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Review of rice–fish-farming systems in China — One of the Globally Important Ingenious Agricultural Heritage Systems (GIAHS)

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Abstract

Rice–fish-farming systems constitute a unique agro-landscape across the world, especially in tropical and sub-tropical Asia. Rice is a globally important staple food crop, with a wide distribution and constituting diversified varieties. The introduction of fish rearing to rice farming creates an integrated agro-ecological system. China boasts a history of 1700 years in rice–fish-farming practice. It is no longer a sole agro-production practice, but an agro-cultural pattern. Therefore, it has been listed by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) as one of the Globally Important Ingenious Agricultural Heritage Systems (GIAHS). Qingtian County of the Zhejiang province has been selected as a pilot conservation site. The rice–fish-farming systems in China diversify China's agro-landscape and favor the conservation of species variety of both rice and fish. The survival of deep-water rice, an indigenous rice variety, and Oujiang red carp, an indigenous fish variety, are cases in point. Being low external input systems, the rice–fish-farming systems necessitate only small amounts of pesticide and fertilizer. The application of pesticides can be lowered to 50% of that of modern, high-input rice production; sometimes, no pesticide application is required. The natural enemies of rice pests show a prominent rise, making the bio-control of rice diseases and pests highly feasible. The rice–fish-farming system is also of great significance in global food security and global change. It provides food and animal protein for subsistence farmers living in ecologically-fragile mountainous regions. It also reduces economic risks that these farmers potentially face. The nitrogen-fixation role of the system increased the content of organic matter, total nitrogen and total phosphorus in the soil by 15.6–38.5%. It also reduces the emission of CH_4 by nearly 30% compared with traditional rice farming. However, the economical development and industrialization in China pose a threat to rice–fish farming and, consequently, the numbers of farmers involved in rice–fish farming are decreasing. This calls for the Chinese government to engage itself in the conservation and development of this system and to innovate the existing technologies. It would also be useful, in the meantime, to exploit and conserve rice–fish farming as eco-tourism resources, so that the income of the mountainous farmers can be increased and this important, indigenous agro-culture be conserved and developed.
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Keywords: Agro-landscape; Agro-biological diversity; Low external input; Integrated eco-system; Global change; Protective strategies

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1. Introduction

Rice–fish farming has been practiced in China for more than 1700 years (Mackay, 1995), which has enabled China to accumulate a rich experience in rice–fish culture, both scientifically and technically. It has become an important agro-cultural activity (Ni and Wang, 1990; Chinese Academy of Agricultural Sciences, Chinese Academy of Fishery Sciences, 1990). The integration of fish into rice farming provides invaluable protein, especially for subsistence farmers who manage rain-fed agricultural systems. Rice fields provide shade and organic matter for fish, which in turn oxygenate soil and water, eat rice pests and favor nutrient recycling. According to the statistics issued by the Ministry of Agriculture of China, the total area of rice–fish farms in China is 1.5 million hectares, which is distributed mainly in the mountainous areas in southeast and southwest China — for example, Qingtian County, Yongjia County in Zhejiang province, Jianning County, Taining County, Sha County, Yong'an County, Shaowu County in Fujian province, Yunling County, Guiling County, Quanzhou County in Guangxi Autonomous Region, the southern part of Guizhou province and Pingxiang County, Ji'an County and Yichun County in Jiangxi province. Rice–fish farming in China, owing to its long history, diversified patterns and mature techniques, was listed by the Food and Agriculture Organization of the United Nations (FAO) as one of the Globally Important Ingenious Agricultural Heritage Systems (GIAHS) early in 2005. Qingtian County in Zhejiang province, a place that is renowned for rice–fish culture, was listed as a conservation site (FAO, 2002, 2003; Boerma, 2005).

Rice–fish systems have constituted a unique agro-landscape in not only China, but also in many other countries across the world — particularly in countries in Asia, such as Thailand, the Philippines, India, Bangladesh and Indonesia (David et al., 1996; Haroon and Pittman, 1997; Mackay, 1995). These farming systems, as part of an integrated ecosystem in line with the local cultural, environmental and economic conditions, are composed of complementary sub-agricultural ecosystems and play important ecological service roles, such as bio-control, nitrogen fixation and landscape combination. The traditional low input rice–fish farming systems have a significant function in protecting the global environment and maintaining its bio-diversity. Therefore, a review and analysis of China's rice–fish-farming systems has vital, theoretical significance in the conservation of these systems as one of the GIAHS.

