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Integrated Emergy and Economic Evaluation of Huzhou Mulberry-Dyke and Fish-Pond Systems

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Abstract: The Huzhou mulberry-dyke and fish-pond system (HMFS) is a compound structure of agriculture with interaction among several subsystems, and it is an effective example of a circular economy by exogenous input and waste reduction to maintain a harmonious relationship between humans and nature. As increases in rural urbanization and transition of peasants occur, the traditional systems remain in a constant state of change, along with different kinds of adaptation models. In this study, two main existing models are examined by field investigation and extensive literature analysis. Emergy theory and methods are adopted to make a further quantitative analysis from emergy structure and indices synthetically and systemically. In this process, the models of HMFS are split into several subsystems, including mulberry dyke, fish pond, rape dyke, and silkworm, in terms of a modularization approach. The proportion of combinations among different subsystems is calculated by the average production level of local peasants. The empirical results of emergy analysis indicate that the two existent patterns of HMFS are themselves superior in terms of environmental capacity and commercial efficiency. The mulberry–silkworm–fish model possesses more sustainable characteristics than the rape–fish model by the mass flow and energy flux. In addition, the rape–fish model may obtain considerably better economic returns by more inorganic resources, and thus achieve higher economic benefits. Therefore, the rape–fish model may be an evolutionary model to make directions for further research and protection, while other adaptive units are introduced to form multiple systems.

Keywords: Huzhou mulberry-dyke and fish-pond systems; existing models; subsystems; emergy analysis; input and output

1. Introduction

The mulberry-dyke and fish-pond system (MFS) is a compound agroecosystem comprising several different subsystems of mulberry dyke, fish pond, rape dyke, silkworm, and so on. By internal material circulation as well as energy flow, the balance and coordination between economy benefits and ecological functions could be realized [1,2]. This system is mainly distributed in the Zhujiang Delta and Taihu Basin (e.g., Huzhou City), and also spreads over low-lying land in China, such as the Three Gorges Reservoir [3–5]. With the economic development and social transition, various forms of MFS management patterns have been springing up through the addition and deletion of modules.

In the region of Huzhou City, the MFS originally started from mulberry–silkworm–fish, and was then later enriched into crop–pig–fish, crop–fish–sheep, rape–fish, and so on [6,7]. Additionally, the interaction among subsystems has been weakened, or even ruptured, because of base collapse, pool eutrophication, a larger scale of fish pond, and so on in recent years [8]. Therefore, the extensive management and insufficient utilization of module resources have become serious obstacles to the protection and sustainable development [9,10].

In order to probe the harmonious and balanced coexistence of the natural environment, social economy, and national culture, the program of Globally Important Agricultural Heritage Systems (GIAHS) was launched by the Food and Agriculture Organization (FAO) of the United Nations in 2002 [11–13]. The Huzhou mulberry-dyke and fish-pond system (HMFS) was designated as one of the GIAHS pilot sites in 2017 [14]. HMFS has had a long history of over 2500 years, with a wealth of traditional and agroecological knowledge [15,16]. However, the system is experiencing recombination and revolution, especially with respect to the composite structure and subsystem modules, due to rapid developments in rural economy and society. This project has attracted the increasing attention of many researchers from various disciplines, and plays an active role in giving support to related research work. Gu et al. [3] combed research achievements in origins and concepts, structure and function, promotion and application, and so on. Ye et al. [17] analyzed the four phases of HMFS performance, and then further emphasized their practical significance to conservation. Wu et al. [18] estimated the condition of HMFS qualitatively, and proposed some concrete implementation measures. Additionally, Li et al. [19] proposed a new pattern of mulberry–(grass)–fish with better benefits the economy and ecology in 1989.

The MFS studies for the Zhujiang Delta may offer a more comprehensive qualitative and quantitative analysis by intensive and extensive investigations. Zhong et al. [2,20–23] originally discussed the proportion and types of base and pond, plant structure, and economic and ecological benefits, and then considered the operating mechanization of material flows, energy flows, and economic flows in detail. The energy conversion processes of the base dyke were expounded based on energy balance equations, and the ecological values of water balance were assessed [24,25]. Appraisals among various patterns under the different conditions of developing stages have been done, and a series of evaluation indices have been settled simultaneously [26,27]. In addition, Li et al. [28,29] and Yue et al. [30] proposed that more ecological values and commercial benefits of the dyke pond system be produced than the conventional ways of agricultural production in the Three Gorges Reservoir. For example, the economic effects of the dyke ponds were estimated to be about 125,986 Yuan [29]. Therefore, available research on MFS is mostly concentrated on the regions of the Zhujiang Delta and Taihu Basin from macroscopic and microscopic perspectives. The quantitative analysis of HMFS is deficient and lacks integrated indicators. Meanwhile, evaluating the resource usage of the major models could help us to realize the present position, and then should be the first essential step to advancing the sustainability of HMFS growing in adaptable systems.

