and Diamond, 2005). In response to failures of previous forestry policies, the severe droughts in 1997, and the massive floods in 1998, the central government decided to implement a series of conservation policies, including NFCP (Liu *et al.*, 2008; Yin, 2009; Zhang *et al.*, 2000).

The goal of the NFCP is to conserve and restore natural forests through logging bans and afforestation because most of the natural forests in China were lost or degraded due to human activities (e.g., logging) and because deforestation was believed to have contributed to the 1998 massive floods (Liu *et al.*, 2008). Specifically, the NFCP aimed to completely ban logging of natural forests in the upper reaches of the Yangtze and Yellow rivers as well as in Hainan Province (Figure 3) by 2000 and substantially reduce logging in other places (Xu *et al.*, 2006a). Furthermore, the NFCP aimed to reduce timber harvests in natural forests from 32 million m³ in 1997 to 12 million m³ in 2003, and to afforest 31 million ha by 2010 through aerial seeding, artificial planting, and mountain closure (i.e., prohibition of human activities such as fuelwood collection and grazing) (Xu *et al.*, 2006a).

Distribution

In 1998, right after the large floods, China started the NFCP pilot study in 12 provinces and autonomous regions/municipalities (Liu *et al.*, 2008). By 2000, the NFCP was expanded to 18 provinces, including the upstream regions of major river systems, especially the Yellow and Yangtze rivers, which had suffered massive ecological degradation (Figure 3). The NFCP target areas are classified into two priorities: the first priority is the state-owned forests, and the second priority is the community-owned forest region. Under different priorities, the levels of financial support from the central government vary, 20% of all costs for the second priority area and 100% for the first priority area (Liu *et al.*, 2007a). In 2011, NFCP was renewed for the 10-year second phase, which also added another 11 counties around Danjiangkou Reservoir in Hubei and Henan Provinces, the water source for the middle route of the South-to-North Water Diversion Project ("China Internet News Center," <http://fangtan.china.com.cn>).

Biophysical Effects

It is a common belief that achieving the NFCP's goal can lead to many biophysical benefits, such as soil erosion reduction, water retention, and flood control. Most indicators of biophysical effects studied so far are immediately observable measures, such as changes in harvested timber, newly forested area, and degree of soil erosion (Liu *et al.*, 2008), partially because it takes time for forests to recover or regenerate. However, some recent

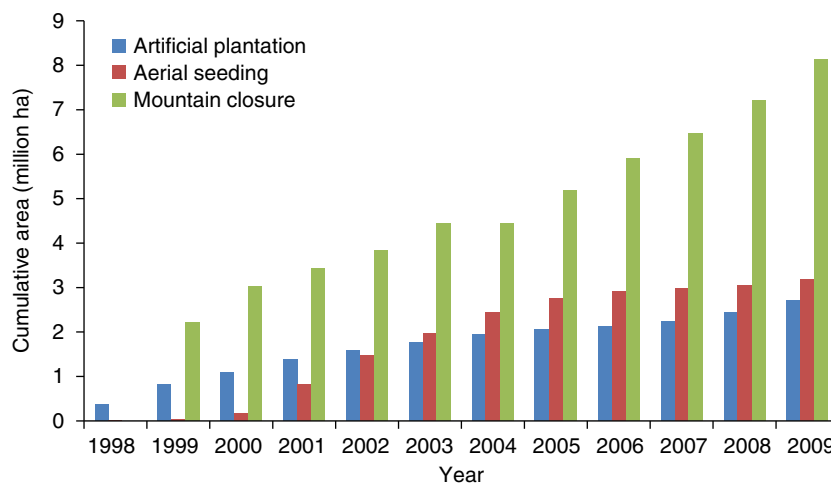


Figure 4 Areas of NFCP by different implementation approaches. Reproduced from State Forestry Administration (2000–2010) *China Forestry Development Report*. Beijing: State Forestry Administration; State Forestry Administration (2001–2009) *Bulletin of Key Forestry Projects*. Beijing: State Forestry Administration, and State Forestry Administration (2006–2010) *Statistical Analysis of National Forestry*. Beijing: State Forestry Administration.

studies have measured changes in forest cover using field data and remotely sensed data (Viña *et al.*, 2011).

Commercial harvesting of natural forests in 13 provinces had stopped, and the unlogged area had amounted to 8.9 million ha by 2000 (Liu *et al.*, 2008). There was a rapid increase in the area under mountain closure and plantation, and the total area had expanded to more than 14 million ha by 2009 (Figure 4). Between 2000 and 2010, NFCP protected 107 million ha forest area and increased forest area by 10 million ha (“China Green Times,” <http://www.greentimes.com>).

The NFCP also has reduced soil erosion. For example, during 2000–2007, sediment concentration in Yellow River had declined by 38%. In Chongqing City alone, the total soil erosion area had reduced in 91% of its administrated counties (“China Green Times,” <http://www.greentimes.com>). In Sichuan Province, from 1998 to 2003, the reduced amount of soil erosion was estimated to be 1.5 billion tons (Zhang, 2006).

Forest cover and wildlife habitat also have been recovering. For instance, since the NFCP started in Wolong Nature Reserve of Sichuan Province, illegal harvesting of natural forests rarely occurs (Bearer *et al.*, 2008) and the habitat of the endangered giant pandas has been recovering (Viña *et al.*, 2007). The NFCP also was helpful in reducing the ecological impact of the devastating 2008 Wenchuan earthquake (Viña *et al.*, 2011). Without the NFCP, much more forest cover would have disappeared due to the earthquake. In the Sichuan Giant Panda Sanctuary and Qinling Mountain Area, the percentage of forest cover has increased since the NFCP was initiated (Li, 2010).

In addition, the NFCP also has had significant ecological effects at the global level. One is increased carbon sequestration. Between 1998 and 2010, the NFCP increased carbon sequestration by an estimated 1.3 billion tons and reduced timber harvest by an estimated 220 million m³ (“China Green Times,” <http://www.greentimes.com>). However, reduced domestic timber production has prompted an increase in the import of timber from other countries (Liu and Diamond, 2005). In 2005, for example, 29.4 million m³ of logs were imported to China, an increase of 10.4% from 2004. Twenty-five percent (or 7.4 million m³) of these logs were from tropical forests.