Rice–fish-farming systems in China have many difõferences to other countries all over the world. First, rice–fish-farming systems have a long history in China (Little et al., 1996). In Japan, the practice began only in the last century and, in Java, in the mid-nineteenth century. Rice–fish farming has followed a chequered pattern in Thailand since its introduction by the Department of Fisheries (DOF) in central and eastern Thailand in the 1950s (Little et al., 1996). In Africa, the introduction of an Asian-based Sawah farming system through an eco-technology approach has opened a new frontier for diversification of the rice-based cropping system, and on-farm rice–fish-culture experiments have been reported in recent years (Ofori et al., 2005). Second, fish yields are highest in China, fish yields could be increased by up to 2.5 t/ha in China, 2.0 t/ha in India, 805.0 kg/ha in Indonesia, 980.0 kg/ha in Bangladesh, 2.2 t/ha in Vietnam and 900.0 kg/ha in Thailand (Haroon and Pittman, 1997). Third, the total area of rice–fish-farming systems in China is also the highest in the world, having reached about 1.5 million ha. In India, about 20 million ha of rice fields is suitable for the adoption of a rain-fed rice–fish integration system; however, only 0.23 million ha is under rice–fish culture at present (Mohanty et al., 2004). Forth, in general, the main species that are stocked in rice fields in China and other countries are *Cyprinus carpio* and *Oreochromis niloticus*. However, *Barbodes gonionotus* (Bleeker) is often stocked in polyculture in rice fields in south (Bangladesh and India) and southeast (Indonesia, Malaysia, Thailand and Vietnam) Asia (Vormant et al., 2002; Little et al., 1996; Mohanty et al., 2004; Ofori et al., 2005). Fifth, increasingly, fish is viewed as a tool within an integrated pest management (IPM) system to make rice production more sustainable and environmentally friendly, as well as having direct monetary benefits and/or nutritional value, such as in Thailand, Vietnam and Bangladesh (Berg, 2001; Haroon and Pittman, 1997; Little et al., 1996). According to Berg's (2001) report, during the 3 years of IPM in Vietnam, farmers on rice–fish farms estimated that they had decreased the amount of pesticides used by approximately 65%, whereas non-IPM farms said that they had increased the amount of pesticide used by 40%.

2. Globally Important Ingenious Agricultural Heritage Systems (GIAHS)

The GIAHS have been created by FAO in partnership with the Global Environment Fund (GEF), the United Nations University's People Land Management and Environment Change (PLEC) Project, and UNESCO's Man and the Biosphere (MAB) and World Heritage Programmes. The so-called GIAHS are "developed over millennia, they [GIAHS] represent a wealth of accumulated knowledge and biodiversity that needs to be preserved —

and allowed to evolve…using diverse species and often ingenious combinations of management practices. All these systems contribute tremendously to food security, agricultural biodiversity and the world's natural and cultural heritage" (FAO, 2002, 2003; www.fao.org/landandwater/giahs; Boerma, 2005). To date, GIAHS have established five pilot sites — namely, Andean Agriculture in Peru; small-scale agriculture on Chiloe Island; rice terrace systems in Ifugao, the Philippines; rice–fish systems in Zhejiang province, China; and the oases of Magrheb. The rice terrace systems in Ifugao, the Philippines, have been listed by UNESCO as a world heritage site.

3. The history of rice–fish farming in China

Most literature traces China's rice–fish farming back to the Eastern Han Dynasty (25–220) (Liang, 1986). Of the two red-pottery rice-field models that were unearthed from the four tombs of the Eastern Han Dynasty in Lao Dao Wu Li village, Mian County of Shaanxi province, in 1978, one is a square-shaped rice field during winter time, in which clay sculptures of frogs, eels, snails, crucian carps, grass carps, carps and soft-shelled turtles (*Trionyx sinensis*) have been found. These animals are also found in the other model of rice fields with ponds. The pottery rice-field models that were unearthed from tombs of the same historical period in Huizi Mountain, Xin Jin County, and Xin Zao, Mian Yang County of Sichuan province, bear the same features: sculptures of fish and other animals have been noted. All this evidence testifies to the fact that rice–fish culture was prevalent in Shaanxi, Sichuan and other places in China during the Han Dynasty.

