Water quality and emergy evaluation of two freshwater aquacultural systems for eutrophic water in the Controlling by Biological Chains

L M Xi¹, C Q Liu², D F Liu¹, W L Huang¹ and Y Sun¹

¹College of Environmental Science and Engineering, Nankai University, Tianjin, China
²College of Life Science, Hebei University, Hebei, China

E-mail: liucunqi@sina.com

Abstract. According to the ecological restoration theory, this experiment establishes aquaculture systems controlled by biological chains in both Xiaoxidian area and Dujiadian area of Baiyangdian Lake separately in order to improve the environment and bring economic benefits. The appearance of emergy theory provides a new method for the quantitative analysis of ecological economic system. Based on the analysis of emergy theory, this thesis compares the eco-economic systems under different polyculture models between Xiaoxidian area and Dujiadian area. The result demonstrates that Xiaoxidian ecological system is of high emergy transformity with higher emergy output and economic income per unit area compared with Dujiadian area. While Dujiadian area has higher emergy yield Rate and lower Environment Load Rate. So Dujiadian area is more sustainable due to the overload non-renewable energy of Xiaoxidian area devoted by human. Therefore, it will be better if we adjust and optimize the management of aquaculture system in Xiaoxidian area in order to find a stable equilibrium point between environmental sustainability and economic benefits.

1. Introduction

For a long period of time, people took energy as a common scale to analyze various systems. Energy analysis, however, has been effective only in the analysis of the same kind of energy. There are fundamental differences on the quality and value of different energy. That cannot be simply modified and compared [1]. So it is impossible to measure and express the essential relationship between natural environment resources and economy through general energy unit. In 1980s, the international ecological community put forward a new concept theory of emergy and a new analysis method (by multiplying a series of emergy transformity with emergy value of every emergy level to get emergy based on “Solar Joule” as unit, in order to analyze energy characteristics and sustainable development condition of system) to develop a new way for the quantitative analysis of ecological system and eco-economic system [2].

The water bloom in lakes caused by eutrophication has attracted more and more attention. Ecological restoration has become an important research direction in the area of water ecology under this kind of situation and the biomanipulation method is a very important method of ecological restoration. The theory of Biomanipulation is traditionally divided into classical [3-5] and non-classical theory [6]. Non-classical Biomanipulation Theory is the direct control of cyanobacteria
[7] by adjusting the filter feeding fishes. In addition, ecological restoration project of submerged plant mainly removes nutrients from water by the absorption and storage of aquatic organisms together with substrate sludge solidification and harvest [8]. With the further research of biomanipulation methods, the method of biological chain control springs up [9]. It controls eutrophication through the combination of submerged macrophytes, benthic animal and filter feeding fish and improves the environment without secondary pollution. The method of biological chain control solves the problem from the root by creating good economic benefits and improving the living standard of local people which lay solid mass foundation for the promotion of this method. According to the theory of biological chain control, our experiment establishes the ecological compound aquaculture system in Xiaodidian area and Duiadian area of Baiyangdian Lake by changing aquaculture methods and planting submerged plants in order to harvest on both environmental and economic benefits. The polyculture method of both silver carps and bighead carps can control algae [10] and bring good economic benefits. At the same time, considering economic development and industrialization of local area, we try to make full use of ecological niche to achieve maximum economic benefits. So we manage to improve the utilization efficiency of regional submerged macrophytes and benthic organisms by adding crab (Eriocheir sinensis) and planting water chestnut (Trapa bispinoso Roxb) in crab breeding area. Simultaneously, Harvest water chestnut and Myriophyllum spicatum to eliminate nitrogen and phosphorus from the aquatic ecosystem. The study compares two kinds of aquatic ecosystems through the method of energy analysis from the perspective of both system conversion efficiency under different models and their effects on the sustainable development of Baiyangdian Lake to analyze the characteristics of two ecological systems, thus providing references for the managers and users of Baiyangdian Lake to make decisions for management and use.