Socioeconomic Effects

NFCP-related activities received a total commitment of 93.7 billion yuan between 1998 and 2009 (Figure 5). The central government contributed ~80% of this amount, whereas local governments provided the remainder. Most of the money was used to offset economic losses of forest enterprises caused by the transformation from logging to tree plantations and forest management (Liu *et al.*, 2008; Ouyang, 2007). The payments varied with specific tasks: aerial seeding (750 yuan ha⁻¹), artificial planting (3000 and 4500 yuan ha⁻¹ in the Yangtze and Yellow river basins, respectively), regenerating forests through mountain closure (1050 yuan ha⁻¹), and protecting forest (10,000 yuan per worker per 340-ha forest) (Liu *et al.*, 2008; Xu *et al.*, 2006a).

Important measures have been taken to create alternative jobs for people previously in forest enterprises and have largely changed forestry’s economic and employment structure. By the end of 2002 (3 years after NFCP implementation), approximately two-thirds of the 1.2 million logging and processing workers impacted by the NFCP had retired or had been transferred to other sectors (Liu *et al.*, 2008; Xu *et al.*, 2006a). The average income from the tertiary industry (e.g., hotels, restaurants, and entertainment) in 32 forest enterprises jumped from 8.5% in 1997 to 20.1% in 2003 (Liu *et al.*, 2008; Zhang, 2006).

Forest management and plantation farming have become the dominant sources of employment since logging was stopped. For example, the proportion of the staff for forest management in the Chuannan Forestry Bureau and Ebian County of Sichuan Province increased from 0% and 13.1% in 1997 to 52.6% and 76.7% in 2001, respectively (Liu *et al.*, 2005, 2008). Even though the income from forestry in some areas such as Longmin Township in Pengzhou County of Sichuan Province declined, there was an increase in the total income, thanks to income from other sources such as tourism (Qiao *et al.*, 2006).

Government data from 35 key state-owned forest enterprises showed that the gross forestry product had continued to

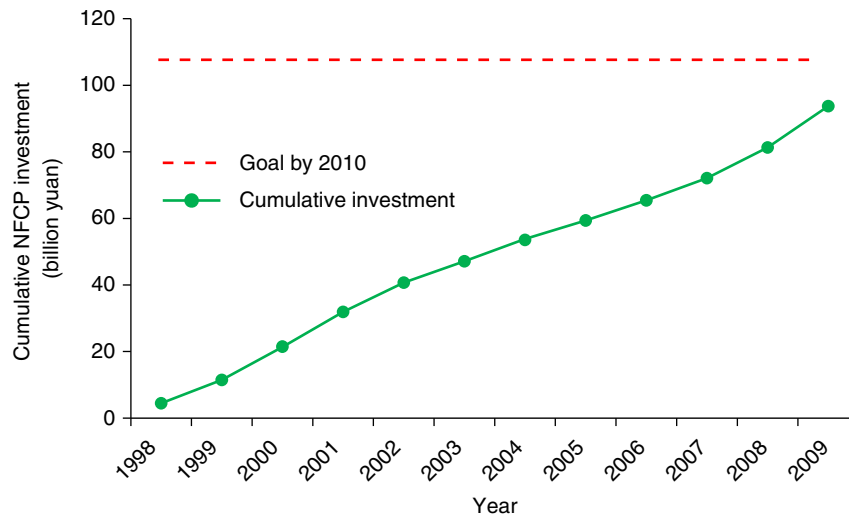


Figure 5 Investment in NFCP. Reproduced from State Forestry Administration (2000–2010) *China Forestry Development Report*. Beijing: State Forestry Administration; State Forestry Administration (2001–2009) *Bulletin of Key Forestry Projects*. Beijing: State Forestry Administration, and State Forestry Administration (2006–2010) *Statistical Analysis of National Forestry*. Beijing: State Forestry Administration.

decline from 1997 to 2000, and then began to increase in 2001. On average, the annual income of employees within NFCP zones had increased from 4437 yuan in 2000 to 12,645 yuan in 2008. Taking the largest NFCP implementation province, Sichuan Province, as an example, the gross forestry product increased more than 10 times from 1997 to 2009. Annual income from forest farmers also increased more than three times from 2000 to 2009 (“China Green Times,” <http://www.greentimes.com>). However, independent studies by scholars have also found adverse effects of the NFCP. For example, in Sichuan Province, 1172 wood-related industry enterprises and 154,000 employees who depended on income from timber harvesting were negatively affected (Zhou, 2006). The tertiary industry in the Chuannan Forestry Bureau of Sichuan Province suffered a big reduction of income (from 5.0 million yuan in 1997 to 1.1 million yuan in 2001) as a result of reduced wood-related activities (Liu and Zhou, 2005). Approximately 55,000 people in Taijiang County of Guizhou Province had a loss of 6 million yuan, placing some forestry workers below the poverty line (Yang, 2004). Some enterprises could not pay back their loans or pay salaries (Huang, 2005). By 2001, these loans amounted to 12.9 billion yuan, and unpaid salaries reached 860 million yuan.

Local governments also had budgetary burdens because they lost revenue from wood-related industries and were responsible for providing matching funds for the NFCP at the same time (Zhou, 2006). For instance, from 1998 to 2001, the Yanbian County Forestry Bureau of Sichuan Province lost 9.7 million yuan in revenue and had to provide matching funds for NFCP (13% of total investment from the central government) (Liu *et al.*, 2005). In northwestern China, 34.9%, 47.0%, and 59.8% of farmers, livestock grazers, and forest workers, respectively, reported on a survey that their livelihoods had been ruined by the implementation of the NFCP, and the poorer the respondents were, the greater the likelihood they believed they had suffered (Cao *et al.*, 2010).

Future Opportunities, Challenges, and Needs

For the second phase (2011–2020), the NFCP plans to increase forest cover by 5.2 million ha, capture 416 million tons of carbon, provide 648,500 forestry jobs, further reduce soil erosion, and enhance biodiversity (“China Internet News Center,” <http://fangtan.china.com.cn>).

In response to the financial burden on local governments of matching ~20% of central government funds during the first phase, that requirement has been eliminated for the second phase of the NFCP for western provinces. The planned cumulative investment for the second phase is 244.0 billion yuan, with 219.5 billion from the central government and 24.5 billion from local investment (“China Internet News Center,” <http://fangtan.china.com.cn>). Although this adjustment may allow local governments to spend more money on local socioeconomic development, it potentially increases the burden of the central government and the financial risk of the program. The program benefits many stakeholders such as hydropower stations, relevant companies and business sectors, people in the Yangtze and Yellow river basins, and even other countries (e.g., Japan, South Korea, and the US would benefit from the mitigation of sandstorms) (Liu *et al.*, 2008). Thus, market-based mechanisms could be attempted to reduce such financial burdens and risks so as to sustain the program in the long run.