The theory of emergy was established by Odum in the 1980s, and is a combination involving ecology and economy subjects. According to this theory, different kinds of inputs and outputs can be transformed into the same energy, which is generally expressed by solar energy equivalents to allow comparisons across various HMFS models [31,32]. Moreover, a set of emergy-based index systems have been brought up and applied to appraise the values of regional natural resources and economic performance, agricultural complex ecosystems, single industries, and others [33–38]. Therefore, this paper will attempt to incorporate the emergy methods into two main existing models of HMFS. Each subsystem will also be assessed in emergy structure in terms of the modularization approach. Ultimately, the differences between HMFS models will be useful to realize the status quo and sustainability of the systems, and the directions and measures of protection and development for the future will also be embodied.

2. Materials and Methods

2.1. Huzhou Mulberry-Dyke and Fish-Pond System (HMFS)

HMFS stems from an ancient construction for water conservancy, "Vertical River and Horizontal Pool", to relieve flooding disaster for low-lying waterlogging regions in the south of Taihu Basin. The region of Huzhou City is characterized by higher drainage density and there are many pools, rivers, and harbors in this area. Coupled with precipitation and temperature conditions, all these natural surroundings are favorable to the formation of HMFS. Additionally, the superior social economic terms have promoted and produced diversified patterns during management and operation. These evolutional modes profit from advanced techniques and economic performances. However, another result is the gradual weakening of links among several subsystems, which eventually gives rise to the degradation and recession of HMFS. In order to make a systematic and complete research on this circulation system, HMFS is defined as dyke pond systems to combine the industries of plant, aquaculture, and processing by reciprocation between base and pool.

In this paper, the two common models of mulberry–silkworm–fish and rape–fish are selected and separated into units. Mulberry–silkworm–fish is the most traditional and original model, including three units of mulberry planting on the base, fish feeding in the pool, and silkworm rearing. Silkworms are raised with mulberry leaves after they have hatched, and their chrysalises are poured into the fish pond as fodder. The excrement of silkworms and pond sludges comprising fish feces fertilize soils of dyke. The rape–fish model has been a burgeoning structure for the last few years, and it is marked by crop rotation on land. Farmers are used to cultivating soy beans from June to November and growing rapes in succession. Therefore, the procedures of this engineering are as follow.

Plant and fish waste feeds the fish and nourishes the pond, and in turn, organic rich mud is annually dug from the pond bottom and spread as fertilizer over the dyke. Throughout the whole year, the mud running off from the dyke gradually returns to the pond bottom, where its nutrients are restored.

2.2. Research Methods

HMFS contains a wealth of heritage values, and it is not only abundant in economic returns, but also with rich ecological functions and corresponding cultural and educational values. At present, the local villagers pay excessive attention to economic interests, which results in environmental deterioration and loss of aesthetic appreciation at the scenic sites. This research adopts emergy theory and methods to make a reasonable and comprehensive evaluation on HMFS. The complicated systems are split into several interdependent modules as subsystems with modularized ideas. The integrated emergy indices are designed to identify and differentiate the efficiency and sustainability of the two ubiquitous models. Based on the above analysis, the obtained results may aid in analyzing circumstances and limitations of different HMFS models, and then making appropriate improvements for future conservation.

Emergy refers to the amount of available energy used on a space–time scale of the biosphere directly and indirectly to make products or services expressed as solar emjoules per joule (sej) [31]. Thus, emergy and emergy monetary values of each energy or material are calculated and compared in production activities. All the system inputs can be divided into four parts: Free local renewable resources (R), free local nonrenewable resources (N), renewable purchased organic resources (T), and nonrenewable purchased supplemental resources (F). Generally, exports are categorized into consumptive product (Y_1) and unserviceable product (Y_2), as depicted in Table 1 [39,40].

Both subsystems and compound models are explored and discussed from input and output. The detailed emergy flows are presented with figures and tables according to small-scale farmers' behaviors. Additionally, per unit area of pond is matched by the same size of base dyke in agricultural production. Solar transformities of related materials and energies are revealed in Table 2.

Energy system language is also employed to generate pathways illustrating a model. Firstly, the system boundary of HMFS must be drawn from others, and mechanisms of interior structures and external connections are reflected from an energy flow diagram. Then, a series of emergy indices are established to measure economic and ecological benefits. The emergy investment ratio (EIR), the environmental loading ratio (ELR), the emergy sustainability index (ESI), the system stability (SS), and the emergy ratio of wasteful to renewable resources (WR) are criteria for environmental quality, and the emergy yield ratio (EYR), input and output ratio (ROI), and the emergy monetary value (EMV) are economic standards [36,41,42] (Table 3).

Table 1. The energy structure of the Huzhou mulberry-dyke and fish-pond system (HMFS).

Item	Expression	Content
Input	R	sunlight, tidal energy, rain, wind falling, etc.
	N	soil, pond water, etc.
	T	feces, labor, seeds, etc.
	F	pesticide, power, nitrogenous fertilizer, etc.
Output	Y_1	fish, soybean, silkworm cocoon, etc.
	Y_2	straw, branch, etc.