2. Materials and methods

2.1. Research site overview
Baiyangdian Lake is the largest freshwater shallow lake in Northern China with severe eutrophication and frequent water bloom dominated by Chlorophyta and Cyanophyta. The evaluation of Baiyangdian Lake is based on trophic state index of modified (TSIM) and dominant species evaluation. According to the results of the evaluation, the level of nutrition is eutrophication which means that the system remains to be repaired. Aquaculture is an important factor which affects the water environment of Baiyangdian Lake. There are 9,615.8 acres of net enclosure culture, 4,602.1 acres of pond culture, 727 acres of cage culture and 20,514 acres of reclamation dam in Baiyangdian Lake (latest statistics from Marine and Fisheries Research Institute of Hebei Province and Aquatic Products Bureau of Anxin County). Most of the aquaculture modes get high output by feeding which leaves serious impact on water quality. Therefore, it is an urgent task to optimize the cultivation mode and protect the water quality influenced by cultivation.

2.2. Research sample area
Mode 1: The place (12 hectares) locates in Xiaodidian area of Baiyangdian which is divided into 2 regions with enclosure. Zone A is a growing area of 4 hectares for 1250 kg water chestnut (Trapa bispinoso). Zone B is a growing area of 8 hectares for Myriophyllum spicatum with the density of 20 strains per square meter; 16000 silver carps (Hypophthalmichthys molitrix) (100 g/tail), 4000 bighead carps (Aristichthys nobilis) (100 g/tail), 1500 kg Cipangopaludina cahayensis, 96000 Eriocheir sinensis and 180000 Macrobrachium nipponenses, together with native mollusk specie freshwater snail (Radix auricularia).

Mode 2: The place (70 hectares) locates in Duiadian area of Baiyangdian Lake with little hydrophyte. It mainly breeds silver carps, bighead carps, Eriocheir sinensis and Cyprinus carpio which are all fed by artificial diet with little benthic organism.

The environmental characteristics of two ecological systems are listed in table 1.
Table 1. The characteristics of two aquacultural ecosystems.

| Parameters              | Mode 1 (Experimental Area)                          | Mode 2 (Control Area)                          |
|-------------------------|----------------------------------------------------|------------------------------------------------|
| Location                | Xiaoxidian (38°51’N,115°58’E) closed aquaculture pond | Dujiadian (38°51’N,115°58’E) closed aquaculture pond |
| Mobility of Water Area (hm²) | 12                                                | 70                                              |
| Depth (m)               | 2~4                                                | 2~4                                             |
| Aquatic Plants          | Myriophyllum spicatum and Trapa bispinosa with the coverage rate of 40% in experimental area | no                                              |
| Community Composition   | Eriocheir sinensis, Hypophthalmichthys molitrix, Aristichthys nobilis, Macrobrachium nipponense, Cipangopaludina cahayensis and Radix auricularia | Eriocheir sinensis, silver carps, bighead carps, Macrobrachium nipponense, Cyprinus carpio and Cipangopaludina chinensis |
| Delivery Volume         | 20000 fishes that ratio of silver carps and bighead carps is 4:1, 1500 kg Cipangopaludina chinensis, 96000 Eriocheir sinensis, 1.8×10^5 Macrobrachium nipponense | 60000 fish fry of silver carps and bighead carps (3:1), 1.125×10^5 Eriocheir sinensis, 2×10^5 kg Cipangopaludina chinensis |
| Delivery Volume of Baits| 2000 kg concentrated fish feed, 1500 kg spiral shell (fish bait), 7500 kg maize, 2000 kg potato (crab bait) | 2×10^5 kg spiral shell (fish bait & production), 5000 kg potato (crab bait), 3000 kg maize (crab bait) |

2.3. Water quality and trophic state index of modified (TSIM)

The measurement of water quality was done between April 8th, 2013 and October 8th, 2013.

Water transparency was measured with a 20-cm diameter black and white Secchi disk [11].