The second phase also increases the payment levels for artificial plantation, mountain closure, aerial seeding, and forest monitoring and management. The payment scheme has been adjusted from a fixed payment level through the year to a payment level that will be adjusted with inflation. However, this planned payment scheme still ignores the spatial heterogeneity of socioeconomic conditions across NFCP implementation areas. Increasing the payment levels simultaneously for all implementation areas may cause overpayment in some areas, whereas some areas still receive unreasonably low payments. To improve the fairness and efficiency of the program,

the payment scheme should consider the spatial heterogeneity of different implementation areas (Chen *et al.*, 2010).

The second phase also emphasizes improvement in people's livelihoods. It plans to improve social insurance (including pension, medical care, unemployment, injury, and maternity), housing conditions, and job opportunities of formal employees in state-owned forest enterprises. Although the increase in NFCP payment levels may also benefit other NFCP-related workers who are not formal employees in state-owned forest enterprises, it will not improve those people's social insurance, housing conditions, and job opportunities. This discriminatory policy not only is unethical but may also induce many social conflicts, because a large number of NFCP-related workers do the same work as, if not more than, formal employees but are not registered as formal employees under the current forestry institutional system.

In addition, many reports on forest recovery have been based only on the statistics of government agencies. More scientifically sound and quantitative studies are needed to more rigorously evaluate the impact of the NFCP on forest quantity and quality changes in both the short and long terms. For example, advanced techniques such as remote sensing are available for comprehensive monitoring (Viña *et al.*, 2011). The complexity of policy implementation in coupled human and natural systems should also be considered (Liu *et al.*, 2007b, c). Instead of assessing various conservation programs separately, further studies should also evaluate their interactive effects (Liu *et al.*, 2008). Interdisciplinary studies are also urgently needed to assess the tradeoffs of NFCP implementation on ecosystem services and human well-being.

GTGP

Background and Goal

Much of China's cropland was on steep slopes, causing serious soil erosion. For example, Yangtze and Yellow river basins had

almost 4.3 million ha of cropland on slopes of $\geq 25^\circ$ (Liu *et al.*, 2008). Although natural forest protection and afforestation efforts of the NFCP are important to reduce soil erosion, another important driving force behind soil erosion is farming on sloping lands. Therefore, a year after the pilot implementation of the NFCP, China initiated the GTGP in 1999. The goal of the GTGP is to convert cropland on steep slopes to forests or grasslands. The main criterion for choosing land plots for inclusion in the GTGP is slope steepness, $\geq 15^\circ$ in northwestern China and $\geq 25^\circ$ in other parts of the country (Uchida *et al.*, 2005).

The major aim of the GTGP was to increase vegetative cover by 32 million ha by 2010, with 14.7 million ha of cropland conversion to forest and grassland and the remaining portion through afforesting barren land and mountain closure (Figure 6) (Xu *et al.*, 2004). It was expected that by 2010 the increase in vegetative cover could control soil erosion across 86.7 million ha and desertification of 102.7 million ha (Yin, 2009). In addition to the primary goal of reducing environmental impacts, the GTGP also aims to alleviate poverty and advance local economic development (Xu and Cao, 2002).

Sloping lands can be converted into ecological and/or economic forests and grasslands, but ecological forests should account for 80% of the total converted land (Liu *et al.*, 2007a). Here, ecological forests refer to forests with high ecological benefits (e.g., carbon sequestration, water and soil retention), while economic forests represent forests with relatively short-term economic returns (e.g., orchards or plantations of trees with medicinal value for commercial use). To offset the lost agricultural revenue due to land conversion, the government provides participating households with a payment in the form of grain and/or cash. The durations of payments are 8 years if the cropland is converted to ecological forests using ecologically important trees, 5 years if it is converted to economic forests using fruit trees, and 2 years if the cropland is converted to grassland (Xu *et al.*, 2004). The payment levels differ by region, with 2250 and 1500 kg of grain, or 3150 and 2100

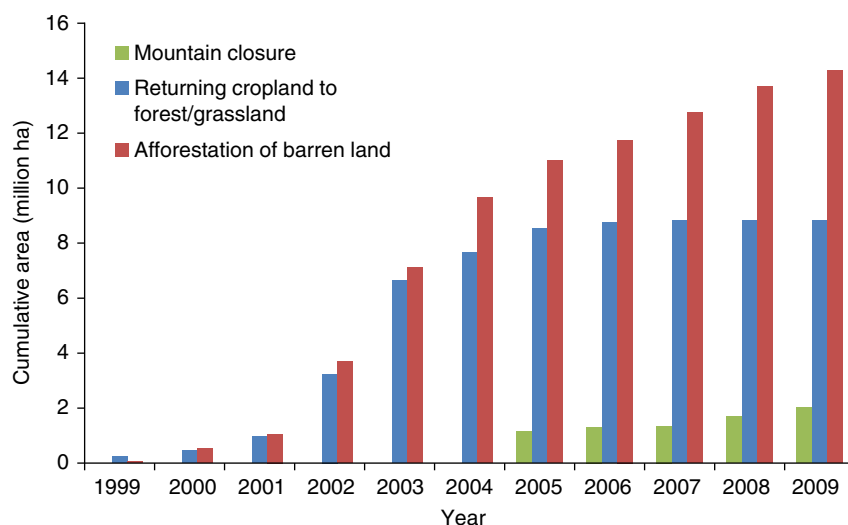


Figure 6 Areas of GTGP by different implementation approaches. Reproduced from State Forestry Administration (2000–2010) *China Forestry Development Report*. Beijing: State Forestry Administration; State Forestry Administration (2001–2009) *Bulletin of Key Forestry Projects*. Beijing: State Forestry Administration, and State Forestry Administration (2006–2010) *Statistical Analysis of National Forestry*. Beijing: State Forestry Administration.

yuan at 1.4 yuan per kg of grain for each hectare of converted cropland annually in the upper reach of the Yangtze River basin and in the upper and middle reaches of the Yellow River basin, respectively (Liu *et al.*, 2008). Furthermore, GTGP offers farmers additional subsidies (300 yuan ha⁻¹ for miscellaneous expenses every year and 750 yuan ha⁻¹ for seeds or seedlings in the first year) (Feng *et al.*, 2005; Xu *et al.*, 2004).

