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Review

Biodiversity Conservation in Rice Paddies in China: Toward Ecological Sustainability

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Abstract: Rice paddies are artificial wetlands that supply people with food and provide wildlife with habitats, breeding areas, shelters, feeding grounds and other services, and rice paddies play an important part in agricultural ecological systems. However, modern agricultural practices with large-scale intensive farming have significantly accelerated the homogenization of the paddy field ecosystem. Modern agriculture mostly relies on chemically-driven modern varieties and irrigation to ensure high production, resulting in the deterioration and imbalance of the ecosystem. Consequently, outbreaks of diseases, insects and weeds have become more frequent in paddy fields. This paper describes the current situation of rice paddy biodiversity in China and analyzes the community characteristics of arthropods and weedy plants. Meanwhile, we discuss how biodiversity was affected by modern agriculture changes, which have brought about a mounting crisis threatening to animals and plants once common in rice paddies. Measures should be focused to firstly preventing further deterioration and, then, also, promoting restoration processes. Ecological sustainability can be achieved by restoring paddy field biodiversity through protecting the ecological environment surrounding the paddy fields, improving paddy cropping patterns, growing rice with less agricultural chemicals and chemical fertilizers, constructing paddy systems with animals and plants and promoting ecological education and public awareness.

Keywords: rice production; ecological sustainability; rice paddy biodiversity; modern agriculture

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1. Introduction

Rice paddies supply people with food, function as artificial wetlands, replacing natural wetlands by providing wildlife with habitats, breeding areas, shelters, feeding grounds and other services. Irrigated rice cultivation was initiated and developed 6000 to 8000 years ago [1–3], and the constructed wetland of the rice paddy field is one of the carriers of the Chinese civilization [4]. China is also the largest rice producing country in the world. In 2012, approximately 30 million ha were planted with rice in China, accounting for 35.76% of the total grain-sowing area [5]. Therefore, paddy fields play an important role in agricultural production. China is among the countries with the greatest biodiversity in the world, but its biodiversity is also among the most seriously threatened. Many species have become endangered species or threatened species: about 4000–5000 species of higher plants are threatened and 156 species of wild animals are endangered species [6,7]; and this phenomenon is particularly prominent in rice paddy agro-ecosystems. Agricultural development and other human activities have caused increasingly obvious damage to rice paddy biodiversity, resulting in unstable and uniform biological communities.

In agro-ecosystems, biodiversity has a positive correlation with agricultural production within a certain range: as the biodiversity increases, the agricultural production also increases. On the contrary, when biodiversity decreases, the agricultural production also will decrease. One of the main reasons is that it can effectively control the number of insect pests. According to the statistics by Risch, the number of plant eaters has reduced by 53% and the number of plant eaters has increased by 18% by decreasing the biodiversity of agro-ecosystems [8]. As for plants, the diversification of complex environment can provide a series of alternative of prey and micro habitats and can form a relatively stable community, which can effectively control the pests. Despite the negative effect of weeds on crop production, it is important to maintain weed diversity in farmland, as weeds can provide diverse ecological services in relation to maintaining the stability and sustainability of agro-ecosystems [9]. In fact, arable weeds constitute the base of the food chain for herbivores and their natural enemies. Additionally, arable weeds also support various species of beneficial insects, especially crop pollinators [10–13]. Meanwhile, high weed diversity is favorable in maintaining and regulating the microbial diversity of the soil and reducing the effects of harmful weeds.

As for insects, natural enemy diversity may benefit the biological control of arthropods [14]. On the basis of the high and stable yield of modern agriculture, the number of insect species has been reduced, and the whole stability of the agricultural system is destroyed. Even species losses in natural enemy communities have unpredictable effects on herbivore suppression, because of the wide range of enemy-enemy interactions (positive, negative and neutral) [15,16], a stable insect community can form a more complex food chain and food web, and the opportunities for community interaction are more (if one way has been disturbed, another will be compensate [17]), and many studies have provided compelling evidence for a link between biodiversity and ecosystem functioning [18].