The rice–fish farming in Qingtian County of Zhejiang province dates back to the Ming Dynasty (1368–1644). The chapter of Local Produce in the Annals of Qingtian County that was compiled in 1392 recorded, "field fish, red, black and mixed in color, are raised in paddy fields and its surrounding dyked marsh", proving that Qingtian County integrated rice farming with fish rearing 600 years ago (Chen and Shui, 1995).

4. A biodiversity perspective on rice–fish-farming system

Rice is the staple crop in China. Currently, 2×10^7 ha of land in China is used for planting rice, which constitutes nearly 20% of the world total. The total yield accounts for 33% of the world total, which is the highest global yield. Of 2×10^7 ha, nearly 7×10^6 ha are suitable for rice–fish farming (Zhang et al., 2001). The integration of fish rearing with rice farming forms a rice–fish ecological landscape. Because of the system's low external input, its ecological service function is strengthened. Meanwhile, the diversified output and its ecological significance minimizes the possible risks that are taken by subsistence farmers. The rice–fish landscape adds to the biodiversity of the ecosystem. Fig. 1 shows the terraced rice–fish landscape in the mountainous region of Zhejiang province, China.

In comparison with modern, high-input rice production, rice–fish culture requires different varieties of rice, varieties with thick stalks and big leaves, strong resistance in lodging and a longer growth cycle. These varieties should also be non-responsive to fertilizer and pest-resistant (Wang and Wang, 1994; Ye et al., 2002). These specific requirements contribute to the conservation of the local rice species, such as *Oryza sativa indica*, *japonica* and *javanica*, and the maintenance of genetic diversity of rice. In addition, China has a deep-water paddy rice farming system that is distributed in the provinces of Hunan, Hubei, Guangdong, Guangxi, Zhejiang and Jiangsu. The rice–fish culture also protects the genetic diversity of deep-water rice.

The introduction of a new species, fish, to rice farming ecosystems entails some changes to be made to the former production pattern. For example, the horizontal structure is changed into a ridge–ditch pattern, and the application of fertilizer and pesticides is reduced. The change of aquatic environment in the field provides the necessary conditions for biodiversity. The number of bio-species in the field is increased. The main species include rice, fish, weeds, plankton, photosynthetic bacteria, aquatic insects, benthos, rice pests, water mice, water snakes, birds, soil bacteria and aquatic bacteria (Li et al., 2001; Lu et al., 2001).

Rice–fish farming favors the maintenance of fish biodiversity. The unique aquatic ecological environment of the system necessitates the maintenance of biodiversity of field fish species. In China, fish that are usually seen in this system include *Ctenopharyngodon idellus*, *Cyprinus carpio* (Feng carpio, Heyuan carpio, Oujiang red carpio), *Carassius auratus* (silver *Carasius auratus*), *Tilapia nilotica*, *Mylopharyngodon piceus*, *Hypophthalmichthys molitrix*, *Mysgurnus anguillicaudatus*, *Oreochromis niloticus* and *Barasilcorus asotus* (Lu, 1986; Lu and Huang, 1988; Cao et al., 2001). *Cyprinus carpio*, an omnivore, stands out from other fish species because of its high viability. *Cyprinus carpio* can lay eggs under natural conditions in ponds or lakes, making it easy for farmers to collect them. If left unattended in the field, these eggs are even able to hatch out. This is the reason why *Cyprinus carpio* is the main fish species used in rice–fish systems.

Oujiang red carp is an indigenous species that is found in the southern mountainous regions of Zhejiang

Fig. 1. Terraced rice–fish landscape in Zhejiang province, China (photo: Lu Jianbo).

province, such as Qingtian County. It is commonly called 'field fish' or 'paddy rice fragrance'. It is so-called because it is usually found along the Oujiang river, Zhejiang province of China. The survival of this indigenous species testifies to the biodiversity conservation function of rice–fish systems. Heyuan carp is the first generation of the hybrid that is mothered by Hebao red carp of Wuyuan County, Jiangxi province, and fathered by wild carp of Yuanjinang County, Yunnan province. It demonstrates both the indigenous color and diversified heredity. It has a fast growth speed, with weight reaching 500 g in the first year. A total of 70% of its weight is made up of flesh, hence the name 'fleshy carp'. It is widely distributed in the rice–fish farming systems in the middle and lower reaches of the Yangzi river basin, China.