In 2007, after 8 years of implementation, payment contracts for many GTGP-enrolled lands began to expire. Since the long-term mechanism for addressing the livelihoods of GTGP-participating households had not been established, the central government decided to extend the program for another 8 years. However, the payment levels have been halved (Liu *et al.*, 2008).

Distribution

Compared to the NFCP, the GTGP is broader in geographic scope (Figure 3). The pilot program started in three provinces – Sichuan, Shaanxi, and Gansu – in 1999 (Figure 3). After initial success, it was extended to 17 provinces by 2000 and finally to 25 provinces by 2002 (Figure 3). As Figure 3 shows, the GTGP covers all provinces in western China, which is ~80% of the total area with soil erosion (>360 million ha), including the headwaters of the Yangtze and Yellow rivers (Figure 3). Western China also contains the most desertification-prone area (174 million ha), three quarters of the cropland with a slope >25° (600 million ha), and 60% of the population below the poverty line (Liu *et al.*, 2008; Ouyang, 2007).

Biophysical Effects

Like the NFCP, indicators of the GTGP biophysical effects are often those immediately observable: amount of land converted and afforested, reduction in soil erosion, and reduction in water surface runoff. Ecosystem service changes on large scales, such as flood control, are mainly inferred from changes in immediately observable factors (Liu *et al.*, 2008).

By the end of 2009, the program had cumulatively increased vegetative cover by 25 million ha, with 8.8 million ha of cropland being converted to forest and grassland, 14.3 million ha barren land being afforested, and 2.0 million ha of forest regeneration from mountain closure (Figure 6). The statistics of the State Forestry Administration suggest that forest cover within the GTGP region has increased 2% during the first 8 years (Liu *et al.*, 2008).

Soil erosion and surface runoff have been reduced under GTGP. For example, in Hunan Province, surface runoff was reduced by ~20% and soil erosion declined by 30% from 2000 to 2005 (Li *et al.*, 2006a). Investigations in 14 counties of Sichuan Province indicate that from 1998 to 2003, the area affected by soil erosion declined 10% (Bao *et al.*, 2005). In Zigui County of Hubei Province, over a period of 5 years, converted plots lowered surface runoff by 75–85% and soil erosion by 85–96% in comparison to unconverted cropland (Wang *et al.*, 2007). In the Yellow River basin, it was estimated that surface runoffs would be reduced by 450 million m³ from 2000 to 2020, which is equivalent to 0.76% of the total surface water resources (Jia *et al.*, 2006).

Water resources have been conserved and desertification has been reduced under the GTGP. For example, Minqin

County of Gansu Province saved 516,000 m³ of water in 2003 by reducing irrigation on 4300 ha of GTGP land (Ma and Fan, 2005). In the meantime, desertification has slowed down due to increased vegetation, an increase in air humidity by 15–25%, and a decrease in wind speed on the soil surface by 30–50% of GTGP land (Hou and Zhang, 2002).

The GTGP also enhances soil structure and lowers nutrient loss. In Guizhou Province, GTGP plots had 35–53% less loss of phosphorus than non-GTGP plots (Liu *et al.*, 2002). In Wuqi County of Shaanxi Province, the Chaigou Watershed had 48% and 55% higher soil moisture and moisture-holding capacity in GTGP plots than in non-GTGP plots, respectively (Liang *et al.*, 2006; Liu *et al.*, 2002).

Although vegetation cover has increased due to the GTGP (Liang *et al.*, 2006; Yang, 2006), tree species planted on GTGP land have low diversity. Different regions have different species, but a single or a few species often dominate one region. For example, during 2000–2005 in Henan Province, 40% of GTGP land was planted with poplar, 58% with fruit trees, and less than 2% with other species. In Jiangxi Province, camellia oil was planted in 60% of GTGP land in 2006 (Liu *et al.*, 2008). In addition, some scholars are concerned that afforestation with water-intensive species (e.g., poplar) in the semiarid and arid northwestern regions may not improve the environment; it might even deteriorate it (Cao, 2008).

Socioeconomic Effects

By the end of 2009, the total investment in the GTGP had exceeded 200 billion yuan (Figure 7) and more than 120 million farmers in 32 million households had participated in the GTGP. However, the socioeconomic effects of the GTGP vary from one area to another. In some areas, the vast majority of households were satisfied with GTGP (Hu *et al.*, 2006; Xu and Cao, 2002), which has helped alleviate poverty and reduce income inequality (Li *et al.*, 2011; Uchida *et al.*, 2005; Xu *et al.*, 2006b). It has helped many households shift from farming to nonfarming activities and thus change their income structures (Xu *et al.*, 2010; Zhang *et al.*, 2008). In Wuqi County of Shaanxi Province from 1998 to 2003 alone, 15,000 farmers changed their activities from farming to construction, transportation, and restaurant businesses (Ge *et al.*, 2006). The average household net income for GTGP participants has significantly increased by 75% in Ningxia and 8% in Guizhou (Uchida *et al.*, 2005). After their cropland was converted to GTGP land, many farmers had little to do in rural areas and went to cities to work as migrant workers. For example, in Guizhou Province, the number of migrant workers increased almost 50% over a period of 5 years (from 2.2 million in 2000 to 3.1 million in 2005) (Yang, 2006). In some other areas, farmers complained that participation is not voluntary as the central government claims, and the payment is low compared to agricultural revenue from the land (Xu and Cao, 2002; Xu *et al.*, 2010). In contrast to the optimism of the government, most households expressed concerns about their future livelihoods when the program ceases (Zhang *et al.*, 2008).

