Ecological and socioeconomic effects of China's policies for ecosystem services

Jianguo Liu*†, Shuxin Li*, Zhiyun Ouyang‡, Christine Tam§, and Xiaodong Chen*

*Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48823-5243; ‡State Key Lab of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China; and §Department of Biology and Natural Capital Project, Woods Institute for the Environment, Stanford University, Stanford, CA 94305-5020

Edited by Gretchen C. Daily, Stanford University, Stanford, CA, and approved December 17, 2007 (received for review July 11, 2007)

To address devastating environmental crises and to improve human well-being, China has been implementing a number of national policies on payments for ecosystem services. Two of them, the Natural Forest Conservation Program (NFCP) and the Grain to Green Program (GTGP), are among the biggest programs in the world because of their ambitious goals, massive scales, huge payments, and potentially enormous impacts. The NFCP conserves natural forests through logging bans and afforestation with incentives to forest enterprises, whereas the GTGP converts cropland on steep slopes to forest and grassland by providing farmers with grain and cash subsidies. Overall ecological effects are beneficial, and socioeconomic effects are mostly positive. Whereas there are time lags in ecological effects, socioeconomic effects are more immediate. Both the NFCP and the GTGP also have global implications because they increase vegetative cover, enhance carbon sequestration, and reduce dust to other countries by controlling soil erosion. The future impacts of these programs may be even bigger. Extended payments for the GTGP have recently been approved by the central government for up to 8 years. The NFCP is likely to follow suit and receive renewed payments. To make these programs more effective, we recommend systematic planning, diversified funding, effective compensation, integrated research, and comprehensive monitoring. Effective implementation of these programs can also provide important experiences and lessons for other ecosystem service payment programs in China and many other parts of the world.

conservation | environment | forests | grassland | sustainability

Over the past three decades, China's economy has grown the fastest among all major nations. By contrast, China's environment is increasingly deteriorating. For example, soil erosion is widespread, and "natural" disasters have caused devastating socioeconomic impacts (1). To mitigate the impacts of the degraded environment, China has been implementing large-scale conservation programs, including the Key Shelterbelt Construction Program, Beijing–Tianjin Sandstorm Control Program, Wildlife Conservation and Nature Reserve Development Program (2), and Forest Eco-Compensation Program (3).

The severe droughts in 1997 and the massive floods in 1998 have prompted China to take two other unprecedented conservation actions—the development and implementation of the Natural Forest Conservation Program (NFCP, also known as the Natural Forest Protection Program) and the Grain to Green Program (GTGP, also known as the Sloping Land Conversion Program and the Farm to Forest Program) (4–6). The NFCP conserves natural forests through logging bans and afforestation with incentives to forest enterprises, whereas the GTGP converts cropland on steep slopes to forest and grassland by providing farmers with grain and cash subsidies. These actions resulted from the realization that those droughts/floods were at least partially caused by farming on steep slopes and deforestation.

The NFCP and GTGP are two of the biggest programs offering payments for ecosystem services in both China and worldwide in terms of scale, payment, and duration (7–11). They are major components of China's six key forest conservation programs, which encompass 97% of China's counties. Planned investment will exceed 700 billion yuan (at present, $1 U.S. = 7.4 yuan). The implementation of these programs is a milestone of China's forest management; it marks the end of an era dominated by timber production.

The NFCP and GTGP also have important global implications (1), although they were initially developed to address pressing environmental problems in China. If implemented adequately and sustainably, these two programs can generate many benefits to China and the rest of the world by addressing a wide array of environmental issues (e.g., biodiversity loss, climate change, desertification, droughts, floods, soil erosion, and water runoff) as well as socioeconomic challenges (e.g., poverty alleviation, social conflicts, and economic development) (1, 4, 5).

In this article, we provide an overview of the goals and payments for the NFCP and GTGP, illustrate their ecological and socioeconomic effects as rigorously as possible from various sources of literature, discuss future opportunities and challenges, and offer recommendations to overcome their shortcomings and enhance their potential.

Natural Forest Conservation Program

Background and Goals. According to the fifth national forest inventory (1994–1998), the size of China's natural forests was only 112 million ha (≈70% of all forests), and most of these forests were degraded because of various human activities (e.g., pervasive logging). The overall goal of the NFCP is to protect and restore natural forests through such means as logging bans (Fig. 1). It is widely believed that achieving this goal can lead to many ecosystem service benefits, such as soil erosion reduction, water retention, and flood control. To achieve this overall goal, the NFCP has also developed short-, medium-, and long-term goals as stepping stones. The short-term goals (1998–2000) were to eliminate or reduce timber harvesting from natural forests and create alternative employment for traditional forest enterprises. The medium-term goals (2001–2010) are to construct and protect forests for ecological benefits and to increase the capacity for timber harvesting from plantation forests. As a final goal (2011–2050), the NFCP aims to restore natural forests and meet domestic demand for timber in plantation forests.

The creators of the NFCP hoped to lower timber harvests in natural forests from 32 million m^3 in 1997 to 12 million m^3 in 2003, and plan to afforest 31 million ha by 2010 through mountain closure (i.e., prohibition of human activities such as fuelwood collection and grazing to allow regrowth) (12), aerial seeding, and artificial planting (4) (Fig. 2). The NFCP required that commercial logging

Author contributions: J.L., S.L., Z.O., C.T., and X.C. designed research, performed research, analyzed data, and wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

†To whom correspondence should be addressed. E-mail: jliu@panda.msu.edu.

