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HYDROELECTRICITY PRODUCTION AND FOREST CONSERVATION IN WATERSHEDS

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Abstract. Globally, particularly in developing countries, hydroelectricity production and economic growth occur together with ecosystem/biodiversity conservation in watersheds. There is a relationship between hydroelectricity production and ecosystem/biodiversity conservation in watersheds, centering on the supply and demand for ecosystem services of river water flow regulation and sediment retention. Here we show that, in the upper reach of the Yangtze River, hydroelectricity production of Three Gorges Hydroelectric Power Plant can form a beneficial relationship with forest conservation through the paid use (compensating residents for their cooperation in the conservation) of ecosystem services launched by the National Natural Forest Protection Project. This interaction can provide additional incentives to encourage local communities' long-term cooperation in conserving and protecting the restored forest ecosystems. Hydroelectricity plants also obtain benefits from this interaction. The industrialization of ecosystem services supply provides an operational framework for this beneficial interaction. Sustainable forest ecosystem conservation will require developing new institutions and policies and must involve local communities in the conservation and protection of their local forests.

Key words: China; ecosystem services; forest conservation; hydroelectricity production; interaction; Three Gorges Hydroelectric Power Plant; watershed; Yangtze River.

Introduction

Evidence indicates that a large amount of hydroelectricity production occurs in countries with biodiversity hotspots, locations that have high species diversity and threatened habitats (World Bank 2004, CI 2005, EIA 2005). Over 85% of biodiversity hotspots overlap with watersheds, and there are large dams in over 80% of those watersheds (WRI 2005). During 1980–2000, the annual growth rate of hydropower was ~100% higher in hotspot countries than in other countries. Over 90% of hotspot countries expanded hydroelectricity production along with an increase in GDP. Worldwide, particularly in the developing world, the development of hydroelectricity production occurs together with the rise in ecosystem/biodiversity conservation efforts in watersheds. This interweaving creates the need for a functional relationship between hydroelectricity production and ecosystem/biodiversity conservation.

In the Yangtze River basin of China, which contains most of the "Mountains of Southwest China" hotspot, over 63 dams were constructed to meet the increasing requirement for electric power. The Three Gorges Hydroelectric Power Plant (TGHPP), the world's largest, has been used for this purpose, so far up to 54% of its capacity. Since the late 1970s, the construction of large dams has, directly and indirectly, resulted in substantial changes in land use and land cover and the capacity of terrestrial/aquatic ecosystems for providing goods and services across the Yangtze River basin (Ellis et al. 2000, Jiang and Yan 2003, Liu et al. 2003, Wu et al. 2004). Intensive farming and logging along the Yangtze River has made it the fourth largest sediment carrier in the world. Since the 1990s, the Chinese government has invested over 10 billion Ren Min Bi (RMB; 8 RMB ≈ 1 U.S. dollar) to implement the National Natural Forest Protection Project (NNFPP) in the upper reach of the Yangtze River to control soil erosion and conserve

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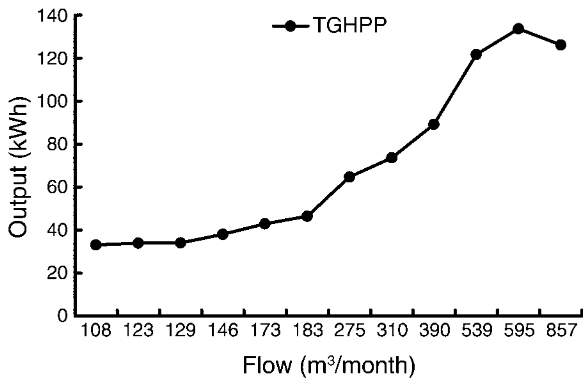

FIG. 1. Output of the Three Gorges Hydroelectric Power Plant (TGHPP) vs. the flow of the Yangtze River.

biodiversity (World Bank 1992, SFA 2005). So far, forestlands of 1.4 million hectares have been restored, and existing natural forests of 7 million hectares have been protected there (SFA 2005). To respond to the NNFPP, local communities completely stopped logging and began converting farmland back to forests in 2000. However, such large-scale conservation action is likely to fail unless adequate incentives are provided for participants in local communities and, more importantly, for these communities to become involved in the long-term management and conservation of the restored forests (Barbier 2006). At this point, local residents obtain compensation from the government for a term of 5–8 years. However, when the government stops providing compensation, the continuation of conservation will be uncertain because there will no longer be any external motivation. Therefore, a major issue is how the NNFPP can provide additional incentives to encourage local communities' long-term cooperation in conserving and protecting the restored forest ecosystems. Here, we explored a solution for the problem from the perspective of the relationship between hydroelectricity production and forest conservation in the Yangtze River basin.