Similar to the NFCP, the GTGP has also generated financial difficulties for many local governments because local governments do not receive tax revenues from GTGP land (Huang,

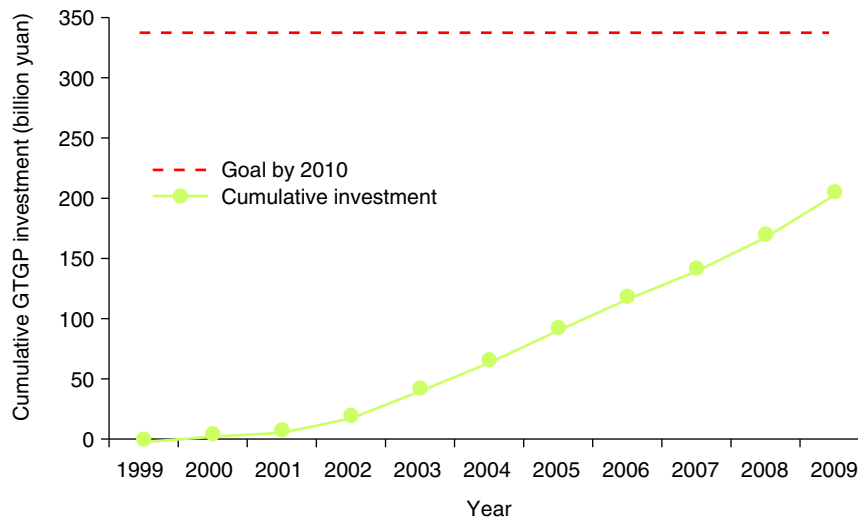


Figure 7 Investment in GTGP. Reproduced from State Forestry Administration (2000–2010) *China Forestry Development Report*. Beijing: State Forestry Administration; State Forestry Administration (2001–2009) *Bulletin of Key Forestry Projects*. Beijing: State Forestry Administration; State Forestry Administration (2006–2010) *Statistical Analysis of National Forestry*. Beijing: State Forestry Administration, and Xu J, Dao R, and Xu Z (2004) Grain to Green Program: Effectiveness, effects of structural adjustment, and economic sustainability. *China Economic Quarterly* 4: 139–162 (in Chinese).

2007; Xu *et al.*, 2006a). Although local governments also receive partial subsidies from the central government, they have to cover other expenses for implementing the GTGP (e.g., monitoring its effectiveness and transporting grain to farmers) (Liu and Zhou, 2005). For example, the local government of Kangding County in Sichuan Province lost 28% of its revenue between 1999 and 2001 (Dong, 2003).

Future Opportunities, Challenges, and Needs

Overall, like the NFCP, the GTGP has led to many accomplishments in terms of both biophysical and socioeconomic effects. However, the program also has induced negative effects on local livelihoods, financial burdens on local governments, and social conflicts between local households and governments over the use of land and associated resources (Miao and West, 2004).

Although the program has been extended for another round, so far there has been no systematic assessment of its effectiveness. Overall assessments were based only on government-reported data with few immediately observable indicators (Liu *et al.*, 2008; Yin, 2009). Considering its tremendous investment and wide distribution, it is crucial to systematically evaluate the biophysical and socioeconomic impacts of this program in both the short and long terms. Although proxies (e.g., slope) could be useful, they may not be sufficient for quantifying erosion severity or other ecological conditions (Yin, 2009). Therefore, further direct measures of environmental conditions, costs, and benefits are important.

The cost-effectiveness of the program can also be enhanced by targeting priority households and lands (Chen *et al.*, 2010; Uchida *et al.*, 2005). This targeting approach is especially useful to balance the environmental and poverty alleviation goals. Currently, in some areas, the GTGP is mandatory rather than voluntary, which has induced enrollment of flat, fertile, and profitable lands, both violating the goals of the program

and harming the program in the long run (Xu and Cao, 2002; Yin, 2009; Zhang *et al.*, 2008).

To improve the performance and ensure the sustainability of the program, greater efforts should be made to improve the program design, engagement, institutional capacity building, and guidance on alternative income sources for participants. Since local communities and households are more able to recognize their needs and constraints, they should be given more power in the program participation, design and implementation. Voluntary participation would avoid enrolling flat and profitable lands and ensure that farmers acquire adequate compensation (e.g., no less than their opportunity costs). A pilot practice may be attempted to decentralize the design and implementation processes to local governments. Decentralization could give local governments more flexibility to adapt to local conditions, reduce the transaction costs for program enforcement, and reduce the financial burden on local governments (Bennett, 2008; Liu *et al.*, 2007a). Furthermore, like many other conservation and development policies in China, the GTGP is implemented separately and the interactive effects between the GTGP and other policies are rarely quantified (Liu *et al.*, 2008). However, for example, the GTGP has had positive impacts on rural household income and rural-to-urban and interior-to-coastal migrations in western China, which implies that it does interact with other policies such as the Western China Development Policy (Li *et al.*, 2011; Zhang *et al.*, 2008).

In addition, the government should improve the provision of alternative income sources for participants to improve their livelihoods in the long run. Although this was a requirement of the GTGP implementation plan at the very beginning, few effective approaches have been taken, and in some places the livelihoods of participants even became worse due to the implementation of the GTGP (Yin, 2009). Remedial actions should also be adopted to offset induced negative impacts on both the environment and the people, especially targeting

priority households such as the poor, minorities, and households with low social capital (Zhang *et al.*, 2008). Another focus area of future research would be how to establish a long-term management mechanism to improve the livelihoods of participants when the program expires.

Concluding Remarks

Despite differences in specific goals and implementation approaches, all three programs – NRS, NFCP, and GTGP – are remarkable ecosystem service policies in terms of investment, scale, and biophysical and socioeconomic effects. Overall, they have dramatically improved China's environmental conditions and ecosystem services, and thus have mitigated the unprecedented ecological degradation in China since the 1950s (Liu, 2010). As these programs continue and ecosystems recover, their ecological impacts will be even larger in the future. Besides the positive biophysical and socioeconomic outcomes, they have also induced some negative consequences. Some of these negative effects (e.g., decrease in revenue due to structural changes in forestry and agriculture) may benefit the government, forest enterprises, farmers, and other stakeholders in the long run. But there are also some common issues in these programs.

The reported effectiveness of these programs is largely based on government-reported data with only a few immediately observable indicators (e.g., implementation area). Rigorous, scientifically sound studies are mostly fragmented and often focus on only one aspect or a few aspects in a small area and for a short period (partly due to data accessibility and costs). Measurements of environmental benefits are mostly based on proxies (e.g., slope of land) rather than on direct observations (e.g., the change in soil erosion). Thus, integrated assessment and direct measurements of environmental conditions are needed to assess these programs.