Measure Total Phosphorus by the ammonium molybdate spectrophotometric method (GB/T11893-1989 of China) [12]. Measure Chlorophyll-a according to ISO10260:1992(E) Water quality-Measurement of biochemical parameters-Spectrometric determination of the chlorophyll-a concentration. TSIM is used to describe the nutritional status of water body based on the parameters such as Total Phosphorus concentration, chlorophyll-a content and transparency of water [13, 14].

\[
\text{TSIM(SD)} = 10 \times \frac{[2.46+(3.69-1.53 \times \ln SD)]}{\ln 2.5}
\]

\[
\text{TSIM(TP)} = 10 \times \frac{[2.46+(6.71+1.15 \times \ln TP)]}{\ln 2.5}
\]

\[
\text{TSIM(Chla)} = 10 \times \frac{(2.46+\ln \text{Chla})}{\ln 2.5}
\]

\[
\text{TSIM} = [\text{TSIM(Chla)} + \text{TSIM(TP)} + \text{TSIM(SD)}] / 3
\]

TSIM<30 represents poor nutrition state; 30<TSIM<50 represents middle nutrition state; TSIM>50 represents eutrophication state. Among them, eutrophication state can be divided into three levels, 50<TSIM≤60 for mild eutrophication; 60<TSIM≤70 for moderate eutrophication; TSIM>70 for severe eutrophication. The higher the index is, the higher the nutritional status of water body will be.

2.4. Emergy analysis method

Both the demonstration area and control area selected by this research are reclamation dam with clear boundary. It is easy to count resource input, resource output and emergy flow and suitable for the use of emergy analysis method to reveal the differences of emergy transformation between two systems. At the same time, we could also analyze the resource utilization efficiency and environmental effects of two aquaculture systems from the perspective of emergy in the aspect of investment, production and marketing. Then the result provides theoretical basis for reasonable application and proper promotion.
of aquaculture mode.

Firstly, we need to define the boundaries of two systems and main energy sources before the emergy analysis of ecological systems. Then we could determine the main components of the systems by defining the emergy flow within each part of the system. Finally, two types of emergy flow diagram (system with aquatic plants and system without aquatic plants) can be drawn according to the communication between the ecological system and social economic system. According to different indicators, system characteristics and sustainable development condition of different systems can be analyzed [15]. Emergy flow diagram of two aquaculture models is shown in figure 1.

![Emergy Flows of Two Aquaculture Ecosystems](image)

**Figure 1.** Emergy flows of two aquacultural ecosystems.

### 2.5. Emergy index

Emergy indexes is shown in table 2.

| Parameters (and abbreviations) | Calculating formula | Meaning |
|-------------------------------|----------------------|---------|
| Solar Emergy Transformity     | applied solar emergy (sej)/energy or quality (J or kg) | The amount of solar energy contained in each unit of energy or quality; an indice to measure energy qualitative level. |
| Emergy Yield Rate (EYR)       | Yield emergy(Y)/ input emergy value(U) | degree of industrialization for ecological system; the higher the value of EYR, the higher the... |
3. Results and analysis

3.1. Water quality
The comparison of water quality are shown in table 3.

|                  | Apr. 8th | Jun. 8th | Jul. 8th | Aug. 8th | Sept. 8th | Oct. 8th |
|------------------|----------|----------|----------|----------|-----------|----------|
| **TP (mg/L)**    |          |          |          |          |           |          |
| Modal 1          | 0.07     | 0.13     | 0.12     | 0.05     | 0.07      | 0.04     |
| Modal 2          | 0.08     | 0.27     | 0.12     | 0.13     | 0.06      | 0.05     |
| **SD (m)**       |          |          |          |          |           |          |
| Modal 1          | 0.60     | 0.50     | 0.46     | 0.31     | 0.33      | 0.39     |
| Modal 2          | 0.31     | 0.22     | 0.29     | 0.11     | 0.09      | 0.12     |
| **Chla (mg/L)**  |          |          |          |          |           |          |
| Modal 1          | 16.40    | 13.36    | 17.62    | 23.16    | 25.05     | 24.27    |
| Modal 2          | 15.94    | 23.56    | 26.51    | 62.05    | 54.58     | 85.51    |
| **TSIM**         |          |          |          |          |           |          |
| Modal 1          | 64.43    | 67.18    | 68.24    | 68.20    | 69.13     | 65.71    |
| Modal 2          | 68.36    | 76.94    | 72.59    | 81.00    | 78.59     | 77.91    |
The water transparency of Xiaoxidian area is much higher than that of Dujiadian area, which means the water of Xiaoxidian area is clearer. The temperature of summer is higher and this is suitable for the growth of plankton which results in lower transparency in summer.