In the upper reach of the Yangtze River, hydroelectricity production is a major industry, and forest conservation is the largest conservation action, so the relationship between them is regionally important. In addition, the Yangtze River basin, where hydroelectricity production is dramatically growing and forest conservation is being extensively carried out, provides a gauge of what is likely to occur in other watersheds of the developing world.

In recent years, we have seen widespread experimentation with market-based mechanisms to address ecosystem/biodiversity conservation (Mountford and Keppler 1999, Kremen et al. 2000, Lybbert et al. 2002). Many people believe that market-based approaches can provide powerful incentives and efficient means of conserving ecosystems and the public goods they provide, while at the same time offering new sources of income to support rural livelihoods. Well-known examples include the Conservation Reserve Program (CRP) in the United States (Bangsund et al. 2004) and the Pagos de Servicios Ambientales (Payments for Environmental Services) program in Costa Rica (Zbinden and Lee 2005). A recent review found almost 300 examples of such programs worldwide (Landell-Mills and Porras 2002), and the list is constantly growing. We hope that our work can make a contribution to sustainable forest conservation by integrating ecosystem/biodiversity conservation with economic development.

Supply and demand for the ecosystem services between hydroelectricity production and forest ecosystems in watersheds

The forest vegetation cover in watersheds provides two important ecosystem services. It provides river water flow regulation. It also provides sediment retention, which acts as a "sponge" to regulate and stabilize water runoff to balance river flow over the seasons; further, it retains soil and decreases silt runoff into rivers. Hydroelectricity production relies on natural systems of watersheds to provide the ecosystem services, including river water flow regulation and sediment retention, because the operation of hydroelectricity plants requires an even distribution of water flow during all seasons to increase output (see Fig. 1) and minimal amounts of silt discharge by rivers in order to reduce accumulation of sediment in reservoirs (Acharya 2000, Daily et al. 2000, Guo et al. 2000, 2001, Van Beukering et al. 2003).

We developed a model to evaluate the ecosystem service of river water flow regulation, which takes into account two such sets of processes: (1) river water flow regulation by forestlands and (2) hydroelectricity generation by river water flow. The model first calculates the capacity of river water flow regulation by forestlands and then estimates the benefit a hydroelectricity plant obtains from the ecosystem service (see Appendix A). The ecosystem service of sediment retention was evaluated by using the difference in soil erosion between forestlands and unforested land (see Appendix B). According to these models and using data surveyed in situ, we evaluated (1) ecosystem services provided by forestlands of ~0.44 million hectares in the three adjacent counties of Hubei Province, Badong, Xingshan, and Zigui, and (2) benefits to the TGHPP, which is located downstream from these counties (~70 km away; Table 1). The results show that the TGHPP is likely to obtain the annual benefit of ~281.92 million RMB from forest ecosystems in the three counties.

Since the NNFPP was implemented, the counties in the upper reach of the Yangtze River have completely stopped logging and have been converting farmland back to forestland. Badong, Xingshan, and Zigui lost income of about 5.46, 7.16, and 13.9 million RMB in 2004, respectively, owing to converting farmland back to forestland. Most of the counties in the upper reach of

TABLE 1. Ecosystem services provided by forestlands in Badong, Xingshan, and Zigui Counties, Hubei Province, China, and benefits the Three Gorges Hydroelectric Power Plant (TGHPP) obtains from those services.

Proximal source of services†	River water flow regulation		Sediment retention, per year
	Wet season	Dry season	
Forestlands in the three counties (442 190.8 ha)	retains 2978.597×10^6 m^3 of rainwater each wet season	releases 1827.132×10^6 m^3 of underground water each dry season	controls 109.63×10^6 m^3 of erosion
Yangtze River	decreases water flow by 1 m^3/s to increase electricity production by 0.04 kWh	increases water flow by 1 m^3/s to increase electricity production by 0.3 kWh	decreases 58.1×10^6 m^3 of silt discharge

Notes: The TGHPP receives several benefits from these ecosystems services. Regulated river water flow increases power output by 667.28 million kWh and results in increased income of 166.82 million RMB. (The selling price of electricity is 0.25 RMB/kWh.) Sediment retention is decreased by 23.02 million m^3, which saves 115.1 million RMB. (The cost of cleaning sediment is ~5 RMB/m^3 [RMB is Ren Min Bi; 1 U.S. dollar ≈ 8 RMB].) For methods, see Appendices A and B.

