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The Emergy Evaluation to a Novel Aquaponics Ecosystem in Deep Reservoir of the Middle Reaches in Yangtze Basin

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Abstract: *The aquaculture was an important industry and far exceeded the estimated carrying capacities of the voluminous reservoirs in China, which derived the problem of overfishing in public waters at the same time. To compare the conventional intensive cage fish farming system in deep reservoir, the aquaponics ecosystem was a novel method, technology and ecological engineering, which was designed suitability key to settle social issues as the lack of arable land area and degradation with water scarcity on agricultural production in widespread world. The objective of this study was to describe aquaponics ecosystem based on emergy theory during operating conditions, inputs (purchase resources, steel, plants and fry) and outputs (aquatic vegetables, aquatic product and water treatment) and their relationship for a multi-level aquaponics model operation in a deep reservoir, a tributary of Yangtze basin. Our results showed that the system was driven primarily by imported emergy from the economy such as labor, purchase resources, steel, plants and fry. In comparison with other aquaculture products, aquaponics ecosystem production was supported by a higher emergy yields ratio (3.964), a lower environmental loading ratio (5.623) than other forms of aquaculture; however, the emergy yield ratio was 0.705 and the emergy density was 3.73E+17 SEJ/yr/ha. The aquaponics ecosystem had a lower environmental loading, a fine environmental influence, a high yield and better feedback due to design and allocate integrated self-system structure with producer, consumer and microcomposer, which reduced motor fuel use, labor, and services with conventional intensive cage fish farming system.*

Keywords: *Ecological Engineering Design, Aquaponics Ecosystem, Emergy Evaluation*

1. Introduction

Aquaculture was globally the fastest growing sector of agriculture that needed to be sustainable and must also meet bioeconomic demands. The problem of overfishing in public waters had led to aquaculture increasingly gaining importance for global fish supply. Currently, aquaculture continued to be the fastest-growing animal food-producing sector, already generating 50 % of global fish supply FAO-Food and Agriculture Organization of the United Nations [1]. Corresponding, the aquaculture was an important industry in China, the gross fisheries production was 2.08×10^3 billion yuan in 2014 year, and the Freshwater aquaculture gross production was 0.57×10^3 billion yuan, about 29.3×10^6 ton in 6.1×10^6 hectare [2]. The cage aquaculture subsector had grown very rapidly during the past 20 years and was presently undergoing rapid changes in response to pressures from globalization and a growing global demand for aquatic products [3]. Considering that most of the energy supply was derived from hydroelectric sources, the government had been strongly encouraging cage farming in federal water bodies.[4,5]

The total amount of the reservoir was about 47842 in main and tributary stream of the Yangtze basin, which could form fine biotope aquatorium for cage farming, but derived the problem of overfishing in public waters at the same time. The number of cages had far exceeded the estimated carrying capacities of the voluminous reservoirs. Recent studies had predicted that fish farming was often changed the structure and function of aquatic ecosystems [6], leaded to eutrophication [7], deteriorated water

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pollution [8] plankton community structure and phytoplankton miniaturization [9]. During the cage farming region, the dissolved oxygen usual decreased in the upper water layer, the chemical oxygen demand, ammonia nitrogen and inorganic phosphate always unmorally increased, the sediment deposition was enriched nitrogen, phosphate, Sulphur and organic matter [10,11]. However, the aquaculture suffered significantly from the effect of biofouling. Biofouling on nettings could lead to a rapid net aperture occlusion [12] and, thus, to significant changes of the porosity of net cages. Consequently, the water exchange across nettings would be reduced, causing a reduction of water quality in the net cage. Poor water quality could affect fish comfort and behavior, and cause economic losses for the fish farming. The biofouling also added considerable hydrodynamic forces to the net cage, which threatened the stability of the aquaculture structures and reduces the life span of mooring lines [13]. Given the above, the biofouling on net cages was detrimental to fish health and production and can cause equipment failure. Furthermore, large dimensions cages may also affect the structure of zooplankton in the water column and phytoplankton brought miniaturization and other issues. [14,15]