The Total Phosphorus of Xiaoxidian area is slightly lower than that of Dujiadian area. Especially in June and August, the Total Phosphorus of Xiaoxidian area only reaches half of that in Dujiadian area. The reasons for the rising of Total Phosphorus in June may be: The water level drops with decreased water yield; The water temperature increases with higher intensity of aquatic organism activity and the increase of disturbance from sediment makes a large amount of phosphorus in both sediment and interstitial water diffuse into overlying water. Then the reason for the following decline includes the effect of biomanipulation. Besides, the slight increase in November may be due to the decrease of biological activities resulting from lower temperature. So the control of Total Phosphorus in Baiyangdian area is of great significance to improve the nutritional status of water body because of the phosphorus limitation in this area.

The Chlorophyll-a of Xiaoxidian area is significantly lower than that of control area in Dujiadian. Especially in August, September and October, the Chlorophyll-a of Dujiadian area reaches two to three times that of Xiaoxidian area. This demonstrates the overall amount of phytoplankton in Xiaoxidian area is far lower than that of control area. From April to July, the low Chlorophyll-a may be due to the low temperature and other external environmental factors which could not embody the advantages of Xiaoxidian area. The biological chain control of Xiaoxidian has an extremely significant effect on reducing the total amount of phytoplankton in water body.

According to TSIM based on water transparency (figure 2), TSIM (SD) in all the areas are larger than 70 and they all belong to severe eutrophication. While it is apparent that Xiaoxidian area is obviously superior than the control area-Dujiadian.

![Figure 2. Comparison of TSIM Based on transparency.](image-url)
Figure 3. Comparison of TSIM based on total phosphorus.

TSIM based on Total Phosphorus is shown in figure 3. According to TSIM based on Total Phosphorus, the demonstration area is basically controlled within moderate eutrophication level and it even reaches the level of mild eutrophication in October. While the control area of Duijadian is basically between moderate and severe eutrophication. So demonstration area of Xiaoxidian area has got fruitful results on the control of nutritional status.

TSIM based on chlorophyll-a (figure 4) shows that the demonstration area has always maintained in moderate or mild eutrophic level, while the control area changes into severe eutrophication level with increasing temperature in summer.

Figure 4. Comparison of TSIM Based on Chlorophyll-a.
The demonstration area is controlled in moderate eutrophication level. In contrast, the control area is severe eutrophication level.

The results in Figure 5 show that compared with the ordinary aquaculture model within Dujiadian, the water transparency of Xiaoxidian aquaculture system is significantly higher than that of Dujiadian. At the same time, Xiaoxidian area has lower Total Nitrogen, Total Phosphorus, chlorophyll-a content and TSIM than Dujiadian area which demonstrates the aquaculture system with control of biological chain has an obvious effect on improving water quality. Judged from the physical and chemical indices, the water quality of demonstration area significantly improves because most of the factors are reduced to moderate eutrophication level from severe eutrophication level before the structural adjustment. In some individual months, the water quality even meets the standard of III (GB3838-2002 of China). Demonstration area not only makes full use of ecological niche, but also improves water quality significantly.