To maximize the outcomes and minimize costs, the cost-effective targeting approach should be incorporated into the design and implementation processes of the programs (Chen *et al.*, 2010). Decentralization could be attempted to give local governments, communities, and households more autonomy in order to reduce transaction costs, avoid social conflicts, and enhance the performance and fairness of the programs. The targeting and decentralization approaches could also address the spatial heterogeneity across different regions and avoid overpayment for ecosystem services in some areas and underpayment in other areas.

Besides the three programs, some other ecosystem service policies have also been implemented recently. One major policy is the designation of EFZs (Ministry of Environmental Protection and Chinese Academy of Sciences, 2008). Based on the integrated analysis of ecological conditions and problems, evaluation of ecological sensitivity, and levels of importance of ecosystems services, 216 EFZs were identified in China. Of them, 50 national key EFZs, covering 23.4% of China's land surface, were identified on the basis of importance for ecosystem services provision, including biodiversity conservation, water resource conservation, soil maintenance, sandstorm prevention, and flood control (Ouyang, 2007). To maintain and improve ecosystem services in EFZs, the financial payments from the central

government to local governments have been carried out since 2008. In 2008 alone, 6 billion yuan was transferred to 221 counties in EFZs. The total payment increased to 12 billion yuan for 372 counties in 2009 and to 24.9 billion yuan for 451 counties in 2010. Although many biophysical and socioeconomic effects have not yet been assessed, these large amounts of payments in EFZs are expected to improve China's ecosystem services and benefit the rest of the world in the long run.

For these and other payment for ecosystem service programs in China, the central government is the dominant buyer for ecosystem services. With the rapid economic development and increase of financial revenue during the past three decades, the central government can afford to pay for these programs. In the long run, however, if these programs continue and new programs emerge, the financial cost will be very high. Moreover, the government compensation approach also has limitations that are difficult to overcome, including the lack of flexibility, the difficulty in defining payment levels, and high transaction costs (Task Force for Eco-Compensation Mechanisms and Policies in China, 2007). To secure the financial sustainability of current and future programs, it is important to diversify the fund sources by engaging both public and private funds as well as funds from other countries and international organizations (Liu *et al.*, 2008).

The interactive effects among these programs and other conservation and development programs also should be studied. It should be recognized that all programs affect both ecosystem services and human well-being. Thus, a coupled human and natural systems perspective (Liu *et al.*, 2007b, c) would be helpful to understand the complexity of policies and their impacts, and to establish long-term management mechanisms to improve the livelihood of participants in these programs and other ecosystem service policies in both China and many other parts of the world.

Acknowledgments

Financial support was provided by the National Science Foundation, National Aeronautics and Space Administration, National Natural Science Foundation of China, National Key Basic Research Program of China, and Michigan AgBioResearch.

See also: Biodiversity and Cultural Ecosystem Services. Biodiversity and Ecosystem Services. Biodiversity, Human Well-Being, and Markets. Biodiversity in Logged and Managed Forests. Biodiversity-Rich Countries. Climate Change and Wild Species. Commons, Concept and Theory of. Commons, Institutional Diversity of. Conservation and People. Conservation and the World's Poorest of the Poor. Conservation Biology, Discipline of. Conservation Efforts, Contemporary. Conserving Biodiversity Outside Protected Areas. Deforestation and Land Clearing. Economic Value of Biodiversity, Measurements of. Economics of Agrobiodiversity. Economics of the Regulating Services. Endangered Ecosystems. Endangered Mammals. Endangered plants. Endangered Terrestrial Invertebrates. Environmental Ethics. Environmental Impact, Concept and Measurement of. Ethical Issues in Biodiversity Protection. Framework for Assessment and Monitoring of Biodiversity. Grazing, Effects of.

Habitat Loss and Fragmentation. Human Impact on Biodiversity, Overview. Human Impacts on Ecosystems: An Overview. Impact of Ecological Restoration on Ecosystem Services. *In Situ, Ex Situ* Conservation. Indigenous Peoples and Biodiversity. International Organizations and Biodiversity. Justice, Equity and Biodiversity. Landscape Ecology and Population Dynamics. Land-Use Patterns, Historic. Loss of Biodiversity, Overview. Mammals, Conservation Efforts for. Market Economy and Biodiversity. Natural Reserves and Preserves. Population Stabilization, Human. Poverty and Biodiversity. Property Rights and Biodiversity. Reforestation. Remote Sensing and Image Processing. Restoration of Biodiversity, Overview. Role and Trends of Protected Areas in Conservation. Social and Cultural Factors. Social Behavior. Soil Conservation. Sustainability and Biodiversity. Systematics, Overview. The Value of Biodiversity. Threatened Species: Classification Systems and Their Applications. Tourism, Role of. Traditional Conservation Practices. Trends in Nature Recreation: Causes and Consequences. Valuing Ecosystem Services. Wildlife Management