Table 2. The solar transformities of related materials and energies.

Item	Unit	Transformity	Item	Unit	Transformity
solar energy	J	1	rapeseed	J	6.90×10^5
chemical energy of rain	J	1.80×10^4	straw	J	3.90×10^4
potential energy of rain	J	1.00×10^4	soybean	J	6.90×10^5
nitrogen fertilizer	g	3.80×10^9	folium mori	J	2.40×10^4
phosphate fertilizer	g	3.90×10^9	ramulus mori	J	3.20×10^4
potash fertilizer	g	1.10×10^9	sorosis	J	5.30×10^5
Pesticide	g	1.60×10^9	cocoon	J	2.70×10^4
rice chaff	J	8.30×10^4	chrysalis	J	2.00×10^6
Power	J	1.59×10^5	mutton	J	2.00×10^6
labor force	J	8.10×10^4	wool	J	4.40×10^6
plastic film	g	3.80×10^8	stropharia	J	2.70×10^4
Manure	g	2.70×10^6	fish	J	9.30×10^6
compound fertilizer	g	2.80×10^9	pond water	J	4.80×10^4
Feedstuff	g	9.26×10^{12}	pond silt	J	3.51×10^3

Table 3. Emergy indices of ecology and economy.

Standard	Index	Expression
Ecology	EIR	$(EM_F + EM_T)/(EM_R + EM_N)$
	ELR	$(EM_F + EM_N)/(EM_R + EM_T)$
	ESI	EYR/ELR
	SS	$\sum_{i=1}^{n}(EM_{Yi}/EM_Y)\ln(EM_{Yi}/EM_Y)$
	WR	$EM_{Y2}/(EM_T + EM_R)$
Economy	EYR	$EM_Y/(EM_F + EM_T)$
	ROI	$EMV_{Y1}/(EMV_F + EMV_T)$

EM_i is the solar emergy of i energy; EMV_i is the value of i emergy.

The EIR represents the contribution degree of natural surroundings and resources exploitation, which is larger to use advanced technology in agricultural production with rapid economic growth. The ELR is the emergy proportion of nonrenewable resources to renewable resources. As the ELR increases, it means to bring about more pressures on the carrying capacity of an agroecosystem. The ESI depends on production efficiency and the emergy structure of models. The SS is an aggregate indicator of automatic regulation, and it could also manifest as the stability characteristic of the whole system.

The WR indicates product availability of all exports and stresses of wastes on environment. The EYR weighs resource utilization and evaluates agricultural performances. The efficiency of purchased energy can be estimated by the ROI.

2.3. Data Collection

To capture agricultural production behaviors of the HMFS, a farm household survey was conducted from March to April in 2017. The sample points lie in the core of the GIAHS sites, which contains the Digang Administrative Village and Shezhong Administrative Village. The mulberry–silkworm–fish model is widespread and traditional in these central zones. Additionally, the emerging rape–fish model has been popular with local farmers these years, so Xindi Administrative Village is also introduced in the semistructural interviews. Therefore, this paper takes the two examples of existing operating models, rape–fish and mulberry–silkworm–fish, to analyze and realize the present situation that HMFS has encountered.

As explained below, the special in-depth questionnaires involved the basic information of peasants and agricultural performances for each subsystem. Forty households engaged in HMFS were set at random in every village. Eventually, only one hundred were propitious and then used to estimate the HMFS values of emergy and economy, with an efficiency rate of 83.3%.

3. Results

3.1. Emergy Analysis on Subsystems

3.1.1. Emergy Inputs and Outputs of Mulberry Dyke

The mulberry dyke is a cardinal primary producer because of plant photosynthesis, and the diversity of mulberry cultivars could endanger differences in emergy values for both inputs and outputs. In production practices among small scale farmers, the mulberries for plucking leaves and picking sorosis are two common types, and the former mulberries need importing 8.9×10^{15} sej solar emergies, while the latter are 9.3×10^{15} sej per unit area. As shown in Table 4, renewable organic energies could account for 75% in all inputs, and the majority are organic fertilizers, which intimates that this subsystem can adjust itself constantly to fit in with changes in the external environment. The embodied emergies of renewable resources are 6.3×10^{15} sej, which is up to 71% in the total inputs. Thus, the results show that mulberry dyke is at a higher level of sustainability. However, for export products, only over 10% of the total outputs are pressed into service with leaves obtained.

Table 4. Emergy inputs and outputs of several subsystems.

Item	Mulberry Dyke	Silkworm	Fish Pond	Rape Dyke
R [1]	1.6×10^{14}	0	7.8×10^{14}	1.6×10^{14}
N	6.3×10^{14}	0	3.7×10^{15}	6.3×10^{14}
F [2]	2.0×10^{15}	4.6×10^{13}	1.1×10^{16}	4.9×10^{15}
T	6.1×10^{15}	7.3×10^{13}	2.5×10^{16}	2.9×10^{9}
Total Input	8.9×10^{15}	1.2×10^{14}	4.0×10^{16}	5.3×10^{15}
Total Output	9.6×10^{15}	3.1×10^{14}	8.0×10^{16}	4.0×10^{16}

[1] For the local renewable resources, we only take the maximum value. [2] The application amount of N. P. K. fertilizers is calculated by their content proportions. In compound fertilizer, the active ingredient of N. is 17%, P_2O_5 is 15%, and K_2O is 17%.