3.2. The emergy input and output

Table 4. Emergy evaluation of two aquacultural ecosystems.

| No. | Item                     | Unit       | Raw data (Dujiadian) | Raw data (Xiaoxidian) | Emergy transformity/Emergy currency ratio (Em/$) (Dujiadian) | Emergy transformity/Emergy currency ratio (Em/$) (Xiaoxidian) | Solar energy (Dujiadian) | Solar energy (Xiaoxidian) | Emergy attribute |
|-----|--------------------------|------------|----------------------|-----------------------|-------------------------------------------------------------|-------------------------------------------------------------|--------------------------|--------------------------|-------------------|
| 1.1 | Solar radiation energy   | J          | 3.7745E+18           | 6.47071E+17           | 1                                                            | 1                                                            | 3.7746E+18              | 6.4707E+17              | R                 |
| 1.2 | Wind energy              | J          | 138983               | 2382575               | 1470                                                         | 1470                                                         | 2.0431E+12             | 3.5024E+11             | R                 |
| 1.3 | Potential energy of rain | J          | 2.5777E+13           | 4.41894E+10           | 10300                                                        | 10300                                                        | 2.6550E+17             | 4.5515E+16             | R                 |
### Water

| 1.4 | Chemical energy of rain water |
|-----|-------------------------------|
| J   | 1.6242 2E+12 2.78438E+11 18100 18100 2.9398E+16 5.0397E+15 R |

| 1 | Total renewable natural resources |
|---|----------------------------------|
|   | 3.7746E+18 6.4707E+17 R |

| 2.1 | Bighead carp fry $ |
|-----|-----------------|
| $   | 1857.9 619.31 4.94E+12 4.94E+12 9.1782E+18 3.0594E+15 F |

| 2.2 | Silver carp fry $ |
|-----|-----------------|
| $   | 7431.7 1486.34 4.94E+12 4.94E+12 3.6713E+16 7.3425E+15 F |

| 2.3 | Shrimp seed $ |
|-----|----------------|
| $   | 0 348.36 4.94E+12 4.94E+12 0 1.7209E+16 F |

| 2.4 | Eriocheir sinensis $ |
|-----|----------------------|
| $   | 4180.3 3963.58 4.94E+12 4.94E+12 2.0651E+16 1.9580E+16 F |

| 2.5 | Water chestnut seeds $ |
|-----|------------------------|
| $   | 0 3870.69 4.94E+12 4.94E+12 0 1.9121E+16 F |

| 2.6 | Feed $ |
|-----|--------|
| $   | 38397.23 4025.56 4.94E+12 4.94E+12 1.8968E+17 1.9886E+16 F |

| 2.7 | Labour cost $ |
|-----|-------------|
| $   | 9103.8 6069.24 4.94E+12 4.94E+12 4.4973E+16 2.9982E+16 F |

| 2.8 | Feedback resources $ |
|-----|----------------|
| $   | 60971.08 20383.04 4.94E+12 4.94E+12 3.0120E+17 1.0069E+17 F |

| Total input sej | 4.0758E+18 7.4776E+17 U |

| 3.1 | Water chestnut kg |
|-----|------------------|
| kg  | 0 13028.8 5.7393E+13 |

| 3.2 | Myriophyllum spicatum kg |
|-----|-------------------------|
| kg  | 0 188696 3.9628E+12 |

| 3.3 | Silver carp kg |
|-----|----------------|
| kg  | 40000 13500 1.0189E+14 5.5390E+13 |

| 3.4 | Bighead carp kg |
|-----|-----------------|
| kg  | 10000 4500 4.0758E+14 1.6617E+14 |

| 3.4 | River crab kg |
|-----|--------------|
| kg  | 3500 3050 1.1645E+15 2.4517E+14 |

| 3.6 | Shrimp kg |
|-----|-----------|
| kg  | 1000 1800 4.0758E+14 4.1542E+14 |