This article contains supporting information online at www.pnas.org/cgi/content/full/0706436105/DC1.

Fig. 1. Current distribution of the NFCP and GTGP in China. Names of provinces, autonomous regions, municipalities, and two major rivers are shown. Data are from refs. 1 and 2 and supporting information (SI) *Text*.

be completely banned in the upper reaches of the Yangtze and Yellow rivers as well as in Hainan Province (Fig. 1) by 2000, and that logging be substantially reduced elsewhere (4).

The NFCP pilot study started in 12 provinces and autonomous regions/municipalities in 1998. It was expanded to 18 provinces in 2000 (Fig. 1).

Payments. From 1998 to 2005, the NFCP received ≈61 billion yuan (Fig. 3). This investment was mainly used for payments to cover economic losses of forest enterprises caused by the shift from timber harvesting to tree plantations and forest management (2). The payments were linked to specific tasks: 1,050 yuan/ha for allowing forest regeneration through mountain closure; 750 yuan/ha for aerial seeding; 3,000 and 4,500 yuan/ha for artificial planting in the Yangtze and Yellow river basins, respectively; and 10,000 yuan per worker for protecting 340-ha forest patches (4).

A total of 96.2 billion yuan has been designated for NFCP-related activities from 2000 to 2010 (4), of which ≈50% has already been spent (Fig. 3); ≈81.5% of this amount is anticipated from the central government, and the remainder, from local governments.

Ecological Effects. Overall, progress has been made toward achieving the goals of conserving and restoring natural forests. Most research and assessment efforts have focused on immediately

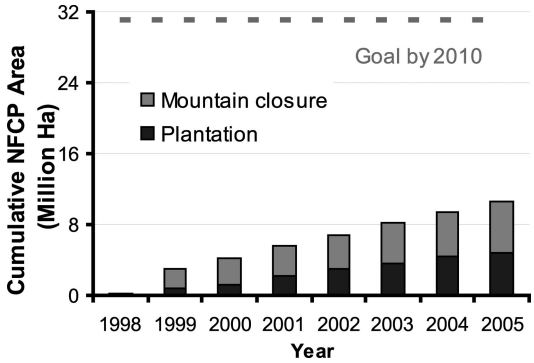

Fig. 2. Cumulative amount of land under the NFCP. The dashed line indicates the goal for 2010. Data are from refs. 66 and 67.

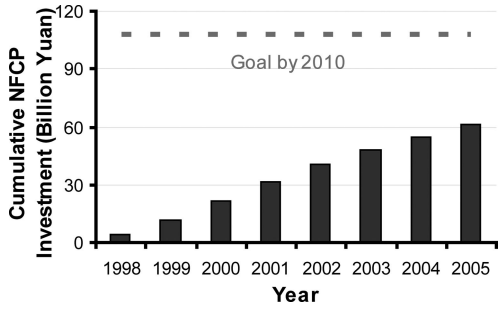

Fig. 3. Cumulative amount of investment in NFCP (1998–2005). The dashed line indicates the goal for 2010. Data are from refs. 66 and 67.

observable indicators such as changes in harvested timber, newly forested area, and degree of soil erosion.

By 2000, commercial harvesting of natural forests in 13 provinces had ceased, and the total area without logging had reached 8.9 million ha. The amount of timber harvested decreased 41% (from 18.5 to 11 million m^3) in northeast China and Inner Mongolia between 1997 and 2003 (13). However, this change may be one reason for increased timber imports from other countries. In 2002, the domestic production of commercial roundwood declined to 44.4 million m^3, but the total import volume increased to 94.5 million m^3 (14). In 2005, China imported 29.4 million m^3 of logs, an increase of 10.4% from 2004 with imports from tropical forests accounting for 7.4 million m^3 (25% of total log imports). However, much of the imported timber to China was used to make products (e.g., furniture) later exported to developed countries.

The area under mountain closure and plantation increased rapidly over time and expanded to almost 11 million ha by 2005 (Fig. 2). Native species (e.g., pine and China fir) are generally encouraged in the NFCP region although nonnative species (e.g., poplar and Hinoki cypress) were planted in some landscapes. Furthermore, only one or a few tree species were usually dominant in a specific landscape, but there are efforts to diversify species composition (15).

Carbon sequestration has also increased. Between 1998 and 2004, 21.3 Tg (1 Tg = 10^{12} g) of carbon was sequestered in the new plantations under the NFCP (of which, 6.4, 12.6, and 2.3 Tg of carbon were sequestered in northeastern China and Hainan Province, the upper Yangtze River Basin, and the upper Yellow River Basin, respectively). In addition, wood production was reduced by 9.7 million m^3, resulting in a reduction of carbon emissions of 22.8 Tg. The total carbon sequestered through the NFCP was 44.1 Tg (1.2% of China's CO_2 emissions) from 1998 to 2004 (16).

Soil erosion has been reduced, but the degree of reduction varied among regions. Sample analyses of 22 counties in the upper and middle reaches of the Yangtze and Yellow river basins indicate that the area suffering from soil erosion declined by 6% from 1998 to 2003. In Sichuan Province, soil erosion was reduced by 1.5 billion tons (13).

Wildlife habitat has also been improving. A long-term study in the Wolong Nature Reserve for the endangered giant pandas in Sichuan Province, which began 5 years before the NFCP started (17), demonstrates that illegal harvesting of natural forests has been rare (18) and that the panda habitat has been recovering since the NFCP's inception (19).