Modern intensive agricultural practices, especially pesticide and fertilizer use and excessive, inadequately coordinated development and landscape transformation, have not only polluted the water and soil environments [19], but have also destroyed the biological refuge and habitat provided by paddy fields. It is well known that rice paddy biodiversity provides the foundation to maintain stable paddy field ecosystems and contributes substantially to the ecosystem services that paddy fields provide, thus creating economic value for society [20]. The pressures on the natural ecology of paddy fields are common for many countries, Japan as an example [21,22], while the situation is even worse in China. Therefore, it is necessary to review the current status of rice paddy biodiversity in China and to analyze its characteristics for identifying pathways toward ecological sustainability. The discussions in the paper are articulated in five main sections, including: (1) the Introduction; (2) Rice Paddy Biodiversity; (3) Modern Changes and Their Impacts; (4) Restoring Rice Paddy Biodiversity for Ecological Sustainability; and (5) Conclusions.

2. Rice Paddy Biodiversity

The biodiversity of the rice paddy ecosystem refers generally to all living organisms in cultivated rice fields, including genetic diversity, species diversity, ecosystem diversity and related ecosystem processes [23]. Crops, weeds, pests and their natural enemies are important parts of paddy field ecosystems and together form biological communities, thus maintaining the stability of the paddy field ecosystem. The community is a key indicator of the structural stability of the paddy field ecosystem, and arthropods and weeds are the most important components of the paddy ecosystem; therefore, we focus on the community characteristics of arthropods and weedy plants below.

2.1. The Community Characteristics of Arthropods

Arthropods exhibit high abundance and species richness in rice paddies in China; 624 pest species and 1303 natural enemies have been recorded [23,25]. The rice paddy arthropod community includes pests, natural enemies, saprophytes and aquatic animals based on their trophic levels and ecological roles. These various groups constitute an organic whole to maintain a stable paddy field ecosystem.

Community stability and diversity are two indicators of the function of ecological communities [26]. Community stability is not smooth, and a community that is far from an equilibrium state may appear relatively stable and structured due to the rice paddy environment and the different stages of rice growth and development. According to [27] and [28], the numbers of species and individuals and the values of diversity and evenness differ distinctly among various habitats, field types and stages of rice growth. Jin *et al.* [29] analyzed the differences in the spatial stratification and seasonal fluctuation of community diversity, and their results showed that community diversity was unstable and exhibits large seasonal fluctuations. Additionally, community diversity was an important standard for the stability of paddy field ecosystems: when the diversity index was lower than three, the community stability was poor; on the contrary, when the diversity index was higher than three, the community was stable. The succession of the paddy field arthropod community is a dynamic characteristic of community stability, reflecting the changes in community type and abundance. According to [30], the complete succession of the paddy field arthropod community due to the growth of rice and season change can be divided into three phases: expansion, fluctuation and decline.

Furthermore, the arthropod community can be divided into three sub-communities based upon each species' effect on rice plants: natural enemies, insect pests and neutral species. The natural enemy sub-community has the highest species richness and diversity, while the weekly cumulative sum of the neutral-species and insect-pest sub-communities are similar. However, their abundance is negatively correlated with succession with the growth of rice and the weather, as the former provides food, the rice grows and the weather gradually cools down from June to October. The sub-communities are interdependent; the natural enemy community relies simultaneously on insect pests and neutral insects during the expansion phase, while neutral species provide more nutrition than insect pests to the natural enemy community during the decline phase [31].

2.2. The Community Characteristics of Weedy Plants

In China, there are about 100 common weed species in paddy fields. The structure of the weedy plant community is closely related to the paddy field environment and is affected by the geographical region, rice plant physiological features (such as glufosinate resistance of some transgenic rice varieties), soil and water chemistry, climate and cultivation practices. Changes in the plant community structure are reflected in the weed population density, dominant species and level of crop damage, and the succession of the weed community is spatially evident. Chang *et al*. [32] analyzed the weed communities of rice fields in three areas within Hubei, central China; their results showed that although the dominant weed species differed among areas, the weed communities were highly similar. Yu *et al*. [33] studied the weed community of Zhejiang Province, southeastern China, where barnyard grass (*Echinochloa crus-galli*, *Paspalum paspaloides*) and broadleaf weeds (*Monochoria vaginalis, Lindernia procumbens, Spirodela*) were the dominant weed species of the early and late rice stages, respectively. In this region, the use of chemical herbicides accelerated the succession of the weed community and significantly increased the frequency of perennial weeds. Li *et al*. [34] thoroughly investigated the weeds in paddy fields in Wenzhou, Zhejiang Province, eastern China, through comparative surveys over a 10-year period. Their results stated that although the degree of damage due to barnyard grass declined, this species remained a malignant weed (*Echinochloa crus-galli*). Additionally, due to the long-term use of sulfonylurea herbicides, many weed species that were initially malignant were reduced to general or secondary weeds as the harmfulness decreased. However, some perennial weeds escalated into malignant weeds.