| 3.7 | Cyprinoid kg |
|-----|-------------|
| kg  | 10000 0 4.0758E+14 |

| 3 | Product output kg |
|---|-------------------|
| kg | 64500 224574.8 6.3190E+13 3.3297E+12 Y |

| 4.1 | TN g/a |
|-----|-------|
| 0   | 3799607.501 3.73E+09 1.4173E+16 |

| 4.2 | TP g/a |
|-----|-------|
| 0   | 457881.7 712 3.83E+09 1.7537E+15 |

| 4 | Pollutant s of retention and purification |
|---|------------------------------------------|
| t/a | 4.0758E+18 7.6369E+17 Y |

| Total output sej | 4.0758E+18 7.6369E+17 Y |
3.3. Emergy evaluation indices
So far, there has been no unified method in high stylization to analyze emergy. Researchers need to pay attention to characteristics of the eco-economic system and the emphasis of the research before determining the specific analysis methods. The two aquaculture ecosystems are both closed ecosystem with all the input emergy converted to a co-product [18]. Nutrient elements such as nitrogen and phosphorus of water chestnut (Trapa bispinosa) and Myriophyllum spicatum are both from water and substrate sludge so they can be treated as emergy output from the retention pollutants after being purified in the system. Because the conversion efficiency of the system needs to be evaluated with no significant change in the energy of the substrate sludge, the system is expected to change all the emergy input into joint product without taking dissipation into consideration, thus treating the emergy output used to purify retention pollutants as the emergy output used for water purification which reduces the indigenous emergy of the two systems.

According to table 4, we could find that Solar emergy transformity of Dujiadian area is always higher than that of Xiaoxidian area for different products (seen as co-production) of the two systems which means that the conversion efficiency of Xiaoxidian is better. So the production efficiency of Xiaoxidian area is higher. We eliminate nitrogen and phosphorus of the system by harvesting aquatic plants, such as Trapa bispinosa and Myriophyllum spicatum in the experimental area, thus picking out the emergy used for purifying water and treating this emergy as the emergy deduction of indigenous system storage. That is because the salvage of mature Trapa bispinosa and Myriophyllum spicatum could be regarded as the deduction of indigenous nitrogen and phosphorus nutrients to a specific level. Besides, Selling Trapa bispinosa and Myriophyllum spicatum could also bring economic benefits.

Further calculations are drawn to get a series of emergy index for system evaluation (table 5).

| Table 5. Comparison of emergy indices for two cultural ecosystems in Baiyangdian Lake. |
|-------------------|-------------------|-------------------|
| Indice             | Dujiadian         | Xiaoxidian        |
| EIR                | 0.08              | 0.16              |
| ESR                | 0.93              | 0.87              |
| EYR                | 13.5              | 7.58              |
| EER                | 7.95              | 2.34              |
| ELR                | 0.08              | 0.16              |
| ESI                | 178.23            | 48.71             |
| Output per hectare| 5.82254E+16       | 6.36408E+16       |
| Economic output per hectare | 1481.92 | 5393.16 |
| Net income per hectare(yuan) | 871.02 | 1698.59 |
3.3.1. Emergy Investment Ratio (EIR): \( EIR = \frac{EmF}{(EmR + EmN)} \). The environmental providing emergy divided by economic feedback (purchase) reflects the degree of system utilization for natural environment. The figure for Xiaoxidian demonstration area is 0.16 and that is twice the figure of Dujiadian area (0.08). While both of them are far less than 1 which means that their dependence on natural resources for the two systems is in high level and the economic investment accounts for low proportion. Simultaneously, the artificial intervention intensity of Xiaoxidian area is slightly larger than that of Dujiadian area. That is to say, economic feedback emergy of Xiaoxidian area is larger together with smaller proportion of local resources utilization.