Socioeconomic Effects. Whereas major types of NFCP impacts on forest enterprises had been anticipated before the NFCP started, the extent of some impacts has exceeded expectations. Furthermore, there were unforeseen negative impacts on other industries and local governments.

Significant steps have been taken toward achieving the NFCP's short-term goals in generating alternative jobs for those previously

in forest enterprises, eventually altering the employment and economic structure in forestry. Among the 1.2 million logging and processing workers impacted by the NFCP, about two-thirds of them had retired or been transferred to other sectors by the end of 2002 (4). The dominant source of employment has shifted from logging to forest management and plantation farming. In the Chuannan Forestry Bureau and Ebian County of Sichuan Province, for instance, the percentages of staff in forest management increased from 0 and 13.1% in 1997 to 52.6% and 76.7% in 2001, respectively (20). Although there was a decline in income from forestry in some areas such as Longmenshan Township of Pengzhou County in Sichuan Province, total income increased because of income from other sources such as tourism (21).

As the central government anticipated, the economic structure in many forest enterprises has changed from timber production only to multiple industries. Industries in China are classified in three groups: (*i*) "first industry" includes agriculture, forestry, animal husbandry, and fisheries; (*ii*) "second industry" includes mining; manufacturing; the production and supply of electricity, natural gas, and water; and construction; and (*iii*) "third industry" includes all sectors that are not in the first or second industries (e.g., restaurants, hotels, and entertainment) (22). The average output of the third industry in 32 forest enterprises increased from 8.5% in 1997 to 20.1% in 2003 (13). However, for some enterprises, income from the third industry decreased after the NFCP began. For example, income from the third industry in the Chuannan Forestry Bureau of Sichuan Province declined from 5.0 million yuan in 1997 to 1.1 million yuan in 2001 because of a reduction in wood-related market activities (23, 24).

Despite changes in economic structure, many forest enterprises have experienced hardship. Although retirees are covered by government social security and pension systems (4), some enterprises cannot pay back their loans (25). By 2001, these loans reached 12.9 billion yuan, and unpaid salaries amounted to 860 million yuan. In Sichuan Province, 1,172 wood-related industry enterprises and 154,000 employees were impacted (26). Forestry workers dependent on income from timber harvesting suffered big economic losses. For instance, 55,000 people in Taijiang County of Guizhou Province lost ≈6 million yuan. This loss pushed some local forestry workers below the poverty line (27).

The NFCP has created budgetary burdens on some local governments (26) because of partial funding responsibilities, resulting in declines in local revenues (27, 28). For instance, from 1998 to 2001, the revenues in Yanbian County, Ebian County, Yanbian Forestry Bureau and Chuannan Forestry Bureau of Sichuan Province decreased by 9.7, 2.8, 3.7, and 32.0 million yuan, respectively; whereas matching funds from local governments accounted for 13%, 44%, 21%, and 0.3% of the total investment from the central government (20). Taijiang County of Guizhou Province was unable to pay back a loan of 15.2 million yuan for developing a timber base and had no funds for seedlings because of a decrease in commercial timber revenues (27). However, in other places, such as those reported in the three case studies in the northeast and southwest (29), subsidies from the central government and other sources (e.g., tourism) have offset losses in timber revenues.

Grain to Green Program

Background and Goals. Conserving natural forests through the NFCP is an important way to reduce soil erosion, but the most important contributor to this erosion is farming on steep slopes (30). In the Yangtze and Yellow river basins alone, nearly 4.3 million ha of cropland were on slopes of ≥25°. To complement the effort of the NFCP, China initiated the GTGP, another large ecosystem service payment policy, in 1999. Compared with the NFCP, the GTGP started a year later but is broader in terms of geographic extent (Fig. 1). The grain oversupply in the late 1990s as well as China's increasing financial capability provided a stable foundation for implementing the GTGP (31).

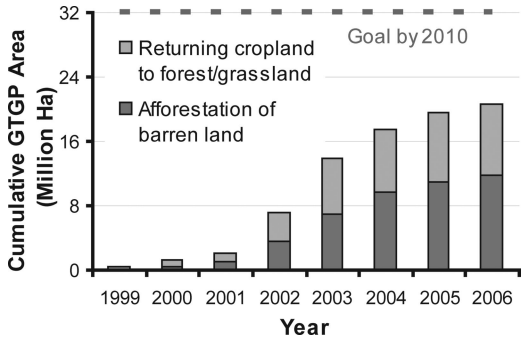

Fig. 4. Cumulative amount of land under the GTGP. The dashed line indicates the goal for 2010. Data are from refs. 66 and 67.

The GTGP aims to increase vegetative cover by 32 million ha by 2010 (Fig. 4). Of this area, 14.7 million ha will be converted from cropland on steep slopes back to forest and grassland (2). Slope steepness, ≥15° in northwestern China and ≥25° elsewhere (32), is the main criterion by which plots are chosen for inclusion in the GTGP. The remaining portion of the 32 million ha of vegetative cover will be created by afforesting barren land. In addition to the primary goal of reducing environmental degradation, two associated goals with the GTGP are to alleviate poverty and to promote local economic development (33).