3.1.2. Emergy Inputs and Outputs of Fish Pond

Pond fishes usually grow from April to December in a year, and the frequency of management is not consistent in different periods. According to the survey results and related standards, ponds usually take 30 h in the month of April, 60 h in May, 90 h in June, 720 h from July to September, and 360 h between November and December. Thus, labor force inputs for one year amount in the aggregate to

157.5 man-days per unit area (one man-day is eight hours). In ancient times, the local villagers used to adopt black carps, grass carps, silver carps, and bighead carps in a hierarchical way. However, a single breed in aquiculture has been the major tendency on a larger scale recently.

From the results of investigations and analyses, fish ponds are in demand of 4.0×10^{16} sej solar emergies when exporting something twice as much as possible, as shown in Table 4. The ratio of nonrenewable purchased supplemental energy to renewable purchased organic energy is 0.44, and mechanical power occupies a larger portion than the other purchased resources. The fingerlings and fodders make up 80% of all organic energies, which exerts an important influence and plays a decisive role in the system yields. Thus, this means that fish pond subsystem could create greater economic benefits by adding more organic resources. In addition, the pond output comprises a single product, which may increase utilization efficiency and destabilize the system in reverse.

3.1.3. Emergy Inputs and Outputs of Rape Dyke

On rape dyke, local farmers usually alternate their crops to improve and retain soil fertilization, and they grow rapes from November to May and soybeans from June to October in rotation. The emergy inputs of rape cultivation are slightly more than those of soybean operation, and the same is true for outputs. In agricultural practices, 5.3×10^{15} sej solar emergies are poured into rape fields, and ultimately 4.0×10^{16} sej goods can be obtained, which is superior to the mulberry dyke subsystem in this sense. However, the energy structure and distribution are not irrational, as the weight of renewable resources is less than 10% and reveals a decreasing share on the whole inputs. Therefore, a larger proportion of nonrenewable resources will result in an absurd system structure, and further cause pressures and endangerments to ecosystem environment and sustainability.

3.1.4. Emergy Inputs and Outputs of Silkworm

Silkworm culture requires stringent conditions in temperature and asepsis, and different quantities of mulberry leaves are in need for each instar. In the region of Huzhou City, it takes about 20 days to go from egg to adult silkworm in each season. Based on previous studies of practical experience and theoretical analysis, spring silkworms and autumn silkworms are generally preferred, as the two seasons are better positioned for breeding and growth. As seen in Table 4, silkworms could take full advantage of mulberry leaves and then improve the efficiency of energy and material. From the perspective of emergy structure, organic energies occupy a larger proportion of the whole inputs, and human resource is the most primary factor. Therefore, silkworm subsystems could be regarded as a labor-intensive sector, and when labor costs raise rapidly in the east of China, this subsystem is facing the crisis of exhaustion.

3.2. Inputs and Outputs of the Two Exiting Models

The two models of mulberry–silkworm–fish and rape–fish are currently typical and representative of HMFS. Base and pond are deemed to be constructed with the same ratio of combination. Both of the patterns are assembled with related subsystems and mechanisms. For the mulberry–silkworm–fish model, one hectare mulberry field could support 30 pieces of silkworm eggs, and dyke and pond also contact each other in the same coverage. Except for the internal provision from material recycling and energy flowing, 4.3×10^{16} sej purchased emergies are introduced. Finally, 8.7×10^{16} sej consumptive products and 1.7×10^{15} sej unserviceable products are attained. In addition, the emergy rate of available product to artificial supplementary is 2.07, and the efficiency of resource utilization has been improved. However, the total output of this system is restricted and limited by the fish sector.

The rape–fish model comprises rape (soybean) dyke and fish pond, and one hectare pond is equipped with the same area of dyke. Farmers usually rotate their crops to keep the soils fertile and to raise yields on the land. Moreover, the rape dyke could generate 2000 kg rapeseeds and 1000 kg beans, less than 10% of which are offered to the other subsystem. Then, other fodders of 1.0×10^{16} sej solar emergies are imported into the fish pond to bridge the gap. Finally, the expedient products are acquired from the two subsystems in equal portions, and the wastes are only 1.8 × 10^{16} sej emergy in Table 5.

Table 5. Emergy inputs and outputs of the two existing models.