5. An integrated system with complex interactions

The principle of symbiosis and mutual-benefits of ecosystems, and the principle of the food web, are applied to optimize the current ecosystem comprising fish, rice and aquatic microbes, so that each subsystem takes advantage of and promotes one another. Consequently, the production of both fish and rice is increasing and their respective economic returns are increased (Lu, 1986). In this integrated ecosystem, rice provides shade for fish, especially in summer when the water temperature in the field can be lowered to a certain extent. The decaying leaves of rice offer favorable conditions for the multiplication of microorganisms, which are the main fish feed. Fish, on the other hand, help to loosen the surface soil on which rice is planted, bringing about increased permeability and oxygen content of the soil, as well as enhanced vitality of microbes. Thus, the decomposition of nutrients in the soil is quickened, making it easy for rice to absorb. Fish make another contribution by preying on pests and weeds. Moreover, their excreta serve as both a natural fertilizer for rice and enrichment for soil. In this way, both fish and rice are positioned in a sound ecological environment with positive circulation systems, strengthened integrated functions and enhanced production abilities. Fig. 2 shows the integrated system with complex interactions (Yang and Lu, 2001).

The bio-control of rice pests is one of the prominent features of rice–fish farming. According to Lu Bingyou et al., a low incidence of insect pests and plant disease occurred in rice–fish integrated farming compared with monoculture rice farming (Table 1).

Lin Zhonghua (1996) and several others, based on their results, showed that fish could play an effective role as a bio-control agent against rice pests and diseases (Table 2).

Several reports have pointed to the fact that, in rice–fish farming, fish can prey on the rice plant hopper, the rice leaf hopper, *Naranga aenescens* Moore, the rice leaf roller, and on *Parnara guttata* Bremer and Grey on the water surface, especially omnivorous fish such as *Tilapia nilotica* and *Cyprinus carpio*. As a result, the use of pesticides in rice–fish systems is substantially reduced to almost none. The natural enemies of rice pests in the system, such as spiders and parasitic wasps, have shown a considerable increase (Lu, 1986; Lu and Huang, 1988; Wang and Lei, 2000; Zhang et al., 2001).

In China, azolla is added to the rice–fish system, turning it into a rice–azolla–fish system (Lin, 1996; Huang et al., 2001). The annual pure nitrogen that is

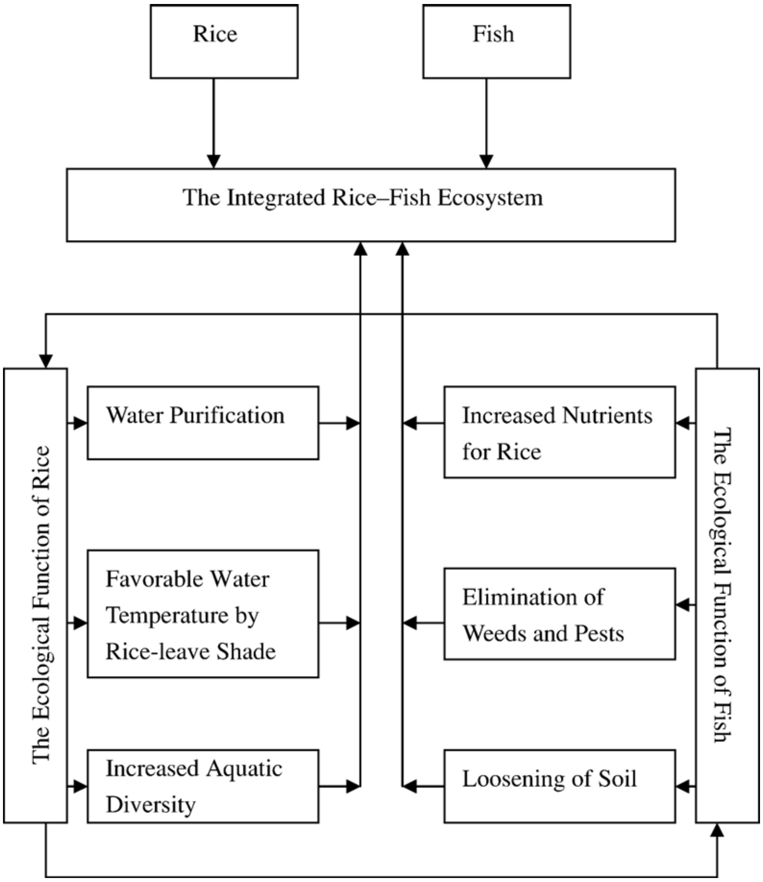

Fig. 2. Interactions among different components in rice–fish agricultural ecosystems.