† The forestlands are the ultimate source of all the ecosystems services. The effects of the forestlands on the Yangtze River, and thus on TGHPP, are also outlined here.

the Yangtze River are low-income regions. In 2004, GDP per capita in Badong, Xingshan, and Zigui was, respectively, about 47%, 73%, and 64% of that in Hubei Province and about 44%, 68%, and 59% of that of the whole nation. Now, the central government provides 75 $RMB \cdot ha^{-1} \cdot yr^{-1}$ in subsidies for local residents involved in the NNFPP. Forest ecosystems in these counties, however, also support hydroelectricity production. Hydroelectricity production brings huge profits for hydropower plants; for example, the financial output of the TGHPP was ~4.7 billion RMB in 2004, which is about 1.6, 1.5, and 2.1 times of the annual financial output in these three counties, respectively.

Paid use of ecosystem service

As we have argued, there is an interaction between hydroelectricity plants and local residents who participate in forest conservation in the basin, centering on the relationship between supply and demand for the ecosystem services of river water flow regulation and sediment retention.

However, local communities barely obtain a benefit from the relationship, while hydroelectricity plants profit greatly. Ecological degradation that occurred in Wolong Nature Reserve, which is located in the upper reach of the Yangtze River, indicates that conservation actions will not be successful if local community needs are ignored; it will be impossible to gain the cooperation of the community if the needs of the community are not acknowledged (Liu et al. 2001). Ecological degradation can result from the disintegration of the relationship between hydroelectric plants and residents and, thus, drop the efficiency of hydroelectricity plants. Therefore, if hydroelectricity plants benefit while local residents do not, the relationship between hydroelectricity plants and local residents is incomplete. This incomplete relationship is unstable and cannot be sustained because local residents' cooperation in maintaining forest conservation will be lost. Paid use of ecosystem service, compensating residents for their cooperation in the conservation, may be the missing link in the relationship.

Through the paid use, local residents could share benefits that the hydroelectricity plants derive from forest conservation and, thus, would be willing to participate in conservation action that improves the supply of ecosystem services. What effects can the paid use have on both beneficiaries and local residents? If the payment is used to encourage local residents' long-term cooperation in the NNFPP, then the payment should not be lower than the government's subsidy, 75 $RMB \cdot ha^{-1} \cdot yr^{-1}$ or ~0.006 RMB/kWh (Table 2). When the TGHPP adds the payment of 0.006 RMB/kWh to the cost of electricity production or the selling price of electricity, the cost and the selling price will still be lower (21.5% or 12.4%) than the mean of the whole nation. The TGHPP mainly supplies hydropower for higher income regions; for example, it transmitted electric power of ~1.2 billion kWh to Shanghai in 2004. In Shanghai, gross domestic product (GDP) attained ~630 billion RMB in 2004, and in the meantime, the use of electricity increased by 13.4% and the output value of ten thousands RMB consumed ~406.66 kWh of electric power (Shanghai Government 2005). If this payment of 0.006 RMB/kWh is added to the selling price of electricity, Shanghai will pay an additional 7.2 million RMB a year. Moreover, to keep a competitive selling price of electricity (less than or equal to the mean of the whole nation), the TGHPP's payment should not be higher than 0.035 RMB/kWh or 437.5 $RMB \cdot ha^{-1} \cdot yr^{-1}$. If the payment is 437.5 $RMB \cdot ha^{-1} \cdot yr^{-1}$, Shanghai would pay an additional 42 million RMB a year. Although this income is not substantial for beneficiaries of ecosystem services like the TGHPP and Shanghai (Table 2), these payments (75–437.5 $RMB \cdot ha^{-1} \cdot yr^{-1}$) can provide profits of about 4.97–87.33, 8.03–46.84, and 8.4–49 million RMB a year, depending on the area of forestlands, for Badong, Xingshan, and Zigui, respectively. These profits are equivalent to the annual income of a local medium-sized industry. These results show that beneficiaries can provide considerable returns for local counties at very

TABLE 2. Economic analysis for forest conservation and hydroelectricity production.