Items	Mulberry–Silkworm–Fish		Rape–Fish	
	Emergy	Emergy Monetary Value	Emergy	Emergy Monetary Value
R	1.6 × 10^{14}	9.3 × 10^{7}	1.6 × 10^{14}	9.3 × 10^{7}
N	4.3 × 10^{15}	2.5 × 10^{9}	4.3 × 10^{15}	2.5 × 10^{9}
F	1.4 × 10^{16}	8.1 × 10^{9}	1.6 × 10^{16}	9.3 × 10^{9}
T	2.9 × 10^{16}	1.7 × 10^{10}	2.5 × 10^{16}	1.5 × 10^{10}
Y_1	8.7 × 10^{16}	5.1 × 10^{10}	1.2 × 10^{17}	7.0 × 10^{10}
Y_2	1.7 × 10^{15}	9.9 × 10^{8}	1.8 × 10^{12}	1.0 × 10^{6}

3.3. The Emergy Indices of Two Exiting Models

The mulberry–silkworm–fish system could produce 5.1 × 10^{10} Yuan emergy monetary values with 2.8 × 10^{10} Yuan costs (Table 5). In accordance with Table 3, the EIR could arrive at 9.56 because of more external energies and expenses. However, each joule of energy has been utilized adequately to achieve higher productivity. The figures of EYR and WR are 2.07 and 0.04, respectively. Further, the quotas of ELR and ESI are 0.64 and 3.23, which means to create fewer pressures and more benefits on the ecology. The index of SS is below zero under such a system framework; therefore, this type is relative to fewer connections among subsystems and a less debasing stability of HMFS.

The rape–fish system requires 9.3 × 10^{9} Yuan industrial materials and 1.5 × 10^{10} Yuan organic resources, and 7.0 × 10^{10} Yuan serviceable products are finally formed and completed. Due to internal circulating being partially transformed, the EIR has fallen to 9.11. In addition, the system must also be obliged to put more nonrenewable resources to achieve higher EYR and simultaneously minimize waste emissions. The environmental sustainability can also be revealed from Table 6. The rape–fish system may have a negative influence on the ecology, as the indices of ELR and ESI are 0.80 and 3.67, respectively. Therefore, the inputs and outputs of energy in this modality tend to be volatile, and this structure will hinder the realization of the target to create a sustainable development.

Table 6. The emergy indices of mulberry–silkworm–fish and rape–fish.

Model	EIR	WR	ELR	ESI	SS	EYR	ROI
1	9.56	0.06	0.64	3.23	−1.26	2.07	2.03
2	9.11	0.01	0.80	3.67	−3.28	2.93	2.88

1 is the model of mulberry–silkworm–fish and 2 is the model of rape–fish.

4. Discussion

Though each subsystem requires renewable and nonrenewable resources during production, the module of the fish pond receives the largest slices of emergy values. Renewable organic resources could also account to 62.5% to raise the yields of pond fish. When some of these units are assembled, the HMFS models of mulberry–silkworm–fish and rape–fish are not only able to cut down inputs, but also increase outputs by positive ecological feedback. For the mulberry–silkworm–fish model, 9.0 × 10^{12} sej silkworm excrement is poured into the fish pond and 1.2 × 10^{9} sej aquatic fecal pellets return to mulberry dyke, except 1.7 × 10^{15} sej mulberry leaves. Thus, it can obviously make full use of outputs and improve energy efficiency compared with each single module. The rape–fish system is mainly compensated by 1.2 × 10^{9} sej organic fertilizers from aquafarm, so it could reduce accessorial investments as a whole, while raising available products. Therefore, both of the two models could create high ecological benefits and economic values, as per previous studies [7,26,43,44].

In this paper, the two existing models were evaluated and contrasted from ecology and economy perspectives by emergy indices and emergy monetary values. We chose the EIR, ELR, ESI, SS, and WR for ecology assessment and the ELR and ROI for economic measure. Additionally, the emergy structure could also reflect the ecological values of HMFS in Table 7. The rape–fish inputs were more than mulberry–silkworm–fish inputs, and the same was true for nonrenewable resources. In model 1, many more renewable factors were introduced to promote internal circulation, especially human resources. Therefore, the system with three parts can better satisfy the requirements of sustainability, while the other model could generate more serviceable products.

Table 7. The emergy structure of mulberry–silkworm–fish and rape–fish.

Model	Emergy Inputs		Emergy Outputs	
	Renewable	Nonrenewable	Consumptive	Unserviceable
1	2.9×10^{16}	1.4×10^{16}	8.7×10^{16}	1.7×10^{15}
2	2.5×10^{16}	1.6×10^{16}	1.2×10^{17}	4.0×10^{16}

1 is the model of mulberry—silkworm—fish and 2 is the model of rape—fish.

For ecological indicators, the EIR, ELR and SS of model 1 are better than those of model 2, while the WR and ESI are in reverse. This indicates that the existent types have themselves superior ecological benefits and economic values, but model 1 possesses more sustainable characteristics than model 2 in terms of the mass flow and energy flux. The EYR reveals that inorganic resources in model 2 are exploited adequately to increase productivity, especially for chemical fertilizers and pesticides. The RIO also indicates that the second pattern could pay back excellent values for fixed investments.