The GTGP began its pilot study in three provinces (Sichuan, Shanxi, and Gansu) in 1999 (Fig. 1). It was expanded to 17 provinces in 2000 and finally to 25 provinces in 2002. The program focuses on western China because of its ecological vulnerability since it contains the headwaters of the Yangtze and Yellow rivers (Fig. 1) and accounts for ≈80% of the total area identified with soil erosion problems (>360 million ha). Furthermore, most desertification (174 million ha), three quarters of the cropland with a slope >25° (600 million ha), and 60% of the population under the poverty line are in western China (2, 31).

Payments. Under the GTGP, the government offers farmers 2,250 and 1,500 kg of grain (or 3,150 and 2,100 yuan at 1.4 yuan per kg of grain) per ha of converted cropland per year in the upper reach of the Yangtze River Basin and in the upper and middle reaches of the Yellow River Basin, respectively. In addition, 300 yuan/ha per year for miscellaneous expenses and a one-time subsidy of 750 yuan/ha for seeds or seedlings are provided (34, 35). The duration of subsidies depends on the outcome of cropland conversion: 2 years if the cropland is converted into grassland, 5 years if converted into economic forests by using fruit trees, or 8 years if converted to ecological forests by using tree species such as pine and black locust (35). Furthermore, no taxes on the converted cropland are collected (4).

By the end of 2005, >90 billion yuan had been invested in the GTGP (Fig. 5). The GTGP began to receive more cumulative investment than the NFCP did in 2004 when its budget amounted to ≈10 billion yuan more than that of the NFCP (Figs. 3 and 5). The planned total investment in the GTGP will reach 220 billion yuan by 2010 (Fig. 5).

Ecological Effects. Similar to those of the NFCP, measures of the GTGP ecological effects are generally those immediately observable: the amount of land converted and afforested, and the changes in vegetative cover, water surface runoff, and soil erosion. Ecosystem service changes on large scales, such as flood control, are mainly inferred from changes in immediately observable factors.

By the end of 2006, the GTGP had converted almost 9 million ha of cropland into forest/grassland and had afforested 11.7 million ha of barren land (Fig. 4). In Guizhou Province alone, the forested area increased by 952,000 ha (5.5%) between 2000 and 2005 (36). The

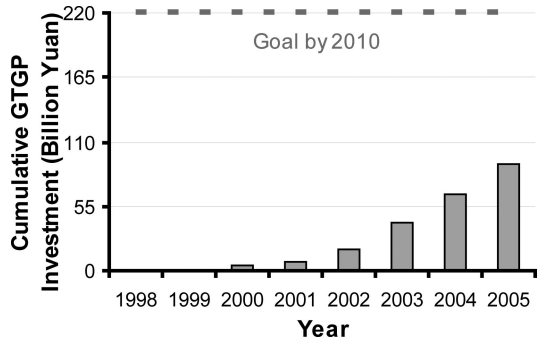

Fig. 5. Cumulative amount of investment in the GTGP from 1999 to 2005. Because data on separate investment in the GTGP for 1999 and 2000 are not available, the combined amount of investment during these 2 years is shown in 2000. The dashed line indicates the goal for 2010. Data are from refs. 66 and 67.

total amount of converted cropland nationwide is higher than the quota for conversion set by the central government (4). Furthermore, the total amount of GTGP land has exceeded the total amount of NFCP land since 2002, with the difference increasing over time (Figs. 2 and 4). The statistics of the State Forestry Administration suggest that forest cover within the GTGP region has increased 2% during 8 years.

The GTGP reduces surface runoff and soil erosion. In Hunan Province, for instance, between 2000 (when the program began) and 2005, soil erosion declined by 30%, and surface runoff dropped ≈20% (37). In 14 counties of Sichuan Province from 1998 to 2003, the forested area increased by 113,100 ha (12.7% of forested area in 14 counties in 2003), and the area affected by soil erosion was reduced 10% (from 13,528 to 12,171 km^2) (38). In Zigui County of the Three Gorges Reservoir Region of Hubei Province (Fig. 1), 3,085 ha of cropland (8.1% of total cropland in Zigui County) were converted to forest in 2000, lowering soil erosion by 54,900 tons/year during 2000–2005. Five years after GTGP implementation, converted plots reduced surface runoff by 75–85% and soil erosion by 85–96% compared with cropland on steep slopes without the GTGP (39).

The program also improves the physical properties of soil structure and reduces nutrient loss for maintaining soil fertility and lowering river sediments. In the Chaigou Watershed of Wuqi County of Shaanxi Province, the average soil moisture and moisture-holding capacity in GTGP plots after 5 years were 48% and 55% greater, respectively, than those in non-GTGP plots (40, 41). In Guizhou Province, loss of phosphorus was 35–53% less in GTGP plots after 2–4 years than in non-GTGP plots (41).

The GTGP conserves water resources and reduces desertification. For example, 516,000 m^3 of water were saved in 2003 through reduced irrigation on 4,300 ha of GTGP land in Minqin County of Gansu Province (42), an area where the rate of desertification has dropped (42) because tree stems and leaves can absorb dust in the air, reduce wind speed on the soil surface by 30–50%, and increase air humidity by 15–25% (42).

Although vegetative cover and forested area have increased (36, 40), diversity of tree species chosen for the GTGP is typically low, and the tree species planted may not be the same as the original local species. Although the specific species planted (e.g., black locust, larch, and poplar) may vary across the GTGP region, GTGP land in many places is often dominated by a single or a few tree species. For instance, in Jiangxi Province, 60% of the converted land in 2006 was planted with Oil Camellia. In Henan Province during 2000–2005, poplar accounted for 40% of the reforested area, whereas other species accounted for <2% and fruit trees were planted on the remaining area.