fixed by azolla is 243–402 kg/ha. The content of coarse protein in azolla is as high as 25%, making it the ideal fertilizer for rice and feed for animals (Liu, 1995). In this system, azolla is used to feed fish, the excreta of fish to fertilize the soil and the enriched soil to promote the growth of rice. The nitrogen that is fixed by azolla is the main source of nitrogen circulating in the system. The N^{15} trace method reveals that, as the feed for fish, 24–30% of nitrogen in azolla is absorbed by fish. After digestion, 17–29% of the nitrogen left in its excreta is

Table 1
The effect of bio-control of rice pests and disease in rice–fish ecosystems (unit: head patch-1)

Treatment	Rice plant hopper	*Naranga aenescens*	Moore *Parnara guttata* Bremer & Grey
Rice monoculture	237	534	20
Rice–fish system	75	107	10
Treatment	Rice leaf roller	Rice leaf hopper	Sheath rot (%)
Rice monoculture	11	839	37.7
Rice–fish system	6	227	4.9

Table 2
The incidence of rice pests, rice diseases and weeds in rice–fish system

Treatment	Rice plant hopper (head patch-1)	Rice blast (%)	Sheath rot (%)
Rice monoculture	8.3	51.3	20.9
Rice–fish system	2.7	27.4	6.7
Treatment	Quantity of weeds (number/m^2)		Biomass of weeds (g/m^2)
Rice monoculture	46–50		420–460
Rice–fish system	0		0

absorbed by rice and 14–15% is drained or lost (Huang et al., 2001). In this way, the circulation of biological nitrogen is promoted in the rice–fish system.

6. Global importance in terms of food production and environmental issues

China has a population of 1.3 billion, which is one-fifth of the world population. However, its arable land is only 7% of the world total, rendering food production a big challenge, especially in the mountainous areas where the per capita arable land is even less and the agricultural basis is poor. Therefore, rice–fish-farming systems are of great importance in assuring food security to farmers. Meanwhile, fish can improve the diet composition of farmers by increasing the supply of animal protein.

Considerable numbers of studies have demonstrated that, in comparison with monoculture rice farming fields, the rice–fish systems either have a higher production of rice or a higher production of fish if the rise in rice production is insignificant (Lu, 1986; Yang and Lu, 2001; Wang and Lei, 2000). Its complex structure and multi-functions have won itself, from the Ministry of Agriculture of China, the title of *Small Four-in-one Eco-engineering* — that is, a small water storage, a small granary, a small bank and a small nitrogen fertilizer plant.

The rice–fish system is conducive to the recovery of soil fertility and the prevention of soil degradation, which is a global environmental issue. An experiment of rice–fish integration for 3 years in the same plot showed that, with rice–fish integrated farming, there was an increase of 27.9, 44.3, 6.5 and 28.2% in total nitrogen, total phosphorus, total potassium and organic matter, respectively, in the soil (Zheng and Deng, 1998). Similarly, another long-term study for a period of 10 years showed a 15.6–38.2% increase of organic matter, total nitrogen and total phosphorus in the soil when rice–fish farming was adopted (Huang et al., 2001).

Global climate change is closely linked to agricultural production. At present, the average content of CH_4 in the atmosphere has increased to 1.8 ml/m^3 (Luo, 2001). The greenhouse effect caused by CH_4 is 20–60 times worse than that caused by CO_2. Therefore, FAO has listed CH_4 as one of the most important micro air pollutants. A total of 10–20% of CH_4 in the atmosphere comes from rice fields. Research has shown that the rice–fish system is capable of lowering the emission of the greenhouse gas CH_4. Huang et al. (2001) previously quoted research of 3 years also proves that the emission of CH_4 from a sole rice field is 4.73 mg/m^2/ha, whereas that from the rice–fish system is 1.71 mg/m^2/ha, which is a dramatic drop. The exception to this is in the ditches of the system in which the emission rises to 13.10 mg/m^2/ha. Because the ditch area only accounts for 12% of the total field, it can be tentatively concluded that the emission of CH_4 from the rice–fish system is 34.6% less than that from monoculture rice fields.