As a result, the emerging rape–fish model of HMFS may obtain considerably better economic returns. Nonetheless, it has engendered stresses on the environment and carrying capacity due to its more inorganic resources, and lacks stability with a simplistic network of energy and material transfer. In addition, the crop straws of base have not been utilized rationally and the immediate and direct consequence of wasteful resources is serious pollution. Therefore, cultivating rapes and soybeans has replaced mulberry and silkworm subsystems and made it easier to alleviate conflict among local villagers in terms of the short supply of labor force, hence why the rape–fish model is an adaptive and evolutional pattern of HMFS, provisionally.

Driven by financial incentives, people in local sites tend to extend ponds with a decreasing proportion of base to pond. These behaviors may directly cut partial linkages of material and energy and even further cause deterioration of system constancy. Then, more industrial energies purchased from human society will be necessary in the next step. All of these performances will lead to an undesirable operation on ecological functions from HMFS. Therefore, HMFS is facing a compromised risk and threatening the sustainability of GIAHS to a certain degree [9,45].

This research only estimated the economic and ecological benefits by emergy structures and indices. In reality, emergy values are not great guarantees of legacy worth in terms of natural policies and the nature of commodities, such as necessities and luxuries [46]. In addition, as one of the GIAHS sites, HMFS plays an important role in society, culture, scientific research, demonstration, education, and others [13,47]. For example, it is full of original spirit properties and embodies many elements of Chinese civilization. The authors made a macro overall evaluation on the whole system regardless of its inner composition, such as the ratio of dyke to pond and the diversities of pond fish. These details are closely concerned with coordination and mechanism, and then significantly influence the evaluation.

5. Conclusions

It is evident that HMFS has considerably better ecological and economic profits with the circulation of materials and energies. The mulberry–silkworm–fish model needs 4.7×10^{16} sej solar emergies to release 8.7×10^{16} sej consumptive products and 1.7×10^{15} sej unserviceable products, while the rape–fish model could produce 1.2 × 10^{17} sej emergies with 4.2 × 10^{16} sej investments. However, the defects of these systems still exist, owing to unrenewable inputs and unserviceable outputs.

The emergy indices suggest that the mulberry–silkworm–fish model is slightly more stable than the rape–fish model, and the latter can achieve higher efficiency and income during agricultural procedure. Both types are superior in ecological benefits and economic values, especially in sustainability and efficiency, and the MFS models in the Zhujiang Delta also demonstrate the advantage of better efficiency, with coordination and balance abilities [43].

With the background of an ecological civilization, HMFS has prominent preponderances to achieve green development. However, with economic developments and labor cost rises, the circulation networks and mechanisms will gradually be diminished and more inorganic substances are coming into use as substitutes. Each of the patterns has presented its related transitions for acclimation. The integrated emergy and economic evaluation are used to identify and contrast various models, and then HMFS will arrive at the optimal pattern to coordinate economic growth and GIAHS perpetuation.

The empirical results show that the emerging rape–fish model could boost sustainable development and initiative conservation, while more nonrenewable resources are required. However, this could give directions for future research and protection. Many adaptive units have been tested and can serve as several sections of HMFS to form diverse multiple systems. Therefore, encouraging new modules and composite structures may be an effective entry point to conserve HMFS and achieve sustainability. Based on the local status, appropriate selection and combination require further studies, and the optimal structure will also be formed in the future. In addition, establishing reasonable HMFS models is in demand of technical support to maintain and develop them in terms of interaction and mechanism.

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References

1. Korn, M. The Dike-Pond Concept: Sustainable Agriculture and Nutrient Recycling in China. *Ambio* **1996**, *25*, 6–13.
2. Lo, C.P. Environmental impact on the development of agricultural technology in China: The case of the dike-pond ('jitang') system of integrated agriculture-aquaculture in the Zhujiang Delta of China. *Agric. Ecosyst. Environ.* **1996**, *60*, 183–195. [CrossRef]
3. Gu, X.; Lou, L.; Liu, M.; Min, Q. Review and Prospect of Studies on the Dyke-Pond System. *J. Nat. Resour.* **2018**, *33*, 709–720. (In Chinese)
4. Li, B.; Yuan, X.; Xiong, S.; Liu, H.; Yue, J.; Tao, D. Preliminary study on the landscape Dike-Pond System in the drawdown zone of urban area: A case study on the Hanfeng Lake in Kaixian of Chongqi. *J. Chongqing Univ.* **2013**, *6*, 51–54. (In Chinese)
5. Zhong, G. Distribution and development of the low-lying land in tropical and subtropical zones. *Trop. Geogr.* **1993**, *13*, 99–105. (In Chinese)
6. Zhong, G.; Cai, G. Dike (field)-pond Eco-agricultural Modes in China—Samples as Pearl River Delta and Yangtze River Delta. *Ecol. Econ.* **1987**, *3*, 15–20. (In Chinese)
7. Chen, Y.; Fei, J.; Jiang, Z. Theory and Practice of Mulberry-dyke and Fish-pond System. *Bull. Sericult.* **1995**, *26*, 4–10. (In Chinese)