Socioeconomic Effects. The GTGP has generated more positive socioeconomic impacts than the NFCP. Unlike the NFCP, which has cut off income from timber harvesting for many forest workers, the GTGP has helped alleviate poverty. The GTGP has directly benefited 120 million farmers in >30 million households nationwide, whereas the NFCP has directly affected only hundreds of state-owned forest enterprises and indirectly impacted numerous households. The GTGP has improved the socioeconomic well-being of participating households in most areas (44). The vast majority of households surveyed were happy with the GTGP (33, 45).

This program has helped numerous farmers to change their income structure by shifting from farming to other activities. In Wuqi County of Shaanxi Province, for instance, 15,000 farmers switched from farming to mainly construction, transportation, and restaurant businesses between 1998 and 2003 after reforesting 103,700 ha of their cropland (46). The GTGP has generated a large number of surplus laborers and prompted many of them to seek jobs in cities, contributing to and facilitating the surge in migrant labor across China. For example, in Guizhou Province, the number of migrant workers increased 48% (from 2.2 to 3.1 million) between 2000 (before the GTGP) and 2005 (36). In Yiyang County of Jiangxi Province, the proportion of income earned by migrant workers increased from one-third in 2000 to one-half in 2002 (47).

Like the NFCP, the GTGP has created financial burdens for many local governments. Because no taxes on the converted cropland have been collected since the program's inception and agricultural taxes on the cultivated land are now also exempted, local governments lose tax revenues (4, 48). The central government provides only partial subsidies to local governments and has stated that other expenses for the GTGP implementation (e.g., monitoring and grain transportation) must be covered by them (24). The degree of loss depends on the region. In Kangding County of Sichuan Province, for example, local government income decreased 28% to 15 million yuan during 1999–2001 (49).

The economic value of the ecosystem services produced by the GTGP is estimated to be very large, but the estimation methods are somewhat controversial. For instance, the total economic value of ecosystem services 4 years after GTGP implementation in the 55,300-ha GTGP land of Zhangjiajie in Hunan Province was 428 million yuan, which is 11 times higher than the amount of direct income from the same land in 2000 (before the GTGP). This value includes ecosystem productivity, tourism, biodiversity, water and soil conservation, and pollution reduction (50). In Wuqi County of Shaanxi Province, the estimated economic value from the first 6 years of the GTGP was 2.48 billion yuan (51).

Opportunities, Challenges, and Recommendations

Both the NFCP and the GTGP have led to a series of accomplishments, but the originally planned duration of subsidies is too short for forests to recover fully or for trees to grow large enough to yield sufficient harvest and income to offset losses from the converted land (2). Many studies have indicated that if subsidies end, it is possible that some of the converted forest and grassland will be converted back to cropland (45) and natural forests will be logged again (52). Considering these and other factors, the central government has recently extended the GTGP for another cycle of 2–8 years. The years of extension are exactly the same as those in the initial program: 2, 5, and 8 years if the cropland is converted into grassland, economic forests, and ecological forests, respectively. The annual payments during the extension will be half of the amounts in the initial program (53), but the 300 yuan/ha per year for miscellaneous expenses will remain the same (53). The planned investment in the GTGP for the second cycle is ≈210 billion yuan, and the total investment in the GTGP will be >430 billion yuan. It is possible that the NFCP also will be extended to achieve the goals established for the program by 2010 (Figs. 2 and 3) and 2050.

Although continuing these programs provides good opportunities for restoring and conserving ecosystem services, there are also many challenges and unexpected outcomes as discussed above and below. For instance, large gaps still exist between the achievements so far and the goals set for 2010 (Figs. 2–5). However, the experiences and lessons learned (13) from the policies on payments for ecosystem services in the past several years have laid a good foundation for their continuation and expansion. It is our hope that the following recommendations will make future endeavors more successful.

Systematic Planning. It would be more productive to carry out systematic planning at multiple government levels. This requires overall strategic planning at the central government level and detailed planning at the local government level with better integration. Instead of taking the traditional top-down approach, more input and feedback from local people affected by the policies should be actively sought and incorporated into the decision-making process.

Complementing the GTGP and NFCP with other conservation programs would improve the efficiency and effectiveness of all programs. Other conservation programs include the other four forest-related programs, the recently enacted forest eco-compensation program for conserving forests (75 yuan/ha per year) in ecologically sensitive areas (e.g., along river banks) (3), and possible future ecosystem service payment programs. In addition, linking the GTGP and NFCP with economic development programs can help generate more alternative off-farm income and thus reduce pressure on vulnerable ecosystems.

To make systematic planning sustainable and effective, laws should consider all ecosystem services, their interrelationships, and coordinated management. Although China already has many laws related to natural resource management, most of them were developed piecemeal and have resulted in conflicts among laws for forests and other resources (e.g., grasslands, soil, and water) (1, 54).

Diversified Funding. So far, the NFCP and GTGP have been largely financed by the central government and have caused financial hardships for some local governments. Establishing endowments for ecosystem services would be helpful for sustainability of the NFCP and GTGP, although annual government funds and contributions from other stakeholders are still important for continuation of these policies.