From the perspective of ecosystem evaluation, fish framing could be seen a system of sustainable. Evaluations must be performed to guide the establishment of regulations. Integrated fish framing was a multiplex system including external environment, ecosystems, socioeconomic situation and mankind's activity essential. To reconcile conflicts between economic development and environmental protection, a science-based evaluation system known as emergy considered both values within a common measure. In this study, we made analysis and evaluation according to the emergy theoretics, and also discussed the sustainable of the fish framing system from energy flow and materials circulation. Emergy regarded both the work of nature and that of humans in generating products and services, was a measure of the available energy of one type used up in transformations directly and indirectly to produce a service or product [16]. Emergy analysis was a type of embodied energy analysis that provides common units (solar emergy joules [sej]) for the comparison of environmental and economic goods by summing the energy of one type required directly or indirectly for the production of goods [17]. Doing so allowed comparisons of different qualities of energy and materials with the same unit of measure and provides an understanding of the relationship between the environment and industries that other analysis methods did not currently provide [18]. This approach was chosen for an analysis of oyster aquaculture because cultivation of oysters was driven by biotic and abiotic factors. Emergy analysis offered insights about the links between the estuarine environment and the oyster industry. Environmental sustainability could then be evaluated quantitatively by comparing emergy inputs from the human economy to the renewable emergy supplied by the environment. Presumably, systems that utilized more renewable emergy had a lower environmental impact and were considered more sustainable because a greater proportion of their basis was replenished as fast as it was used.

2. Methods

2.1 Characteristics of the studied area

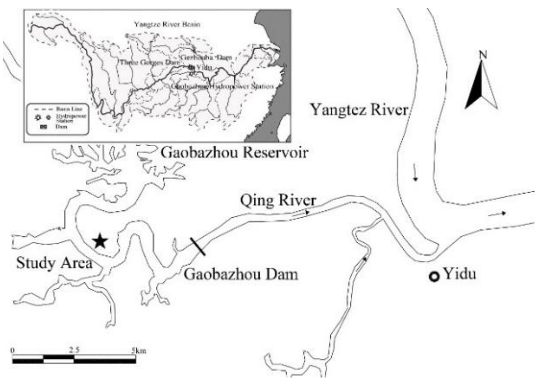

Fig.1 Study area position in the Yangtez river basin

The present study was carried out in a reservoir, the west of Yidu city in Hubei province (E 111°18′14.94″ N 30°23′38.25″), located in Qing river basin, a tributary of the Yangtze river (fig. 1). Local climate mainly dominated by atmospheric circulation and terrain conditions. The climate characteristics was monsoonal with radial and vertical distribution, hot and rainy during the same season. The region was characterized by north subtropical humid monsoonal climatic conditions with average annual precipitation of 1100-1500 mm, average annual temperature of 16.7 ℃, effective solar radiation average

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annual 2.6 kWh/m^2/day, sunshine duration average annual about 1738.9 h.

2.2 Description of the design systems

In 2021, the novel aquaponics system was established in an area on a bay in Gaobazhou reservoir. The novel aquaponics system required the flows exchange unblocked on the surface of water region, water level fluctuant slight, water deep suitable moderately about 7-9 m because the bottom of cage would touch the sludge form bad affection of residue and dejection with too shallow and residue and dejection would anaerobic decomposition form bad affection of water quality in thermocline with too deep. The novel aquaponics system was made up of floating bed and net cage, which the floating bed could be planted vegetables or flowers on the surface and net cage could be raised fish or aquatic products under water. The roots of aquatic plant were through the bed and spread out in water which link with two space (fig. 2). The floating beds were joined by each single unit. The single unit was designed square structure with 1m^2. The structure above water of single unit had 16 pits with planted vegetables or flowers (fig. 3 a). The structure under water of single unit had 9 pits with hydrobiont (such as mussel (*Mytiloidea*))and fish eggs (fig. 3 b). The single unit could be assembled many kinds type and suspended net periphery with anchor immobilization.