8. Ding, N.; Jin, R.; Zhang, J.; Li, J.; Zhu, X.; Li, W.; Dong, K.; Wang, L. The Development and Protection of Mulberry-dyke and Fish-pond System in Shezhong Village, Huzhou City. *Mod. Agric. Sci. Technol.* **2015**, *9*, 334–335. (In Chinese)
9. Liu, S.; Jiao, W.; Min, Q.; Yin, J. The Influences of Production Factors with Profit on Agricultural Heritage Systems: A Case Study of the Rice-Fish System. *Sustainability* **2017**, *9*, 1842. [CrossRef]
10. Zhang, Y.; Li, X.; Min, Q. How to balance the relationship between conservation of Important Agricultural Heritage Systems (IAHS) and socio-economic development? A theoretical framework of sustainable industrial integration development. *J. Clean Prod.* **2018**, *10*, 553–563. [CrossRef]
11. Koohafkan, P.; Burlingame, B.; Dernini, S. Dynamic conservation of globally important agricultural heritage systems: For a sustainable agriculture and rural development. Sustainable Diets and Biodiversity: Directions and Solutions for Policy, Research and Action. In Proceedings of the International Scientific Symposium, Biodiversity and Sustainable Diets United Against Hunger, Fao Headquarters, Rome, Italy, 3–5 November 2012; pp. 319–321.
12. Min, Q.; Sun, Y. The concept, characteristics and conservation requirement of agro-cultural heritage. *Resour. Sci.* **2009**, *31*, 914–918.
13. Min, Q. GIAHS: A new kind of world heritage. *Resour. Sci.* **2006**, *28*, 206–208. (In Chinese)
14. Huzhou Mulberry-Dyke and Fish-Pond System: One of the Globally Important Agricultural Heritage Systems. Available online: http://csj.xinhuanet.com/2017-11/25/c136778190.htm (accessed on 25 November 2017).
15. Ding, N.; Jin, F.; Zhang, J.; Li, J.; Zhu, X.; Li, W.; Dong, K.; Wang, L. Mulberry-Base-Fishpond System of Linghu and the Protection and Utilization of the Agricultural Culture Heritage. *Bull. Sericult.* **2015**, *46*, 5–8. (In Chinese)
16. Hu, D.; Yan, J.; Liu, T.; Chen, J.; Yuan, S.; Wang, R. *Wetlands Ecosystems in Asia*, 1st ed.; Elsevier Science: London, UK, 2004; pp. 183–220, ISBN 9780444516916.
17. Ye, M. The Formation and Protection Value of Huzhou Mulberry-dyke and Fish-pond System. *Chin. Agric. Sci. Bull.* **2014**, *30*, 117–123. (In Chinese)
18. Wu, H.; Ye, M.; Lou, L.; Wang, L.; Yin, Y.; Zhang, Z. The Situation and Planning of Mulberry-dyke and Fish-pond System. *Bull. Sericult.* **2017**, *48*, 40–47. (In Chinese)
19. Li, Y.; Zhang, Y. The Research on the Mulberry-dyke and Fish-pond System Models of Mulberry (grass)-fish. *Soil Fertil. Sci. China* **1989**, *6*, 27–29. (In Chinese)
20. Zhong, G. The Structural Characteristics and Effects of the Dyke-pond System in China. *Outlook Agric.* **1989**, *18*, 119–123.
21. Zhong, G.; Wang, Z.; Wu, H. *Land-Water Interaction of Dyke Pond System*, 1st ed.; Science Press: Beijing, China, 1993; pp. 17–27, ISBN 9787030036162.
22. Zhong, G. The Research on Questions of Mulberry-dyke and Fish-pond System in the Pearl River Delta. *J. Ecol.* **1982**, *1*, 10–11.
23. Zhong, G.; Deng, H.; Wang, Z. *Dyke Pond System in the Pearl River Delta*, 1st ed.; Science Press: Beijing, China, 1987; pp. 55–127, ISBN 130313904.
24. Wu, H. The Ecological Function of Water Balance for Mulberry-dyke and Fish-pond System in the Pearl River Delta. *Trop. Geogr.* **1986**, *6*, 299–308. (In Chinese)
25. Wu, H.; Deng, H.; Liang, G. The Energy Flow of the Mulberry-dyke and Fish-pond System in the Pearl River Delta. *Trop. Geogr.* **1983**, *3*, 13–17. (In Chinese)
26. Zhao, Y.; Li, H.; Nie, C. Eco-economic Analysis on several Typical Models of Mulberry-dyke and Fish-pond System in the Zhujiang Delta. *J. South China Agric. Univ.* **2001**, *22*, 1–4. (In Chinese)
27. Li, M.; Nie, C.; Long, X. Constructing Evaluation Index of Ecological Environment Quality for Dyke Pond System. *J. Agric. Environ. Sci.* **2007**, *26*, 386–390. (In Chinese)
28. Li, B.; Xiao, H.; Yuan, X.; Martin Willison, J.; Liu, H.; Chen, Z.; Zhang, Y.; Deng, W.; Yue, J. Analysis of Ecological and Commercial Benefits of a Dike-pond Project in the Drawdown Zone of the Three Gorges Reservoir. *Ecol. Eng.* **2013**, *61*, 1–11. [CrossRef]
29. Li, B.; Yuan, X.; Xiao, H.; Chen, Z. Design of the Dike-pond System in the Littoral Zone of a Tributary in the Three Gorges Reservoir, China. *Ecol. Eng.* **2011**, *37*, 1718–1725. [CrossRef]
30. Yue, J.; Yuan, X.; Li, B.; Ren, H.; Wang, X. Emergy and Exergy Evaluation of a Dike-pond Project in the Drawdown Zone (DDZ) of the Three Gorges Reservoir (TGR). *Ecol. Indic.* **2016**, *71*, 248–257. [CrossRef]