3. Modern Changes and Their Impacts

In China, traditional agriculture maintained ecosystem stability and sustained food production by the interaction between biodiversity and biological. However, with the improvement of agricultural productivity, modern agriculture relies on chemically-driven modern varieties and irrigation to ensure production. However, modern agriculture has brought a mounting crisis threatening to animals and plants once common in rice paddies and also has caused a loss of habitats for various species; meanwhile, the paddy biodiversity has tended to simplicity, and the species interactions have been ignored, which has led to serious damage to the paddy field ecosystem. This phenomenon was similar in some other countries, Japan as an example [35]; we focus on the features of China.

3.1. Water Management

Traditional rice cultivation in China generally uses the flooding irrigation mode. With the rapid economic development in the country, however, the shortage of water resources has become a serious obstacle to sustainable development [36,37]. In China, the water resources of per capita and cultivated land, respectively, accounts for only 25% and 50% of the world's average level; agricultural water shortages are more than 80% of the total water resources, and the use efficiency of agricultural irrigation water is less than 50% [38,39].

Since the 1990s, researchers have developed, tested and disseminated several water-saving irrigation techniques for rice cultivation, including controlled irrigation [40,41], intermittent irrigation [42,43], half-dry cultivation [44], filmed ground and dry cultivation [44], systems of alternate submergence-nonsubmergence [45] and alternate wetting and drying [46,47]. These methods share the absence of continuous standing water on the paddy field surface or soil moisture content lower than saturation; thus, the paddy field moisture conditions differ from those created by traditional flooding irrigation.

These changes in water management inevitably alter the paddy ecological environment, thus affecting rice paddy biodiversity. Studies have shown that annual and perennial weeds can appear without standing water on the field surface. Aquatic plants are far more abundant in traditional flooding irrigation. When rice undergoes two consecutive drought phases, the aquatic plants are inhibited. The total abundance of weeds may be similar under novel water-management practices compared to flooding irrigation, but the species composition of the weed community differs widely [48]. In addition, under semi-arid cultivation, sheath blight decreased by 24%, planthoppers decreased by 46% and rice leafrollers decreased by 70%. Meanwhile, the pest disease rate fell from 36.7% to 3.3%, and the plant disease rate declined from 12.8% to 0.4% [49]. Thus, this cultivation method can promote the reduction of insect pests in rice. Zhu *et al.* [50] studied the effects of filmed ground and dry cultivation on pest occurrence (diseases, insects and weeds) and on the richness of natural enemies and saprophagous insects. Under these growing conditions, the occurrence of rice sheath blight decreased, the population densities of parasitic wasps and spiders changed and the population densities of natural enemies and decomposers declined compared to conventional irrigation. Simultaneously, thin-leaved dicotyledonous weeds decreased, but the number of broad-leaved dicotyledonous weed seedlings increased.

3.2. Agrochemicals

In the past, the area using agricultural chemicals covered 1.5×10^8 ha. There are more than 100 kinds of agricultural chemicals that were widely used, which included some main organochlorine agricultural chemicals, HCH (hexachlorocyclohexan) and DDT, and the average use of agricultural chemicals was about 5.0×10^5–6.0×10^5 tons each year, of which this number was only less than the USA compared to the rest of the world [51].