The novel aquaponics system occupied 60 m^2 (length 10m, width 6m) with 52 units. The floating bed was 52m^2 and water 8m^2. During this aquaponics system, the alternative choice in floating bed were Cyperus (*Cyperus alternifolius* L. ssp. *flabelliformis* (Rottb.) Kükenth.), Spiked Loosestrife herb (*Lythrum salicaria* L.), India Canna (*Canna generalis* Baliley), Crested Iris (*Iris tectorum* Maxim.), Wild rice stem (*Zizania latifolia* (Griseb.) Stap f), total 736 occupied 46m^2, and Water Spinach (*Ipomoea aquatica* Forsk) total 96 occupied 6 m^2. At the same time, the Hornwort (*Ceratophyllum demersum* L.) was planted during free aquatorium. The productions were Grass Carp (*Ctenopharyngodon idella*), Bighead Carp (*Hypophthalmichthys nobilis*), Silver Carp (*Hypophthalmichthys molitrix*), Crucian Carp (*Carassius carassius*), because this kind manner of programming was taken full advantage of food chain affection, fish stocks could feed the wrack and excrement to clean water and make maximization utilization of material resources during internal system, and also as much as used the space under water. The amount of fries put on the aquatic ecosystem were 240 Bighead Carp (500 g each), 60 Silver Carp (500 g each), 30 Crucian Carp (300 g each), 10 Grass Carp (500 g each). For farming systems, fingerlings were introduced in the early spring in March. The whole growth period lasted about eight months from March to November. All the fishes were caught for market at the end of November before the temperature of the water became too low. In addition, bleaching powder and trichlorphon were used for water disinfection and prevention of diseases.

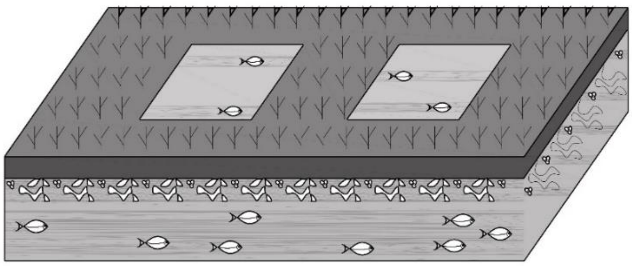
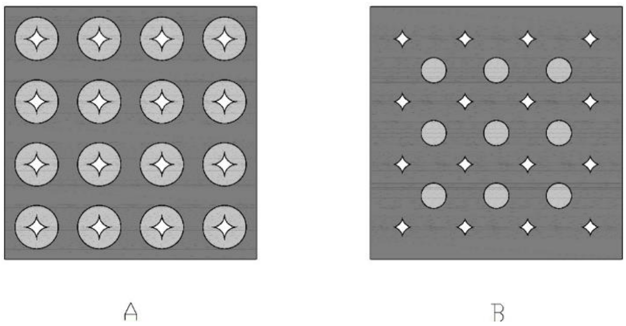


Fig.2 The structure of aquaponics systems



(A the structure above water, B the structure under water)