3.3.2. Emergy Self-sufficiency Rate (ESR). Emergy self-sufficiency rate has two concepts. In scale of country or a large area, it means the ratio between emergy input provided by the local region and the emergy input from foreign countries. In the analysis of small scale, it equals to the ratio between natural resources emergy provided by local region and the total emergy input of the system. The figure for Xiaoxidian demonstration area is 0.87 and slightly smaller than that of Dujiadian area (0.93). The result demonstrates that both of the two systems gain considerable supports from natural resources and the influence of market on Dujiadian area is smaller with higher degree of independent development.

3.3.3. Emergy Yield Rate (EYR). EYR equals to the devoted emergy (purchase) divided by emergy output which reflects the return rate of emergy investment and whether the product is competitive in price. It also symbolizes the degree of industrialization for the ecological system-the higher the value is, the higher the degree of industrialization will be. Compared with the national average level of 1.42 for agriculture, return rate of emergy investment in aquaculture industry is very good. In the two areas, we release fish fry of 60 tail / kg in Dujiadian area and 10 tail/kg in Xiaoxidian area. The actual emergy contained in unit weight of both areas is different and price will also influence the parameters to some extent. So the emergy may change in the future if we use other fish fry in the same size. In addition, due to the limitation of methods, people still have different opinions about choosing which method to purify nitrogen and phosphorus [19] and the specific conversion rate is not accurately equivalent to the plant purification function. The parameters will be more accurate if there is further research on the basis of specific emergy contribution to ecological service function.

3.3.4. Emergy-monetary value (Em$). Em$ reflects consumer's willingness to purchase the emergy contained in the product. The monetary value of emergy output for unit area of Xiaoxidian area equals to 5393.16, which is almost four times that of Dujiadian area (1481.92). As for the economic benefits, the value of Dujiadian area is 1698.59 and that is a double value of Dujiadian area (871.02). This proves that economic evaluation and emergy evaluation may gain different results within the same system. But both economic benefits and emergy benefits in Xiaoxidian area exceeds those of Dujiadian area.

3.3.5. Emergy Exchange Rate (EER). EER equals to currency emergy for purchasing commodity divided by stored emergy within commodity which indicates the relationship between the natural value of commodity and the willingness of people to pay for commodity. Dujiadian area has higher emergy exchange rate which means the products from Dujiadian area contain more emergy than Xiaoxidian demonstration area. In contrast, the product of Xiaoxidian area reflects its better natural value.

3.3.6. Environmental Load Rate (ELR): No non-renewable natural resources are provided by local area. So the Environmental Load Rate equals to emergy investment rate and both of them prove the same problem.

3.3.7. Emergy Sustainability Index (ESI): \( ESI = \frac{EYR}{ELR} \). ESI evaluates the sustainable development ability of system. Dujiadian area is higher in ESI and sure to gain more advantages in sustainable development.
4. Discussion and conclusions
As we have mentioned before, aquaculture modes with different fish fry specifications and feed species may all result in a series of different parameters. Under the same aquaculture condition, the stocking of large-size fingerling is an important measure to yield large amount of fish. So managers in Xiaoxidian area purchase large-size fingerling in order to get stable short-term economic benefits. Other studies have also proved that energy transformation rate (ETR) and Environmental Load Rate (ELR) will drop by at least 26% if the energy input decreases 50%. At the same time, energy sustainability index (ESI) and emergy index for sustainable development (EISD) will also increase at least 39% and 88% respectively [20]. The two indices mean that the system has more powerful sustainability. Then the next step is to fix all the aquaculture factors gradually in order to determine which management factors cause the differences in the system characteristics. It is important to take economic benefits into comprehensive consideration. Though Xiaoxidian area needs larger economic investment for large-size fingerling, the survival rate of large-size fingerling is high with lower risk of breeding. This is a kind of performance for farmers to reduce their own risk and increase environmental load.