Agricultural chemicals (including pesticides and growth regulators) have contributed substantially to the development of modern agriculture, but the overuse has also damaged agricultural areas and the surrounding natural vegetation, aquatic environment and wildlife, thus decreasing rice paddy biodiversity [52]. A survey [53] showed that there was *Ottelia alismoides* in rice paddies before 1988, while it was difficult to find in rice paddies in Zhejiang Province after herbicide use for several years. Due to the use of herbicides, the number of weed species decreased, while some weed species that had adapted to the changed environment usually broke out. Wan and Chen [54] studied the pests and natural enemy communities in paddy fields in two areas with different management practices. The observed species richness of the pest, parasite and spider groups was nearly twice as high under integrated pest management compared to chemical control. The species richness of the predator group was three times higher under integrated pest management than under chemical control, and the ability of the community to resist environmental disasters and to self-regulate was stronger under integrated pest management than under chemical control. Yu *et al.* [55] investigated plant diversity in paddy fields in Zhejiang Province, southeastern China, and discovered that herbicide use alters the dominant weed species in paddy fields.

Paddy field ecosystems are highly unstable, and the loss of rice paddy biodiversity inevitably perturbs the ecological balance, thus affecting the biological community. Natural enemies that are sensitive to pesticides, especially natural enemies or parasitic natural enemies that are biochemically or morphologically similar to insect pests, are easily influenced by pesticide use, while insect pests can easily develop pesticide resistance. Weed community changes resulting from herbicide use exhibit successional behavior; long-term chemical use will effectively control the target weed, but promote the emergence of non-target species as major weeds. Wu *et al.* [56] studied the effects of different herbicides on the weed community in paddy fields, and their results showed a close relationship between the structure of the weed community and the number of years of herbicide application. Their study also indicated a dramatic linear correlation between the abundance of the target weed and the years of herbicide application.

In modern intensive agriculture, due to population growth and social demand, farmers constantly increase the use of chemical fertilizers (mainly nitrogen) to obtain high rice yields. However, the average application of chemical fertilizers in China is 314.3 kg/ha, which is more than three times the world average. Meanwhile, the use efficiency of chemical fertilizers is very low, with a use efficiency of 30%–40% of nitrogen and 10%–20% of phosphorus [57]. As a result, the rice plants grow rapidly, and their growth performance is altered. The pest resistance of rice has been reduced, which provides pests with appropriate nutritional conditions and environments [57,58]. The host plant morphology and biochemistry and the ecological adaptability of the insect community affect the trophic structure and dynamics of the plant parasite, insect pest and natural enemy communities. In a recent study, the number of predatory natural enemies increased significantly with increasing fertilizer application, but the number of egg parasitoid wasps decreased dramatically [59]. Meanwhile, the excessive use of chemical fertilizers can lead to the rapid growth of pest populations, worsening the damage to the rice crop [60,61]. The growth of crops and weeds involves selective nutrient absorption, and synthetic fertilizers alter the original competitive relationships and prompt the weed community to develop in different directions [62]. The effects of long-term fertilization on weed communities have been evaluated in a rice-oilseed rape cropping system in the Tai Lake region of Jiangsu Province. The results show that different fertilization methods lead to different weed community compositions and dominant species [63].

Although many chemical fertilizers used in paddy fields have negatively affected rice paddy biodiversity, some studies have shown that rice paddy biodiversity can be improved by the reasonable and rational use of chemical fertilizers. Huang *et al.* [64] have indicated that the abundance and degree of damage of major rice pests can be significantly reduced by appropriately increasing the number of types and proportions of phosphorus (P) and potassium (K), while increasing nitrogen (N) use. Meanwhile, the abundance of neutral insects and predatory natural enemies will increase with increasing organic matter in paddy fields [65]. Zhao *et al.* [66] have shown that paddy field weed biodiversity can be improved by the combined application of organic and inorganic fertilizers compared to a single inorganic fertilizer. The composition of paddy field weed communities and the pattern of species dominance can be significantly altered by using balanced quantities of N, P and K, thus decreasing the damage caused by paddy field weeds.

3.3. Modernization of Irrigation Systems

Since the implementation of the Rehabilitation and Water-Saving Reconstruction of Large-Scale Irrigation Districts Project in the late 1990s, modern irrigation techniques have been widely used, the level of irrigation management has improved and losses of irrigation water have decreased dramatically. From 1998 to 2010, 393 large-scale irrigation districts were rehabilitated and implemented water-saving transformation, a 33,600 km canal was lined, and there were 94,200 structures renovated. In the future (to 2020), the number will be larger. With the development of the economy, the number of rehabilitated large-scale irrigation districts will increase to 434, the length of canal lining will reach to about 260,000 km and the number of renovated structures will be 480,000 [67,68]. However, the modernization of irrigation systems has also altered the ecological and environmental conditions of paddy fields. Canal lining significantly decreases the moisture content and salinity of the underlying soil, thus altering the effects of water and salt stress on the plants, promoting weed-community succession and restricting the growth of drought-susceptible plants. In a diversity assessment and plant-species analysis of a large-scale irrigation district, Yuan *et al.* [69] have found that plants along non-lined channels grow better than those along lined channels.