Fig.3 The structure of the floating bed

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2.3 Emergy analysis

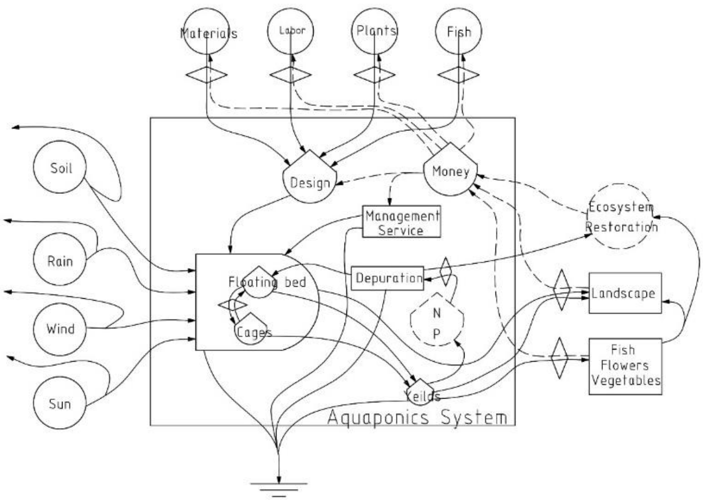

Fig.4 Conceptual framework for evaluating the aquaponics systems

This study followed the methodology set forth by Odum [16]. The classifies emergy of the aquaponics system were nature resources (local, from natural contributions) (E), society purchase resources (external, purchased from the economy) (S), system yield resources (Y) and system feedback resources (F). Pathways of the aquaponics system diagram of processes drawn to organize evaluations and account for all inputs to and outflows from processes may indicate casual interactions, show material cycles, or carry information, but always with some energy (fig. 4). The S group comprises resources from outside the system (e.g. electricity, formulated feeds), while the E group refers to natural contributions available within the system boundaries (e.g. wind, solar energy). According to the methodological change proposed by Agostinho et al. [19], the E and S groups were split further into renewable (R) and non-renewable (N) resources. Total emergy input within the system was designed by I. The renewability fraction values came from previous work [19]. To avoid double-counting, only the largest input from nature was used. The following step is the drawing of a table (table. 1) of the actual flows of materials, labor and energy; the fluxes, expressed in common units, are then converted into solar emergy by multiplication by transformities (or alternative conversion factors). Transformities for different resources are taken from peerreviewed literature [20] and cited accordingly within the table footnotes. We used the solar emergy global baseline of 15.83×10^{25} sej [21]. We verified that this baseline was used throughout our selected transformities and adjusted those that were not on the same baseline as suggested by Campbell [22]. Once the relative contributions of emergy were accounted, emergy indicators were calculated and used to answer questions about system sustainability. A number of different indices can be obtained by the application of emergy analysis supporting a concise interpretation of the results. Emergy indicators are calculated to understand the functioning of the system in regards to emergy. These indicators are based on quantitative data of the various flows of emergy within the analyzed system, such as: Emergy density (ED), Emergy yields ratio (EYR), Environmental loading ratio (ELR), Emergy sustainability index (ESI) and Emergy feedback ratio (EFR). The calculation and Formula as follow:

Emergy density (ED) = Total Emergy Investment (I) / Area (1)

Emergy yields ratio (EYR) = Total Emergy Investment (I) / system yield resources (Y) (2)

Environmental loading ratio (ELR) = Emergy renewable resources (R) / Emergy non-renewable resources (N) (3)

Emergy sustainability index (ESI) = Emergy yields ratio (EYR) / Environmental loading ratio (ELR) (4)

Emergy feedback ratio (EFR) = Emergy system feedback resources (F) / Emergy society purchase resources (S) (5)