Factors	RMB·ha^{-1}·year^{-1}	RMB/kWh
Forest conservation in the upper reach of the Yangtze River		
Investment for forest conservation	79.4	
Compensation for local residents' forest conservation	75	
Hydroelectricity production in the TGHPP		
Cost of electricity generation		0.045
Selling price of electricity		0.248
Benefit from both ecosystem services	637.55	
Minimum payment for using both ecosystem services	75	0.006
Maximum payment for using both ecosystem services	437.5	0.035
Electric power use in Shanghai		
Output value		24.59
Minimum payment for forest conservation		≈0.0001
Maximum payment for forest conservation		≈0.001

Notes: According to the total investment of 10 billion RMB (RMB is Ren Min Bi; 1 U.S. dollar ≈ 8 RMB) during 15 years (1990–2004) for the NNFPP and forestlands of 8.4 million hectares constructed by the project, we estimated the annual investment for a hectare of forestland. The benefit the Three Gorges Hydroelectric Power Plant (TGHPP) obtains from both ecosystem services was estimated based on data in Table 1. We calculated the TGHPP's payment for using ecosystem services (RMB/kWh), using the area of forestland in the upper reach of the Yangtze River (54.95 million ha), the annual hydropower production in the basin (731.6 billion kWh), and the annual compensation provided by the central government (75 RMB/ha).

little cost. Encouraged by these considerable returns, ecosystem services could be commercialized.

The industrialization of ecosystem services supply

The commercialization of ecosystem services defines ecosystem services as products produced by local residents. Therefore, local residents can sell ecosystem services, and beneficiaries should pay for the ecosystem services they use. To enhance ecosystem services supply, we proposed to industrialize ecosystem services supply in order to foster intensive management and production. Through industrialization, local residents can manage the ecosystem services supply as an industry might be managed. Then, local residents can actively make conservation profits, not just passively receive conservation compensation. Moreover, ecosystem services supply is less affected by market and weather fluctuations than farming, thus the industrialization of ecosystem services supply provides more stable income for local residents than farming would; for example, in some counties of Hubei, the selling prices of two main agricultural products, wheat and rapeseed, were lower than their costs of production in 2004, owing to impacts of market and weather.

After industrializing ecosystem services supply, suppliers' revenue will rely on the quality of the ecosystem services they supply. Therefore, forest conservation will become a means of local residents' safeguarding and expanding their own welfare. This gives local residents a clear and direct incentive to do their best for forest conservation. The demands of hydroelectricity plants for ecosystem services are sustained. Encouraged by sustained paid use, the industrialization of ecosystem services supply would be likely to promote sustainable forest conservation in the basin. Moreover, when the prices of ecosystem services are fixed according to their quality, hydroelectricity plants will substantially participate in supervising forest restoration and conservation. The participation of hydroelectricity plants is likely to promote better forest conservation since it will be appraised based on the capacity of ecosystem services. Therefore, paid use of ecosystem services based on industrialized ecosystem services supply is more advantageous for forest conservation than are the government's compensation payments.

Through the industrialization of ecosystem services supply, a beneficial interaction occurs between hydroelectricity plants and local residents for using and conserving ecological resources. This interaction brings subsidies for local residents who participate in the NNFPP, and the TGHPP also benefits from increased river water flow regulation and sediment retention. When hydroelectricity plants and local residents foster each other, the interaction between both sides will become stable and sustained.

After stopping logging, local communities gained benefits from forests by means of providing forest tours and producing forest-related products, such as mushrooms and traditional Chinese medicinal materials. Ecosystem services supply has no competing forest use interests with these activities. Local communities can still have access to forests for forest tours and may collect forest products, so long as such harvesting activities are conducted sustainably. Moreover, according to the NNFPP, even if local communities do not carry out ecosystem services supply, they cannot farm or log in protected and restored forests, and forests must be conserved. Therefore, the industrialization of ecosystem services supply provides additional benefits for local counties without additional costs.

The beneficial relationship between hydroelectricity production and forest conservation in watersheds

In the Yangtze River basin, the annual hydroelectricity production of ~731.6 billion kWh stimulates the demand of hydroelectricity plants for ecosystem services of river water flow regulation and sediment retention. The forest conservation initiative launched by the NNFPP has increased capacities of the ecosystem services, which reduce water and soil loss by 42% in protected areas (SFA 2005). The development of hydroelectricity production and the rise in forest conservation in the Yangtze River basin expands the supply and demand of ecosystem services and lays a sound foundation for industrializing ecosystem services supply. Hydroelectricity production and forest conservation in watersheds can form a beneficial relationship on the basis of the beneficial interaction between hydroelectricity plants and local communities, which integrates ecosystem/biodiversity conservation with economic development.