Naturally occurring plants along the borders of paddy fields provide a stable habitat and abundant food for parasitoid wasps and other predatory natural enemies. Thus, these plants can effectively increase rice paddy biodiversity. Studies have shown that non-paddy weeds provide a species pool for the rice paddy arthropod community, and those predatory natural enemies can control pest populations if a certain area of non-paddy weeds is maintained [70]. Weeds growing near paddy fields can also provide shelter and food for parasitic insects [71]. However, the destruction of habitat surrounding paddy fields promotes the invasion of novel plant and animal pests, thus aggravating the damage to paddy field biodiversity.

Similarly, the modernization of irrigation systems has changed the habitat of primitive paddy fields, which reduced the amount and type of species. The fish and young frogs should grow in water bodies, but many small ponds and ditches have disappeared because of land leveling, and worse still, the use of irrigation pipes has led to a decrease of water bodies, which seriously affected the growth of fish and frogs. Meanwhile, it is difficult for frogs and snakes that have fallen into a lined canal to escape, and they are usually trapped, which seriously reduces the number of local species and destroys the paddy field biodiversity.

4. Restoring Rice Paddy Biodiversity for Ecological Sustainability

The maintenance of rice paddy agriculture cannot be separated from the promotion of rice paddy biodiversity, and rice paddy biodiversity exhibits a reciprocal relationship with ecosystem stability. However, the ecological conditions of modern agriculture tend to restrict biodiversity, reducing interspecific competition and degrading the environment to obtain temporary high yields. Therefore, it is necessary to protect paddy-ecosystem biodiversity and to promote the sustainable development of paddy agriculture, and in fact, it is possible to foster both food security and biodiversity using appropriate alternative agricultural practices [72]. China is encountering various environmental and ecological problems that some developed countries faced through the 1960s–1980s, due to the rapid economic development of the last three decades. The experience on restoring rice paddy biodiversity from these countries is useful, while local farming practices, climate, economic conditions and other factors should be taken into consideration. Although ecological awareness is growing, damage to paddy field diversity continues. Measures should be taken before it is too late, and it is viable to firstly prevent further deterioration and then to restore.

4.1. Protecting the Ecological Environment Surrounding the Paddy Fields

Protecting habitat diversity is an important element in conserving rice paddy biodiversity. This goal can be achieved by increasing the diversity of the artificial habitat. The destruction of the paddy habitat not only reduces the living space and food resources available to wildlife, but also leads to poor intraspecific communication and reproduction in various species. Therefore, it is necessary to strengthen the protection of paddy fields within cultivated areas and to restore degraded paddy field ecosystems. Simultaneously, the intervention synergy of the management of different marginal zones, ridges, irrigation ditches and natural habitats along roads and in woods is needed to link the communities in paddy fields, irrigation ditches, water bodies and ponds. Agricultural landscapes should be designed to protect the natural habitat diversity, as many arthropod species found in natural habitats (especially natural enemies) can have a positive role in controlling the insect pests of paddy fields.

Ecological facilities are combined with the ecology principle and actual production and create a mutual benefit for human society and the natural environment. Paddy ecological engineering construction is an important measure of paddy biodiversity conservation, which can restore connectivity between water and paddy fields, providing shelter for animals and plants and increasing the diversity of animals and plants.