Table 1 The emergy analysis of the aquaponics systems

Item		Data	Unit	Transformity (SEJ/unit)	Emergy flow (SEJ /yr)	Recycle rate
E	Solar	1.82E+11	J	1	1.82E+11	1
	Wind	1.25E+10	J	2.51E+03	3.14E+13	1
	Rain, chemical	3.41E+08	J	3.12E+04	1.06E+13	1
	Rain, geopotential	6.82E+05	J	4.66E+04	3.18E+10	1
	River water	1.81E+07	J	8.13E+04	1.47E+12	1
S	Plastic	1.22E+05	g	5.85E+09	1.43E+14	0.05
	Fishnet	9.00E+03	g	3.14E+09	5.65E+12	0.05
	Steels	3.06E+05	g	1.30E+10	7.98E+14	0.05
	Young fry	1.15E+03	￥	2.42E+11	2.78E+14	0.05
	Plants	3.54E+03	￥	2.42E+11	8.57E+14	0.27
	Labour	5.00E+02	￥	2.42E+11	1.21E+14	0.1
Y	Aquatic vegetables	240	kg	3.48E+09	8.35E+14	
	Bighead Carp	265	kg	3.79E+06	1.00E+12	
	Silver Carp	65	kg	3.79E+06	2.46E+11	
	TN	1230	kg	4.19E+09	5.15E+15	
	TP	17	kg	2.00E+10	3.44E+14	
	COD	1567	kg	1.53E+09	2.40E+15	
F	Aquatic flowers	220	kg	3.48E+09	7.65E+14	
	Aquatic roots	14	kg	3.48E+09	4.87E+13	
	Potamomya	48	kg	1.50E+05	7.20E+09	
	Birds	9	Sp.	2.00E+12	1.80E+13	

2.4 Data collection

We collected data by touring the facilities in June 2022, estimating resource use and measuring mass of aquaculture gear. We interviewed aquaculturalists about fuel use, and energy consumption (electrical costs). Raw data on fluxes maintaining the fish farm are derived from four different sources: (1) solar radiation and wind intensity from previous studies found in the literature; (2) rain quantity and tide excursions from direct data gathering on the Qing river territory; (3) goods and services and fingerlings from farmers interviews; and (4) feed quantity and biomass reared from the model as calculated outputs.

3. Results and discussion

3.1 Emergy analysis

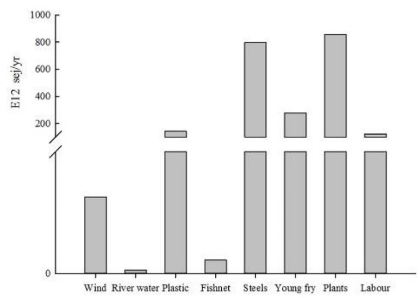

Fig.5 The Structure of emergy inputs for the aquaponics systems

As shown in fig. 5, the main resource inputs for aquaponics systems, reflected the emergy structure in a more detailed way. According to the classification, environmental renewable emergy resources are comprised of two parts, local renewable resources (sunlight, wind and rainfall) and renewable resources input from outside (river water). Thus, to avoid double counting of local renewable resources, only the item wind resources emergy the highest value was considered in the total amount of emergy, 3.14E+13 SEJ/yr. The renewable environmental resources input from outside was 1.47E+12 SEJ/yr. During the society purchase resources, steel, plants and fry were occupied most in total input resources emergy about

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36.27%, 38.94%, 12.65%, respectively. The material of the floating bed and nets could use about 5 years and some material could reuse. So the society purchase resources had 1.90 E+15 SEJ/yr non-renewable resources and 3.05 E+14 SEJ/yr renewable resources. The cycle rate was reference from Yue et al. [23]. The total emergy was .24 E+15 SEJ/yr, so the emergy density (ED) was 3.73E+17 SEJ/yr/ha, to compare other system in domestic researchers, the ED was higher than Nansi Lake area, similar to eel system and mullet system in Pearl River Estuary, lower than weever system.