31. Odum, H. Environmental Accounting—Emergy and Environmental Decision Making. *Child Dev.* **1996**, *42*, 1187–1201.
32. Lan, S. *Emergy Analysis for Eco-Economic System*, 1st ed.; Chemical Industry Press: Beijing, China, 2002; pp. 17–20, ISBN 9787502538354.
33. Lan, S.; Qin, P. Emergy Analysis for Ecosystem. *Chin. J. Appl. Ecol.* **2001**, *12*, 129–131. (In Chinese)
34. Ulgiati, S.; Odum, H.; Bastianoni, S. Environmental Loading and Sustainability an Emergy Analysis of Italy. *Ecol. Model.* **1994**, *73*, 215–268. [CrossRef]
35. Yan, M. Emergy Analysis and Sustainable Development Research on Eco-economic System in Tibet. *J. Nat. Resour.* **1998**, *24*, 116–125. (In Chinese)
36. Zhang, L.; Tang, S.; Hao, Y.; Pang, M. Integrated Emergy and Economic Evaluation of a Case Tidal Power Plant in China. *J. Clean. Prod.* **2018**, *182*, 38–45. [CrossRef]
37. Qi, W.; Deng, X.; Chu, X.; Zhao, C.; Zhang, F. Emergy Analysis on Urban Metabolism by Counties in Beijing. *Phys. Chem. Earth Parts A/b/c* **2017**, *101*, 157–165. [CrossRef]
38. Li, Z.; Luo, X.; Zhang, J.; Qiu, W. Green Economy Growth of Agriculture and Its Spatial Convergence in China Based on Energy Analytic approach. *China Popul. Resour. Environ.* **2016**, *26*, 150–1159. (In Chinese)
39. Luo, S. *Agricultural Ecology*, 1st ed.; Chinese Agricultural Press: Beijing, China, 2001; pp. 146–160, ISBN 9787109133075.
40. Wen, D. Energetics Study of the Agroecosystems in Northeastern China, I. Energy Flow through a Typical Agroecosystem in Songnen Plain. *Chin. J. Ecol.* **1986**, *4*, 3–7. (In Chinese)
41. Zhong, Z.; Weng, B.; Huang, Q.; Huang, X.; Chen, Z.; Feng, D. Evaluating the ecosystem sustainability of circular agriculture based on the emergy theory: A case study of the Xingyuan circular agriculture demonstration site in Fuqing City, Fujian. *Acta Ecol. Sin.* **2012**, *32*, 5755–5762. (In Chinese) [CrossRef]
42. Corcelli, F.; Ripa, M.; Ulgiati, S. Efficiency and Sustainability Indicators for Papermaking from Virgin Pulp—An Emergy-based Case Study. *Resour. Conserv. Recycl.* **2018**, *131*, 313–328. [CrossRef]
43. Lu, H.; Peng, S.; Lan, S.; Chen, F. Energy value evaluation of dike-pond agro-ecological engineering modes. *Chin J. Appl. Ecol.* **2003**, *14*, 1622–1626. (In Chinese)
44. Zhang, J.; Zhong, G.; Wu, H. Analysis of harmonizing human and geographic environment relationship in the dike-pond econ-ecological system. *Ecol. Sci.* **1993**, *2*, 55–59. (In Chinese)
45. Jiao, W.; Fuller, A.M.; Xu, S.; Min, Q.; Wu, M. Socio-Ecological Adaptation of Agricultural Heritage Systems in Modern China: Three Cases in Qingtian County, Zhejiang Province. *Sustainability* **2016**, *8*, 1260. [CrossRef]
46. Wu, C.; Hua, B.; Wang, Y. Import substitution elasticity and price conduction effect of consumer goods. *Inq. Econ. Issues* **2014**, *10*, 1–10. (In Chinese)
47. Min, Q.; He, L.; Sun, Y.; Zhang, D.; Yuan, Z.; Xu, Y.; Bai, Y. On the value, conservation and sustainable development of GIAHS pilot sites in China. *Chin. J. Eco-Agric.* **2012**, *20*, 668–673. [CrossRef]