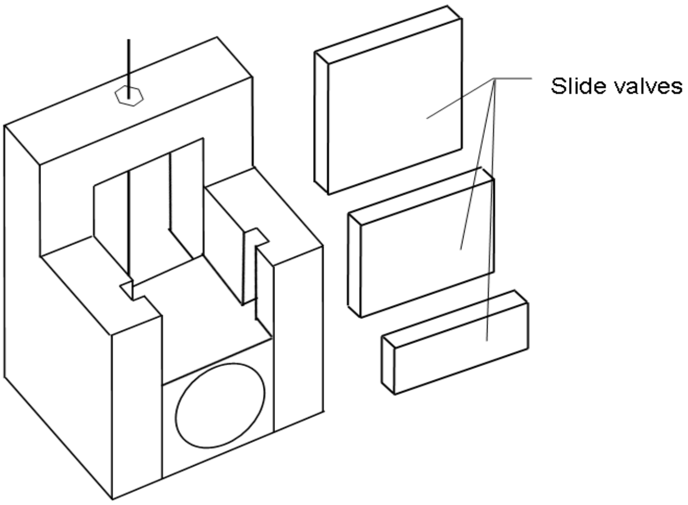
In modern paddy ecological engineering, fish ladders are used to connect drainage ditches and paddy fields [73]. A fish ladder makes small drops, so that fish are able to run through wood or polyethylene half-pipe and detachable plates [74–76]. Some fish ladders that are made of wood or polyethylene half-pipes have been used in paddy fields [75], and the fish ladders can connect drainage ditches and paddy fields; when the water comes out from paddy fields, the fish are able to run through the ladders [76–78].

Frogs and snakes that have fallen into a concrete-lined canal usually cannot survive, due to the slippery slides, while escape paths for wild animals along the irrigation canal slope sides (Figure 1) can help reptiles (frogs and snakes, for example) successfully escape and provide habitats and shelter [56]. Meanwhile, a drainage control gate can also raise the water level in the drainage ditch in order to provide habitats for animals and plants, as well as to maintain and enrich paddy field biodiversity [27]. Figure 2 shows a schematic diagram of a drainage control gate also constructed at our experiment site in Gaoyou Irrigation District (GID), China. The different heights of slide valves were designed to maintain different water levels for corresponding rice growing stages, and the culvert allows complete drainage during the wheat growing season and the late tillage stage of rice.

The water bodies in rice-based areas play an important role in the paddy field ecological environment; they maintain the whole paddy field ecosystem by combining with drainage ditches, canals and wetlands. Through previous studies, we know that water-saving irrigation can effectively prevent weed plant diseases and pests; it also can improve the stability of the arthropod community and prevent the outbreak of weeds, which has a positive effect on maintaining paddy biodiversity [79–81]. Besides, water shortage has become a reality, and traditional flood irrigation cannot adapt to modern paddy cultivation; therefore, strengthening the management of the paddy field water environment and promoting the technology of water-saving irrigation also have positive effects on the construction of the ecological environment and the biodiversity.

Figure 1. Escape paths for wild animals along irrigation canal slope sides in Gaoyou Irrigation District (GID).

Figure 2. Schematic diagram of a drainage control gate.



4.2. Improving Paddy Cropping Patterns

Traditional paddy cropping in China is monocultural and extensive. There were 150 kinds of plants that could be served as food in Chinese history, but now, food mainly only comes from more than 20 kinds of plants, which include rice, wheat, corn, and so on [82]. This cropping pattern does not protect genetic diversity and thus threatens rice paddy biodiversity. Multi-species mixed planting or row planting can be used to fully utilize the available space and environmental resources, thus improving the community structure and strengthening resource allocation. Effective disease control relies on genetic heterogeneity, the pathogen dilution effect, the physical isolation of resistant plants, the induced-resistance effect and the co-evolution of mixed plant populations [83]. Zhu *et al.* [84] have reported that planting rice varieties of different genotypes in the same production area increases genetic diversity and decreases the incidence of *Pyricularia grisea*. Additionally, Tang *et al.* [85] have found that the cultivation of multiple rice varieties using interval planting can reduce the occurrence of barnyard grass by promoting the growth of repressible weeds, which provide mutual influence and competition.

4.3. Growing Rice with Low Agrochemicals

A serious ecological crisis arises because of the adverse impact of agricultural chemicals and chemical fertilizers, of which the polluted area is more than 6.67×10^6 ha in paddy fields [86]. From the late 1990s, ecological and environmentally sustainable rice production spread rapidly; meanwhile, organic agriculture and rice production without pesticides or chemical fertilizers were increasing in Japan and many other countries. It is an effective way to protect ecological effects by growing rice with low agricultural chemical and chemical fertilizer. Consumers can easily prefer organic rice production and other unique kinds of production if they exist inside a region with agricultural methods of low agricultural chemicals and chemical fertilizers.