The yield of the aquaponics system were aquatic vegetables (Water Spinach), aquatic product Bighead Carp and Silver Carp, water treatment (TN, TP, COD). The emergy of the yield from the aquaponics system was 8.35 E+14 SEJ /year, 1.00 E+12 SEJ /year, 2.46 E+11 SEJ /year, 7.89 E+15 SEJ /year, respectively. The emergy indicators in this study were shown in table 1. The EYR was 3.964, indicating that the system had more production than investment. To compare with some studies in domestic, the aquaponics system was higher than the Eel,Mullet and Weever in Peal river estuary, at the same time higher than Cage system, Intensive pond system and Semi-natural extensive system in Nasi lake area, but little lower than the organic rice-duck mutualism system in Yangtze river estuary. To compare with some studies in foreign, it was higher than T.mariae, SMS, S.aurata and Intensive fish system, and similar with Semi-natural extensive system. The ELR of the aquaponics system was 5.623, between 3 and 10, indicating that the system had moderate environmental impacts. To compare with some studies in domestic, the aquaponics system was lower than the Eel, Mullet and Weever in Peal river estuary, but higher than Cage system, Intensive pond system and Semi-natural extensive system in Nasi lake area, the organic rice-duck mutualism system in Yangtze river estuary. To compare with some studies in foreign, it was lower than T.mariae, and similar with SMS, S.aurata and Intensive fish system, but higher than Semi-natural extensive system. The ESI of the aquaponics system was 0.705. The higher the ESI was, the more sustainability the emergy in the system had. To compare with some studies in domestic, the aquaponics system was higher than the Eel, Mullet and Weever in Peal river estuary, but lower than Cage system, and Semi-natural extensive system in Nasi lake area, the organic rice-duck mutualism system in Yangtze river estuary, similar with Intensive pond system. To compare with some studies in foreign, it was higher than T.mariae, and similar with SMS, S.aurata and Intensive fish system, but lower than Semi-natural extensive system. The system also had a fine feedback ratio (0.38).

3.2 Economical benefits

The investment of aquaponics system were fishnet, floating bed (plastic fixed with steels), young fry and labour, accounting with depreciation, the total investment was 2970 ￥. The production were aquatic fish and vegetables, the total income was 5880 ￥. As account, the net production was 2910 ￥ from 60 m^2 (the details shown in table 2). The Water Spinach was harvested 240 kg, the maximum production was 0.8 kg/m^2 in 3 days. The Bighead Carp was harvested 300 kg and Silver Carp was 90 kg. From the May to December, the rate of living Bighead Carp was 99.6%, the average weight was 900 g each, and the rate of living Silver Carp was 98%, the average weight was 600 g each (the change of growth shown in table 3). The price of market condition was 4 ￥/kg (Water Spinach), 14 ￥/kg (Bighead Carp), 8 ￥/kg (Silver Carp), respectively.

Table 2 Economic costs and benefits of aquaponics system

Investment (￥)					Earnings (￥)			Interest (￥)
fishnet	floating bed	fry	labour	depreciation	vegetables	Bighead Carp	Silver Carp	
600	6000	1150	500	1320	960	4200	720	
		2970				5880		2910

Table 3 The fish growing process in the aquaponics system

	Jun.	Jul.	Aug.	Sep.	Oct.
Bighead Carp (g/each)	600	800	1000	1300	1500
Silver Carp (g/each)	400	500	600	900	1000

4. Conclusions

The aquaponics system was the good focus to solve the ecology environment problem and people's livelihood in the deep reservoir. The conventional fish farming methods could increase the income of the

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fisherman, but that would make water pollution because of the large density and widely overspreading, so the local government must to suppress the conventional cages which would make negative action to fisherman income. The aquaponics system developed the Aquaculture, kept the water quality to normal and increased the income, which bring in collaborative benefit to society, environment and peasantry.

In this study, accounting to the emergy evaluation, the result shown that had a lower environmental impact, higher use of renewable sources of emergy and better feedback in comparison with other aquaculture products. The model of the aquaponics system, which was made up of the plants, birds, fish and eco-cage, was a novel and sustainable system to compare the conventional fish farming methods. As the results of the aquaponics system bring in affection, we would structure another system about 1000 m^2 with vegetables, flowers and woods, while feed fish for economy and some others for sightseeing in future. The huge system could be made up with farm, garden, woods and league on the surface, which was a multiplex system formed with agriculture production, aquatic production, waterfowl habitat, flower base, tourism, entertainment, study and research.

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