7. Threats and challenges of rice–fish system

With the deepening of the agricultural reforms in China, pesticide and chemical fertilizers are applied to rice fields in large quantities. The increase of fertilizer-resistant and high-yielding rice species further quickens the change of rice–fish systems — namely, the steady increase of the percentage of monoculture rice fields and the continuous decrease of that of rice–fish fields. The statistics from the Ministry of Agriculture of China shows that rice–fish farming area in China has increased from 667,000 ha in 1959 to 985,000 ha in 1986 and 1,532,000 ha in 2000. However, since 2002, the area has dropped annually. It has decreased to 1,528,000 ha in 2001 and 1,480,000 ha in 2002. After 2002, an average of 30,000 ha have been reduced annually.

Furthermore, the rice–fish system is more labor-intensive than the rice monoculture, but the cost of labor is rising in China owing to its rapid economic development. This is particularly true in the eastern coastal provinces where economic performances are better. Therefore, a labor transference from agriculture to the second or third industry is appearing. A number of rural households in which young laborers are no longer engaged in agricultural production have chosen rice monoculture over the rice–fish system because of the low labor requirement of the former.

The third threat comes from intensive fish farming by which more fish catches and high economic returns are possible. Driven by high economic profits, many rural households in mountainous regions with suitable conditions prefer raising fish in ponds to rice–fish systems.

8. Strategy for rice–fish farming system in China as one of the GIAHS in the world

The focus on agricultural productivity, specialization and global markets has led to a general neglect of research and development support for diversified, ingenious systems. These pressures are constraining farmer innovation and leading to the adoption of unsustainable practices, overexploitation of resources and declining productivity (FAO, 2002).

The GIAHS aims to establish the basis for the global recognition, dynamic conservation and sustainable management of these systems in the face of economic and cultural globalization, environmental variability and inappropriate policy, incentive and regulatory environments.

The rice–fish-farming system in China is in urgent need of dynamic conservation. A full recognition of its multi-ecological functions must be achieved, such as its role in preserving biological diversity, protecting food security, enriching soil and lowering the emission of greenhouse gases. In light of the present situation of China's rice–fish-farming systems, the following protective strategies are suggested:

1. As an important model of Chinese Ecological Agriculture (CEA), the conservation of rice–fish-farming systems should be included in the government's plan of action. Measures should be taken to encourage farmers and rural communities to conserve and develop this model of agriculture.
2. Basic research on rice–fish eco-systems should be emphasized, including research on the basic techniques of rice–fish farming, principles of rice farming and fish raising, integrated techniques of the rice–fish-farming system and the technology required for rice–fish-farming engineering.
3. The production of organic rice and fish should be encouraged in rice–fish systems, which will add economic value to the system and will also raise farmers' incomes.
4. Eco-tourism should be developed on the landscape of rice–fish systems. Rice–fish systems that are exploited as tourist resources will not only provide an opportunity for people to learn about agriculture and ecology, but will also promote the local economic development.
5. As an agro-cultural system, the rice–fish system boasts a history of 1,700 years, evolving as a traditional Chinese culture; therefore, protective measures of such an environmental farming system and its publicity for global benefit is highly recommended.

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References

Berg, H., 2001. Pesticide use in rice and rice–fish farms in the Mekong Delta, Vietnam. Crop Protection 20 (10), 897–905.

Boerma, D., 2005. Globally Important Ingenious Agricultural Heritage System. Magazine on Low External Input and Sustainable Agriculture 21 (2), 36.

Cao, Zhiqiang, Liang, Zhijie, Zhao, Yixin, 2001. Symbiotic effects of cultivating in rice field in north China. Chinese Journal of Applied Ecology 12 (3), 405–408 (in Chinese with English Abstract).

Chen, Defu, Shui, Maoxing, 1995. Rice–fish Culture in China: Present and Future. In: Mackay, K.T. (Ed.), Rice–Fish Culture In China. IDRC. Document(s) 10 of 41.

Chinese Academy of Agricultural Sciences, Chinese Academy of Fishery Sciences, 1990. The New Advance on Rice–Fish Faring Technology. Chinese Agricultural Press, Beijing. (in Chinese).

David, C.L., Pimjai, S., Nick, I., 1996. Fish culture in rainfed rice fields of northeast Thailand. Aquaculture 140 (4), 295–321.

FAO, 2002. Agricultural heritage systems. Agriculture 21 (http://www.fao.org/ag/magazine/0211sp1.htm).

FAO, 2003. Biodiversity and the Ecosystem Approach in Agriculture, Forestry and Fisheries. Publications Division, Food and Agriculture Organization of the United Nations (FAO), 00100 Rome, Italy.