Rice growers usually use much more chemical fertilizers and pesticides to ensure yield in modern agriculture. Irrigation water is also over used; thus, most of the applied fertilizers is flushed out of the fields and causes eutrophication of downstream water bodies [41]. We can control the downstream water bodies, and let some aquatic plants absorb the nutrients in the drainage. This measure can be combined with other farming practices, such as water-saving irrigation. The first step might be to reduce chemical fertilizers to a minimal threshold without yield reduction, just reducing the non-beneficial use of chemical fertilizers. Then, organic fertilizers can be gradually used to partially replace chemical fertilizers in the second step [87,88]. As for agricultural chemicals, eco-friendly pest control measures include trap lamps, biological pesticides and non-pesticide management (e.g., the example of the *Azadirachta indica*, known as neem tree).

4.4. Constructing Paddy Systems with Animals and Plants

The introduction of additional species (such as fish, ducks and *Azolla*) is an effective strategy to improve rice paddy biodiversity and to enhance the species richness of the ecosystem through practical ecosystem management [89]. For example, from [90,91], compared with monoculture, paddy systems with animals and plants can increase the mortality of 50% of pests and decrease the mortality of 11.1% of pests. Meanwhile, the increment of natural enemies is 72% and the decrement of pests is 74%. By introducing selected species, managers can establish artificial biological diversity to inhibit the growth and reproduction of harmful species, while creating favorable conditions to promote paddy field biodiversity. Quan *et al.* [92] have reported that the development of rice-sheath blight can be delayed and the disease severity can be reduced by approximately 50% by raising ducks in the paddy fields. Yang *et al.* [93] have studied the incidence of rice diseases while raising crabs in the paddy field. Their results showed that the disease incidences of *Pyricularia grisea* and *Ustilaginoidea oryzae* are lower in crab-raising paddy fields than in conventional paddy fields. Su *et al.* [94] have reported that *Azolla* can suppress the photosynthesis of weedy plants, thus inhibiting weed occurrence and crop damage in rice-duck-*Azolla* integrated farming systems.

4.5. Promoting Ecological Education and Public Awareness

Protecting rice paddy biodiversity and paddy field ecosystems will be a long process. In addition to effective support for science and technology, further efforts are needed. Current rice-cultivation methods are not sustainable, and public awareness, education and training are the keys to moving society toward sustainability. It is vital for the public to recognize the significance of the ecosystem services that paddy fields as artificial wetlands provide and also understand the pathways to restore paddy field biodiversity before actions are taken. Farmers may be trained and empowered with eco-friendly rice farming practices, and ecologically sustainable rice production societies may be established to unite the farmers into a network. Moreover, the ecology of paddy fields should also be opened to elementary and middle school students to use as a tool for environmental and ecological education and learning. China is facing the aging of agriculturalists and a shortage of successors and needs to upgrade from traditional agriculture towards modern agriculture. Although it is difficult to change the farming method of the current generation of farmers, we may place our hopes on the next generations.

5. Conclusions

Paddy fields are the basis of Chinese culture; the rice has brought up the Chinese people for 5000 years. Meanwhile, paddy fields are an important component of agriculture and play an important part in the agricultural ecological system. Paddy fields took over part of the functions of artificial wetlands and have been providing people with ecosystem services. They are also the basis of Chinese culture and play an important part in the agricultural ecological system. Although modern agriculture improves food production, the paddy ecosystem and biodiversity are constantly worsening, which leads to the unsustainable development of the paddy field ecosystem. The conservation of the paddy ecosystem and biodiversity are very insufficient in China, so it needs to be further strengthened through protecting the ecological environment surrounding the paddy fields, improving paddy cropping patterns, growing rice with less agricultural chemicals and synthetic fertilizers, constructing paddy systems with animals and plants and promoting ecological education and public awareness. In this way, it is possible to restore biodiversity in rice paddies and, thus, achieve ecological sustainability. An engineering-social system is needed in which rice production and biodiversity gain from each other.

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Author Contributions

Yufeng Luo conducted the main research and review work that provided the basis for this paper, Haolong Fu participated in the literature review and drafted the manuscript, and Seydou Traore revised and significantly improved the manuscript. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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