Market-based mechanisms (55) should also be explored with assistance and support from the central government and other stakeholders (54). The NFCP and GTGP have many beneficiaries who could contribute to the payments, including hydropower plants, insurance companies for flood and drought disasters, people and businesses in the lower reaches of the Yangtze and Yellow river basins, and even other countries (e.g., Japan, Korea, and the United States) that benefit from an increase in vegetative cover to thwart sandstorms originating in western China and improve carbon sequestration (56).

Effective Compensation. The amount and duration of compensation should be determined by multiple factors, including ecosystem values, risks to ecosystem services, basic needs of affected stakeholders, and benefits and costs across space and time. Current payments for the two programs are relatively uniform across space (33, 34), although there are large variations in the costs of implementing the programs in different regions. In the past, annual subsidies remained basically constant despite increases in market prices of agricultural products over time. Market prices of agricultural products also affect the opportunity cost of GTGP land. For example, in Xiqu Township, Minqin County of Gansu Province, farmers lost 3,852–4,000 yuan/ha partially because of increased prices for agricultural products in 2003 (42).

The central government has included eco-compensation in China's 11th Five-Year Plan (2006–2010). The NFCP and GTGP should be incorporated into the eco-compensation system to provide a legal basis for appropriate long-term payments to farmers so that positive ecological effects of these programs can be sustained.

Offering job information and training to farmers and employees of forest enterprises to develop new skills are indirect compensation approaches and are sometimes more effective than grain and cash (36). Providing households with off-farm skills can help transform farmers and employees of forest enterprises from directly depending on the land to finding off-farm jobs or creating new businesses, thus ultimately changing household economic structure and reducing dependence on compensation.

Interdisciplinary Research. Whereas many studies have assessed the ecological and socioeconomic effects of the NFCP and GTGP, they are mostly scattered, fragmented, short-term, and opportunistic. For example, although both the NFCP and GTGP are concurrently implemented in many regions (Fig. 1), they are rarely discussed together (4, 54, 57). Little is known about their interactive effects. Although both the NFCP and GTGP have significant ecological and socioeconomic consequences, they are often evaluated by ecologists and social scientists separately. As these policies affect both ecosystems and humans, treating them as part of coupled human and natural systems (58, 59) would produce new insights into the complexity of the policies and their impacts.

The future successes of the NFCP and GTGP could benefit from a national network of interdisciplinary research on ecosystem services, with a particular focus on the NFCP and GTGP. The network would coordinate and promote integrated social and ecological research on important questions from local to national levels. In addition to temporal comparisons (i.e., before/after the NFCP and GTGP), using intervention analysis (60) would allow for more rigorous experimental approaches (e.g., treatment, with the NFCP and/or GTGP, vs. control, without the NFCP and GTGP) to evaluate outcomes of these programs. Spatially explicit modeling tools can help evaluate long-term ecological and socioeconomic impacts under various policy scenarios (61, 62).

Comprehensive Monitoring. Comprehensive monitoring can help provide timely feedback for adjusting and refining large programs such as the GTGP and NFCP. Many advanced tools are available for comprehensive monitoring. High-resolution remote-sensing data (e.g., IKONOS and QuickBird) can be useful (63–65), because they can detect many ecological effects across large areas efficiently and quickly. Also, frequent surveys of various stakeholders can generate timely information on socioeconomic effects. In some NFCP and GTGP regions, some local officials have exaggerated reports on the amounts of cropland converted into forest or grassland to receive higher payments. A combination of remote-sensing data, social surveys, or third-party involvement could help ensure accurate reporting. A web-based nationwide database would facilitate the synthesis and dissemination of all relevant information (including detailed research and monitoring methods) for adaptive management of these programs.

Concluding Remarks

Despite the relatively short time since the NFCP and GTGP began, both programs have already demonstrated substantial ecological and socioeconomic impacts. Some goals (e.g., converting cropland to forest/grassland) have been overachieved, some (e.g., the logging ban) have been achieved, and some are still in progress. Although the programs have produced many positive ecological and socioeconomic outcomes, they have also generated some negative consequences. Whereas some socioeconomic effects are negative in the short run, structural changes in forestry and agriculture may ultimately benefit forest workers, farmers and other stakeholders.

The impacts of these programs will be larger in the future as they continue and as ecosystems recover.

To make the GTGP and NFCP more successful, it is essential to develop and adopt new strategies to overcome their shortcomings and enhance their potential. These two programs provide important insights regarding opportunities and challenges in the development, implementation, and sustainability of similar ecosystem service payment programs, at present and in the future, both inside China and around the world.

Additional references can be found in *SI Text*.

ACKNOWLEDGMENTS. We thank Gretchen Daily and Pamela Matson for their invitation to write this paper. We also thank Joanna Broderick, Gretchen Daily, and two anonymous reviewers for their constructive comments on an earlier draft. Financial support was provided by the National Science Foundation (Grants 0216450 and 0709717), National Aeronautics and Space Administration (Grants NNG06GI29G and NNX08AL04G), National Natural Science Foundation of China (Grant 40621061), National Key Basic Research Program of China (Grant 2006 CB403402), and Michigan Agricultural Experimental Station.