Haroon, A.K.Y., Pittman, K.A., 1997. Rice–fish culture: feeding, growth and yield of two size classes of *Puntius gonionotus* Bleeker and *Oreochromis* spp. in Bangladesh. Aquaculture 154 (3–4), 261–281.

Huang, Yibin, Wen, Boqi, Tang, Jianyang, Liu, Zhongzhu, 2001. Effect of rice–azolla–fish system on soil environment of rice field. Chinese Journal of Eco-Agriculture 9 (1), 74–76 (in Chinese with English Abstract).

Liang, Jiamian, 1986. History of China's Agricultural Sciences and Technology. Chinese Agricultural Press, Beijing. (in Chinese).

Lin, Zhonghua, 1996. Technology and benefits of controlled paddy field. Journal of Soil and Fertilizer 4, 37–41 (in Chinese with English Abstract).

Little, D.C., Surintaraseree, P., Innes-Taylor, N., 1996. Fish culture in rainfed rice fields of northeast Thailand. Aquaculture 140 (4), 295–321.

Li, Xuejun, Qiao, Zhigang, Nie, Guoxing, 2001. Ecological benefits of rice–fish–frog stereoscopic agriculture. Chinese Journal of Ecology 20 (2), 37–40 (in Chinese with English Abstract).

Liu, Zhongzhu, 1995. Rice–Azolla–Fish Cropping System. In: Mackay, K.T. (Ed.), Rice–Fish Culture in China. IDRC. Document(s) 41 of 41.

Lu, Bingyou, Wang, Rusong, Zhang, Renwu, 2001. Relationship between populations diversity and its micro-environments in farmland ecosystem — evaluation for diversity of several farmlands ecosystems. Chinese Journal of Ecology 20 (2), 5–7 (in Chinese with English Abstract).

Lu, Jianbo, 1986. Rice–fish farming experiments in double rice cropping system. Chunan Journal of Sciences and Technology 4, 40–42 (in Chinese with English Abstract).

Lu, Shenggao, Huang, Chongping, 1988. Economic and ecological effects of fish culture in paddy fields. Chinese Journal of Ecology 7 (4), 26–29 (in Chinese with English Abstract).

Luo, Shiming, 2001. Agro-Ecology. Chinese Agricultural Press, Beijing. (in Chinese).

Mackay, K.T., 1995. Rice–Fish Culture in China. IDRC.

Mohanty, R., Verma, H.N., Brahmanand, P.S., 2004. Performance evaluation of rice–fish integration system in rainfed medium land ecosystem. Aquaculture 230 (1–4), 125–135.

Ni, Dashu, Wang, Jianguo, 1990. Theory and Application of Rice–fish Faring. Chinese Agricultural Press, Beijing. (in Chinese).

Ofori, J., Abban, E.K., Otoo, E., Wakatsuki, T., 2005. Rice–fish culture: an option for smallholder Sawah rice farmers of the West African lowlands. Ecological Engineering 24 (3), 235–241.

Vormant, N., Nam, C.Q., Ollevier, F., 2002. Growth performance of *Barbodes gonionotus* (Bleeker) in intensively cultivated rice fields. Aquaculture 212 (1–4), 167–178.

Wang, Ying, Lei, Weici, 2000. Studies on the ecological effect of planting breeding models in the rice field. Acta Ecologica Sinica 20 (2), 311–316 (in Chinese with English Abstract).

Wang, Yutang, Wang, Youtian, 1994. Ecological Fishery Technology in Paddy Field. Chinese Agricultural Press, Beijing. (in Chinese).

www.fao.org/landandwater/giahs.

Yang, Jingping, Lu, Jianbo, 2001. Agro-Ecological Engineering and Technology. Chinese Chemical Industry Press, Beijing. (in Chinese).

Ye, Chongguang, Ye, Chaoyang, Zhou, Zhongying, 2002. Integrated Technology of Rice–Fish Farming. Chinese Agricultural Press, Beijing. (in Chinese).

Zhang, Chengyuan, Shan, Zhifen, Zhao, Liansheng, 2001. Outline of rice–fish culture and cropland ecology. Chinese Journal of Ecology 20 (3), 24–26 (in Chinese with English Abstract).

Zheng, Yonghua, Deng, Guobin, 1998. Benefits analysis and comprehensive evaluation of rice–fish–duck symbiotic model. Chinese Journal of Eco-Agriculture 6 (1), 48–51 (in Chinese with English Abstract).