References

- Balmford A, Bruner A, Cooper P, *et al.* (2002) Economic reasons for conserving wild nature. *Science* 297: 950–953.
- Bao J, Tang D, and Chen B (2005) Socioeconomic effects of Grain to Green Program in Sichuan Province. *Sichuan Forestry Exploration and Design* 1: 26–32 (in Chinese).
- Bearer S, Linderman M, Huang J, An L, He G, and Liu J (2008) Effects of timber harvesting and fuelwood collection on giant panda habitat use. *Biological Conservation* 141: 385–393.
- Bennett MT (2008) China's sloping land conversion program: Institutional innovation or business as usual? *Ecological Economics* 65: 699–711.
- Cao SX (2008) Why large-scale afforestation efforts in China have failed to solve the desertification problem. *Environmental Science & Technology* 42: 1826–1831.
- Cao SX, Wang XQ, Song YZ, Chen L, and Feng Q (2010) Impacts of the Natural Forest Conservation Program on the livelihoods of residents of Northwestern China: Perceptions of residents affected by the program. *Ecological Economics* 69: 1454–1462.
- Chen XD, Lupi F, Viña A, He GM, and Liu JG (2010) Using cost-effective targeting to enhance the efficiency of conservation investments in payments for ecosystem services. *Conservation Biology* 24: 1469–1478.
- Dong J (2003) A comparative study of values between sloping fields and forestland – Effects of Grain to Green Program. *China Population, Resources and Environment* 13: 81–83 (in Chinese).
- Fan J, Li J, Quan Z, Wu X, Hu L, and Yang Q (2011) Impact of road construction on giant panda's habitat and its carrying capacity in Qinling Mountains. *Acta Ecologica Sinica* 31: 145–149.
- FCCDP (1998) Forest conservation and community development project rapid rural appraisal report: Nuozhadu Nature Reserve and its surrounding communities. Kunming: Forest Conservation and Community Development Project.
- Feng Z, Yang Y, Zhang Y, Zhang P, and Li Y (2005) Grain-for-green policy and its impacts on grain supply in West China. *Land Use Policy* 22: 301–312.
- Ge W, Li L, and Li Y (2006) On sustainability of Grain to Green Program – A survey of Wuqi and Zhidan counties in Shaanxi Province. *Forestry Economics* 11: 33–49 (in Chinese).
- He GM, Chen XD, Liu W, *et al.* (2008) Distribution of economic benefits from ecotourism: A case study of Wolong Nature Reserve for Giant Pandas in China. *Environmental Management* 42: 1017–1025.
- Hou J and Zhang S (2002) Evaluating effects of Grain to Green Program in the Loess Plateau Area. *Bulletin of Soil and Water Conservation* 22: 29–31 (in Chinese).
- Hu C, Fu B, Chen L, and Gulincik H (2006) Farmers' attitudes towards the Grain-for-Green programme in the loess hilly area, China: A case study in two small catchments. *International Journal of Sustainable Development and World Ecology* 13: 211–220.
- Huang Q (2007) On Grain to Green Program – The case of northwestern China. *Ecological Economy* 2: 60–63 (in Chinese).
- Huang Y (2005) Countermeasures to the main problems in Natural Forest Conservation Program in Guizhou. *Guizhou Forestry Science and Technology* 33: 49–51 (in Chinese).
- Jia Y, Zhou Z, Qiu Y, *et al.* (2006) The potential effect of water yield reduction caused by land conversion in the Yellow River basin. In: Zhang L, Bennett J, Wang XH, Xie C, and Zhao JC (eds.) *A Study of Sustainable Use of Land Resources in Northwestern China*. Beijing: China National Forestry Economics and Development Research Center.
- Li D, Bo F, and Tao J (2006a) Achievements in and strategies for Grain to Green Program in Hunan Province. *Hunan Forestry Science & Technology* 33: 1–5 (in Chinese).
- Li J, Feldman MW, Li SZ, and Daily GC (2011) Rural household income and inequality under the Sloping Land Conversion Program in western China. *Proceedings of the National Academy of Sciences of the United States of America* 108: 7721–7726.
- Li WJ, Ge XD, and Liu CY (2005) Hiking trails and tourism impact assessment in protected area: Jiuzhaigou Biosphere Reserve, China. *Environmental Monitoring and Assessment* 108: 279–293.
- Li WJ, Zhang Q, Liu CY, and Xue QF (2006b) Tourism's impacts on natural resources: A positive case from China. *Environmental Management* 38: 572–579.
- Li Y (2010) *Effects of Conservation Policies on Forest Cover Change in Panda Habitat Regions, China*. East Lansing: Department of Fisheries and Wildlife, Michigan State University.
- Li Z, Zimmermann F, Hebblewhite M, *et al.* (2010) *Study on the Potential Tiger Habitat in the Changbaishan Area, China*. Beijing, China: China Forestry Publishing House.
- Liang W, Bai C, Sun B, Hao D, and Qi J (2006) Soil moisture and physical properties of regions under Grain to Green Program in the Gullied Rolling Loess Area. *Soil and Water Conservation in China* 3: 17–18 (in Chinese).
- Liu C, Meng Q, Li Y, and Lu J (2005) A case study on ecological and socioeconomic benefit evaluation of Sichuan provincial Natural Forest Conservation Program. *Acta Ecologica Sinica* 25: 428–434 (in Chinese).
- Liu C, Wang S, Zhang W, and Liang D (2007a) Compensation for forest ecological services in China. *Forestry Studies in China* 9: 68–79.
- Liu F, Huang C, He T, Qian X, Liu Y, and Luo H (2002) Role of Grain to Green Program in reducing loss of phosphorus from yellow soil in hilly areas. *Journal of Soil and Water Conservation* 16: 20–23 (in Chinese).
- Liu J (2010) China's road to sustainability. *Science* 328: 50.
- Liu J, Daily GC, Ehrlich PR, and Luck GW (2003a) Effects of household dynamics on resource consumption and biodiversity. *Nature* 421: 530–533.
- Liu J and Diamond J (2005) China's environment in a globalizing world. *Nature* 435: 1179–1186.
- Liu J and Diamond J (2008) Science and government: Revolutionizing China's environmental protection. *Science* 319: 37–38.
- Liu J, Dietz T, Carpenter SR, *et al.* (2007b) Complexity of coupled human and natural systems. *Science* 317: 1513–1516.
- Liu J, Dietz T, Carpenter SR, *et al.* (2007c) Coupled human and natural systems. *Ambio* 36: 639–649.
- Liu J, Li S, Ouyang Z, Tam C, and Chen X (2008) Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America* 105: 9477–9482.
- Liu J, Linderman M, Ouyang Z, An L, Yang J, and Zhang H (2001) Ecological degradation in protected areas: The case of Wolong Nature Reserve for giant pandas. *Science* 292: 98–101.
- Liu J, Ouyang Z, Pimm S, *et al.* (2003b) Protecting China's biodiversity. *Science* 300: 1240–1241.
- Liu J, Ouyang Z, Taylor WW, Groop R, Tan Y, and Zhang H (1999) A framework for evaluating the effects of human factors on wildlife habitat: The case of giant pandas. *Conservation Biology* 13: 1360–1370.
- Liu J and Raven PH (2010) China's environmental challenges and implications for the world. *Critical Reviews in Environmental Science and Technology* 40: 823–851.
- Liu Y and Zhou Q (2005) Shortcomings in the incentives of Grain to Green Program. *China Population, Resources and Environment* 15: 104–107 (in Chinese).
- Lu HF, Campbell D, Chen J, Qin P, and Ren H (2007) Conservation and economic viability of nature reserves: An emergy evaluation of the Yancheng Biosphere Reserve. *Biological Conservation* 139: 415–438.
- Ma Y and Fan S (2005) Ecological-economic effects of Grain to Green Program in desertification areas. *Journal of Natural Resources* 20: 590–596. in Chinese.