1. Liu J, Diamond J (2005) China's environment in a globalizing world. *Nature* 435:1179–1186.
2. Ouyang Z, ed (2007) *Ecological Construction and Sustainable Development in China* (Science Press, Beijing) (in Chinese).
3. Ministry of Finance of China, State Forestry Administration of China (2007) *Notice on Managing Forest Eco-Compensation Funds* (State Forestry Administration of China, Beijing) (in Chinese).
4. Xu J, Yin R, Li Z, Liu C (2006) China's ecological rehabilitation. *Ecol Econ* 57:595–607.
5. Loucks C, *et al.* (2001) Giant pandas in a changing landscape. *Science* 294:1465.
6. Zhang P, Zhou X, Wang F (1999) *Introduction to Natural Forest Conservation Program* (Chinas Forestry Publishing House, Beijing) (in Chinese).
7. Daily GC, ed (1997) *Nature's Services*: *Societal Dependence on Natural Ecosystems* (Island Press, Washington DC).
8. Daily GC, Ellison K (2002) *The New Economy of Nature* (Island Press, Washington, DC).
9. Li S, Zhai H (2002) A comparative study on forestry ecological projects in the world. *Acta Ecol Sin* 22:1976–1982 (in Chinese).
10. Wunder S (2005) *Payments for Environmental Services* (Center for International Forestry Research, Jakarta, Indonesia).
11. Ferraro PJ, Kiss A (2002) Direct payments to conserve biodiversity. *Science* 298:1718–1719.
12. Editorial Department of *Chinese Agriculture Encyclopedia* (1989) Entry for "forestry." *Chinese Agriculture Encyclopedia* (Agriculture Publishing House, Beijing) (in Chinese).
13. Zhang Z (2006) Review of the 10th Five-Year Plan and perspective on the 11th Five-Year Plan in relation to Natural Forest Conservation Program. *For Econ* 1:49–52 (in Chinese).
14. State Forestry Administration of China (2003) *China Forestry Development Report* (China Forestry Publishing House, Beijing) (in Chinese).
15. An J (2002) Strategies and suggestions for conserving natural forests in Qilian Mountain. *For Gansu* 6:16–17 (in Chinese).
16. Hu H, Liu G (2006) Carbon sequestration of China's Natural Forest Conservation Program. *Acta Ecol Sin* 26:291–296 (in Chinese).
17. Liu J, *et al.* (2001) Ecological degradation in protected areas. *Science* 292:98–101.
18. Bearer S, *et al.* (2008) Effects of timber harvesting and fuelwood collection on giant panda habitat use. *Biol Conserv*, in press.
19. Vina A, *et al.* (2007) Temporal changes in giant panda habitat connectivity across boundaries of Wolong Nature Reserve, China. *Ecol Appl* 17:1019–1030.
20. Liu C, Meng Q, Li Y, Lu J (2005) A case study on ecological and socioeconomic benefit evaluation of Natural Forest Conservation Program in Sichuan. *Acta Ecol Sin* 25:428–434 (in Chinese).
21. Qiao R, Gao J, Zhang A (2006) Effects of Natural Forest Conservation Program on farmers' income. *Res Agric Modernization* 27:40–43 (in Chinese).
22. National Bureau of Statistics of China (2003) *Classification of Industries* (Beijing) (in Chinese).
23. Liu C (2004) The effects of Natural Forest Conservation Program on farmers' income and animal husbandry. *For Sci Technol Manage* 3:14–17 (in Chinese).
24. Liu Y, Zhou Q (2005) Shortcomings in the incentives of Grain to Green Program. *China Popul Resour Environ* 15:104–107 (in Chinese).
25. Huang Y (2005) Countermeasures to the main problems in Natural Forest Conservation Program in Guizhou. *Guizhou For Sci Technol* 33:49–51 (in Chinese).
26. Zhou X (2006) Countermeasures to problems in implementing Natural Forest Conservation Program in Sichuan Province. *For Resour Manage* 2:19–23 (in Chinese).
27. Yang L (2004) Natural Forest Conservation Program and forest eco-compensation system. *J Mountain Agric Biol* 23:158–163 (in Chinese).
28. Wei Z (2004) An analysis of social and economic benefits of Natural Forest Conservation Program in Xiaolongshan Forest Bureau. *J Northwest For Univ* 19:156–160 (in Chinese).
29. Liu C (2002) *An Economic and Environmental Evaluation of the Natural Forest Protection Program* (State Forestry Administration, Center for Forest Economic Development and Research, Beijing), Working Paper.
30. Cha S, Li Q (1998) Water and soil loss of sloping field in the Three Gorges Area. *Agro-Environ Dev* 2:31–34 (in Chinese).
31. Wang R, Chen K (2006) Analysis of the current status and problems in Grain to Green Program in China. *Chinese Agric Sci Bull* 13:188–192 (in Chinese).
32. Uchida E, Xu J, Rozelle S (2005) Grain for green: Cost-effectiveness and sustainability of China's conservation set-aside program. *Land Econ* 81:247–264.
33. Xu J, Cao Y (2002) On sustainability of converting farmland to forests/grasslands. *Int Econ Rev* Z2:56–60 (in Chinese).
34. Feng Z, Yang Y, Zhang Y, Zhang P, Li Y (2005) Grain-for-green policy and its impacts on grain supply in West China. *Land Use Policy* 22:301–312.
35. Xu J, Dao R, Xu Z (2004) Grain to Green Program: Effectiveness, effects of structural adjustment, and economic sustainability. *China Econ Q* 4:139–162 (in Chinese).