According to the beneficial relationship between hydroelectricity production and forest conservation in watersheds, the improvement of the capacities of ecosystem services will be considered as a major target of conservation projects to meet the requirements of hydroelectricity production for river water flow regulation and sediment retention. Furthermore, hydroelectricity plants will provide a return to local residents, which will enhance their support of the conservation project. Local residents can obtain additional profits and hydroelectricity plants can increase the output of hydroelectricity production. More importantly, this beneficial relationship provides additional incentives to encourage local communities' long-term cooperation in conserving and protecting the restored forest ecosystems. Forest conservation launched by the NNFPP is likely to be carried out sustainably, owing to local communities' long-term cooperation. Sustained conservation brings sustained benefits for local communities and hydroelectricity plants. All parties involved will benefit from this beneficial relationship.

Discussion

Our results demonstrate that a beneficial relationship can form between hydroelectricity production and forest conservation by adding the missing link of paid use of ecosystem services. When the government bears the cost of forest restoration and the power plant provides compensation, this interaction can provide additional incentives to encourage local residents' long-term cooperation in conserving and protecting the restored forest ecosystems, which is, in turn, likely to promote more effective and sustainable forest conservation than the compensation. The industrialization of ecosystem services supply provides an operational framework for the beneficial relationship based on paid use of ecosystem service. In this framework, beneficiaries benefit from ecosystem services at low cost, and local communities require outside investment for only a short time to build their conservation capacity and then continue on their own steam to yield conservation and development benefits. Along with the development of hydroelectricity production, this beneficial interaction can promote sustainable ecosystem/biodiversity conservation in watersheds. Moreover, the beneficial interaction between hydroelectricity production and forest conservation can also play an important role in establishing a mutually beneficial relationship between natural and human systems in watersheds.

The beneficial relationship between hydroelectricity production and forest conservation in watersheds integrates ecosystem/biodiversity conservation with economic development. However, the current formal institutional structures of forest management do not recognize this relationship. Therefore, a new institutional framework for forest management in the Yangtze River basin should include the following features: (1) Forest restoration should be designed to meet the requirements of hydroelectricity production for river water flow regulation and sediment retention. For example, special ecosystem services supply zones should be built in catchments. (2) The appraisement of forest restoration and conservation should consider the capacities of ecosystem services as essential indexes, not solely the area of forestland and forest cover. Governments should provide technical support for reforming the appraisement system. (3) In the framework of ecosystem services supply industrialization, the right to use forests should be granted to local communities, and then they should be allowed to make investments in relevant development projects by using natural capital or to sell ecosystem services. In this way, local communities can participate in forest conservation. Governments should provide relevant technical and educational support for the local community. (4) Those that benefit from ecosystem services should be pay for the services, and the government should promote systems of relevant accounting to reflect values of the ecosystem services and natural capital. (5) The ecosystem services should be paid for according to their qualities. This will require the active participation of the power plants in supervising forest conservation and will allow power plant operators to express opinions and make decisions regarding the management plan and regulations related to the forest resources. (6) Proactive efforts should be made to recognize contributions and rights in the relationship and to shape markets to provide equal access to both producers of forest ecosystem services and those that benefit from them. As in the development of any new market, rules governing the market tend to be set by the more powerful sectors of society that have the capital and capacity to invest in designing the rules (Khare et al. 2005).

Such an institutional framework is particularly relevant to maintaining the beneficial relationship between hydroelectricity production and forest conservation in watersheds. If the ultimate goal is sustainable forest ecosystem conservation, then local communities' cooperation in these efforts is a priority, and this beneficial relationship provides incentives to encourage their long-term cooperation in conserving and protecting the restored forest ecosystems.

"In advocating greatly increased funding for the maintenance of natural ecosystems, we are not arguing against development" (Balmford et al. 2002). Ecosystem/biodiversity conservation and economic development are not always in conflict. We can learn from the example of the Yangtze River basin to integrate the use of natural resources with their conservation (Palmer et al. 2004) and develop win–win solutions between ecosystem/biodiversity conservation and economic development.

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APPENDIX A

Methods for estimating the benefit the Three Gorges Hydroelectric Power Plant (TGHPP) obtains from river water flow regulation (*Ecological Applications* A017-065-A1).

APPENDIX B

Methods for estimating the benefit the TGHPP obtains from sediment retention (*Ecological Applications* A017-065-A2).