- Miao GP and West RA (2004) Chinese collective forestlands: Contributions and constraints. *International Forestry Review* 6: 282–298.
- Millennium Ecosystem Assessment (2005) *Ecosystems & Human Well-Being: Synthesis*. Washington, DC: Island Press.
- Ministry of Environmental Protection (2010) *The List of Nature Reserves in China by the End of 2009*. Beijing: Environmental Science Press.
- Ministry of Environmental Protection (2011) *Bulletin of China's Environmental Status 2010*. Beijing: Ministry of Environmental Protection of China.
- Ministry of Environmental Protection and Chinese Academy of Sciences (2008) *National Ecosystem Function Zones*. Beijing: Ministry of Environmental Protection of China.
- Ouyang Z (2007) *Ecological Construction and Sustainable Development in China (in Chinese)*. Beijing: Science Press.
- Ouyang Z and Wang R (1997) A primary study on the indirect value of biodiversity in China. In: Editorial Committee of State Report on Biodiversity of China (ed.) *State Report on Biodiversity of China*. Beijing: China Environmental Science Press.
- Ouyang Z, Wang X, and Miao H (1999) A primary study on Chinese terrestrial ecosystem services and their ecological-economic values. *Acta Ecologica Sinica* 19: 607–613.
- Ouyang Z, Wang X, Miao H, and Han N (2002) Problems of management system of China's nature preservation zones. *Science & Technology Review* 49–52 (in Chinese).
- Qiao R, Gao J, and Zhang A (2006) Effects of Natural Forest Conservation Program on farmers' income – The cases of Hubei, Sichuan and Chongqing. *Research of Agricultural Modernization* 27: 40–43 (in Chinese).
- State Forestry Administration (2001) China wildlife conservation and nature reserve construction master plan. Beijing: State Forestry Administration of China.
- State Forestry Administration (2006) *The Third National Survey Report on Giant Panda in China*. Beijing: Science Press.
- Statistic Bureau of Zhangjiajie City (2011) 2010 *National Economic and Social Development Statistical Bulletin of Wulingyuan District*. Zhangjiajie: Statistic Bureau of Zhangjiajie City.
- Task Force for Eco-Compensation Mechanisms and Policies in China (2007) *Eco-Compensation Mechanisms and Policies in China*. Beijing: Science Press.
- Uchida E, Xu JT, and Rozelle S (2005) Grain for green: Cost-effectiveness and sustainability of China's conservation set-aside program. *Land Economics* 81: 247–264.
- Viña A, Bearer S, Chen X, et al. (2007) Temporal changes in giant panda habitat connectivity across boundaries of Wolong Nature Reserve, China. *Ecological Applications* 17: 1019–1030.
- Viña A, Bearer S, Zhang H, Ouyang Z, and Liu J (2008) Evaluating MODIS data for mapping wildlife habitat distribution. *Remote Sensing of Environment* 112: 2160–2169.
- Viña A, Chen XD, McConnell W, et al. (2011) Effects of natural disasters on conservation policies: The case of the 2008 Wenchuan Earthquake, China. *Ambio* 40: 274–284.
- Viña A, Tuanmu MN, Xu WH, et al. (2010) Range-wide analysis of wildlife habitat: Implications for conservation. *Biological Conservation* 143: 1960–1969.
- Wang Z, Wang X, Shi Y, Pan L, Yu X, and Tang Z (2007) Effects of Grain to Green Program on soil and water conservation in Zigui County of the Three Gorges Reservoir Region. *Science of Soil and Water Conservation* 5: 68–72 (in Chinese).
- WU RD, Zhang S, Yu DW, et al. (2011) Effectiveness of China's nature reserves in representing ecological diversity. *Frontiers in Ecology and the Environment* 9: 383–389.
- Xu J and Cao Y (2002) On sustainability of converting farmland to forests and grasslands. *International Economic Review* 22: 56–60 (in Chinese).
- Xu J, Dao R, and Xu Z (2004) Grain to Green Program: Effectiveness, effects of structural adjustment, and economic sustainability. *China Economic Quarterly* 4: 139–162 (in Chinese).
- Xu J, Yin R, Li Z, and Liu C (2006a) China's ecological rehabilitation: Unprecedented efforts, dramatic impacts, and requisite policies. *Ecological Economics* 57: 595–607.
- Xu JC and Melick DR (2007) Rethinking the effectiveness of public protected areas in southwestern China. *Conservation Biology* 21: 318–328.
- Xu JT, Tao R, Xu ZG, and Bennett MT (2010) China's Sloping Land Conversion Program: Does expansion equal success? *Land Economics* 86: 219–244.
- Xu Z, Xu J, Deng X, Huang J, Uchida E, and Rozelle S (2006b) Grain for green versus grain: Conflict between food security and conservation set-aside in China. *World Development* 34: 130–148.
- Xue D, Bao H, and Li W (1999) A valuation study on the indirect values of forest ecosystem in Changbaishan Mountain Biosphere Reserve of China. *China Environmental Science* 19: 247–252.
- Yang L (2004) Natural Forest Conservation Program and forest eco-compensation system: The case of Taijiang in Guizhou Province. *Journal of Mountain Agriculture and Biology* 23: 158–163 (in Chinese).
- Yang S (2006) Policy recommendations for Grain to Green Program in the "Eleventh Five-Year Plan" – Thoughts from studying the program in Sichuan and Guizhou provinces. *Forestry Economics* 9: 7–10 (in Chinese).
- Yin R (ed.) (2009) *An Integrated Assessment of China's Ecological Restoration Programs*. New York: Springer.
- Yuan JQ, Dai LM, and Wang QL (2008) State-led ecotourism development and nature conservation: A case study of the Changbai Mountain Biosphere Reserve, China. *Ecology and Society* 13: 55.
- Zhang L, Tu Q, and Mol APJ (2008) Payment for environmental services: The sloping land conversion program in Ningxia autonomous region of China. *China & World Economy* 16: 66–81.
- Zhang P, Shao G, Zhao G, et al. (2000) Ecology: China's forest policy for the 21st century. *Science* 288: 2135–2136.
- Zhang Z (2006) Review of the Tenth Five-year Plan and Perspective on the Eleventh Five-year Plan in relation to Natural Forest Conservation Program. *Forestry Economics* 1: 49–52 (in Chinese).
- Zhou X (2006) Countermeasures to problems in implementing Natural Forest Conservation Program in Sichuan Province. *Forest Resources Management* 2: 19–23 (in Chinese).