36. Yang S (2006) Policy recommendations for Grain to Green Program in the ''11th Five-Year Plan.'' *For Econ* 9:7–10 (in Chinese).
37. Li D, Bo F, Tao J (2006) Achievements in and strategies for Grain to Green Program in Hunan Province. *Hunan For Sci Technol* 33:1–5 (in Chinese).
38. Bao J, Tang D, Chen B (2005) Socioeconomic effects of Grain to Green Program in Sichuan Province. *Sichuan For Explor Des* 1:26–32 (in Chinese).
39. Wang Z, *et al.* (2007) Effects of Grain to Green Program on soil and water conservation in Zigui County of the Three Gorges Reservoir Region. *Sci Soil Water Conserv* 5:68–72 (in Chinese).
40. Liang W, Bai C, Sun B, Hao D, Qi J (2006) Soil moisture and physical properties of regions under Grain to Green Program in the Gullied Rolling Loess Area. *Soil Water Conserv China* 3:17–18 (in Chinese).
41. Liu F, *et al.* (2002) Role of Grain to Green Program in reducing loss of phosphorus from yellow soil in hilly areas. *J Soil Water Conserv* 16:20–23 (in Chinese).
42. Ma Y, Fan S (2005) Ecological-economic effects of Grain to Green Program in desertification areas. *J Nat Resour* 20:590–596 (in Chinese).
43. Hou J, Zhang S (2002) Evaluating effects of Grain to Green Program in the Loess Plateau Area. *Bull Soil Water Conserv* 22:29–31 (in Chinese).
44. Xu Z, *et al.* (2006) Grain for green versus grain: Conflict between food security and conservation set-aside in China. *World Dev* 34:130–148.
45. Hu C, Fu B, Chen L, Gulinck H (2006) Farmers' attitudes towards the Grain-for-Green programme in the loess hilly area, China. *Int J Sustainable Dev World Ecol* 13:211–220.
46. Ge W, Li L, Li Y (2006) On sustainability of Grain to Green Program. *For Econ* 11:33–49 (in Chinese).
47. Wang H, Yan C, Jiang L (2007) A comparative study of effects of Grain to Green Program on farmers' income in central and western regions of China. *Acta Agric Univ Jiangxiensis* 29:318–322 (in Chinese).
48. Huang Q (2007) On Grain to Green Program. *Ecol Econ* 2:60–63 (in Chinese).
49. Dong J (2003) A comparative study of values between sloping fields and forestland. *China Popul Resour Environ* 13:81–83 (in Chinese).
50. Zhuang D, Tang X (2006) Ecological-economic effects of Grain to Green Program in Zhangjiajie. *J Mountain Sci* 24:373–377 (in Chinese).
51. Lai Y, Zhu Q, Zhang Y, Qin W, Li W (2006) Valuing ecological effects of Grain to Green Program in Wuqi County. *J Soil Water Conserv* 20:83–87 (in Chinese).
52. Shen Y, Liao X, Yin R (2006) Measuring the socioeconomic impacts of China's Natural Forest Protection Program. *Environ Dev Econ* 11:769–788.
53. State Council of China (2007) *State Council's Notice on Improving Grain to Green Program* (State Forestry Administration of China, Beijing) (in Chinese).
54. Xu J, Katsigris E, White T, eds (2002) *Implementing the Natural Forest Protection Program and the Sloping Land Conversion Program* (China Forestry Publishing House, Beijing).
55. Pagiola S, Bishop J, Landell-Mills N, eds (2002) *Selling Forest Environmental Services* (Earthscan, London).
56. Huang F, Kang M, Zhang X (2002) Economic compensation strategies in the process of converting cultivated land back into forests/grasslands. *Acta Ecol Sin* 22:471–478 (in Chinese).
57. Weyerhaeuser H, Wilkes A, Kahrl F (2005) Local impacts and responses to regional forest conservation and rehabilitation programs in China's northwest Yunnan province. *Agric Syst* 85:234–253.
58. Liu J, *et al.* (2007) Complexity of coupled human and natural systems. *Science* 317:1513–1516.
59. Liu J, *et al.* (2007) Coupled human and natural systems. *Ambio* 36:639–649.
60. Stewart-Oaten A, Bence JR (2001) Temporal and spatial variation in environmental impact assessment. *Ecol Monogr* 71:305–339.
61. Liu J (1993) ECOLECON: A spatially explicit model for ECOLogical-ECONomics of species conservation in complex forest landscapes. *Ecol Modell* 70:63–87.
62. An L, Linderman M, Shortridge A, Qi J, Liu J (2005) An agent-based spatial model for cross-discipline and cross-scale integration. *Ann Assoc Am Geogr* 95:54–79.
63. Du L (2006) Remote sensing technology and application perspectives for monitoring Grain to Green Program. *Remote Sens Technol Appl* 21:477–482 (in Chinese).
64. Huang J, Ju H, Zhao F, Yue Y, Zhang L (2004) Application of high resolution Quickbird satellite data in Grain to Green Program. *For Res* 17:167–271 (in Chinese).
65. Shi L, Du J, Tan B (2006) Application of SPOT-5 data in monitoring Grain to Green Program. *For Resour Manage* 2:84–87 (in Chinese).
66. State Forestry Administration of China (2006) *Bulletin of the Six Major Forestry Projects in 2005* (State Forestry Administration of China, Beijing) (in Chinese).
67. State Forestry Administration of China (2000–2007) *China Forestry Development Report* (China Forestry Publishing House, Beijing) (in Chinese).