The conversion efficiency of Xiaoxidian demonstration area is higher from the analysis of current situation with superior energy output and economic income for unit area compared with Dujiadian area. While Dujiadian area has higher energy output rate and lower Environmental Load Rate which reflects better sustainability. In the final analysis, farmers in Dujiadian area purchase less energy in the process of aquaculture management. Less economic investment means the emergy purchased within feed and fry is low. So Dujiadian area shows better sustainability with emergy analysis. Besides, the area of Dujiadian is larger with more stable water condition in recent years. So there is a considerable amount of wild carps available for fishing and this also increases the emergy output rate. In contrast, Xiaoxidian area is a new reclamation dam with short formation time of water system and no reproduction of wild fish inside the area. This kind of phenomenon will be improved over time because planting grass provides a good ecological niche for snails and natural baits for fish fry. Then this increases the conversion rate of the whole system. In addition, it should be stressed that compared with aquaculture systems in other regions such as Pearl River Estuary [20], Mai Po [21], T marae Mai [22] and S Aura [23], the environmental load rate (ELR) and emergy sustainability index (ESI) of Xiaoxidian area and Dujiadian area (as the representatives of Baiyangdian Lake aquaculture model) are much higher. So the sustainability of the aquaculture model in Baiyangdian Lake is still relatively good.

Farmers inevitably incline to choose Xiaoxidian aquaculture model with higher income for economic benefits. While from the angle of comprehensive benefits for long-term, the sustainable degree of Dujiadian area is better to maintain the stability of eco-economic system. So Dujiadian area has its unique advantages for the use and development of long-term. From the comparison of economic income, production amount for unit area of Xiaoxidian area is 3 times as much as Dujiadian area, while net profit only reaches twice of that in Dujiadian area. This shows that we invest too much in unit area of Xiaoxidian area without getting the return in the same amount. If farmers in Xiaoxidian area agree to reduce a specific amount of economic investments, the net profit may not significantly reduce with improved emergy self-sufficient rate and output rate, thus increasing the sustainability of the system. As Vassallo has found, the results show that the environmental load rate (ELR) and emergy sustainability index (ESI) of aquaculture system depend largely on the utilization of renewable resources[18]. Based on emergy analysis, it will be better if we make full use of some management measures to improve aquaculture system such as better use of baits, reasonable fish / feed ratio and appropriate feed frequency. These measures are used to improve the utilization efficiency of baits and reduce the residual organic compounds in wastewater. In addition, the water in the aquaculture system should be frequently changed in order to provide adequate dissolved oxygen for fish. Therefore, the use of electric oxygen pump can reduce the frequency of changing water to some degree. The uncertainty, regional feature, social feature (different groups of people have different perceptions and attitudes towards environment), comprehensive feature and non-comparable feature of environmental
issues decide that one of the most remarkable features for environmental policy formulation is to build consensus on stakeholders. Because the value of environment is always difficult to make analogy with economic value, only when we get supports from the whole society, can we really take effective measures to solve complex problems in the area of ecological environment. Therefore, we need to further determine the capacity of environmental load and ultimately find the balance point of economic and environmental benefits to achieve a win-win situation.

Reference
[1] Odum H T 1983 Self-organization, transformity and information Science 242 1132-9
[2] Odum H T 1996 Environmental Accounting: Emergy and Environmental Decision Making (New York: John Wiley & Sons) pp 20-50
[3] Reynolds C S 1994 The ecological basis for the successful biomanipulation of aquatic communities Arch. Hydrobiol. 130 1-33
[4] Shapiro J, Lamarra V and Lynch M 1975 Biomanipulation: An ecosystem approach to lake restoration Symp. Water 21 85-96
[5] Shapiro J and Wright G I 1984 Lake restoration by biomanipulation: Round lake, Minnesota, the first two years Freshwater Biol. 14 371-383
[6] Xie P and Liu J K 2001 Practical success of biomanipulation using filter-feeding fish to control cyanobacteria blooms: A synthesis of decades of research and application in a subtropical hypereutrophic lake Sci. World 8 337-356
[7] Liu J K and Xie P 2002 Enclosure experiments on and lacustrine practice for eliminating microcystis bloom Chin. J. Ocea. Limn. 20 113-117
[8] Gu G and Lu G F 2004 On the integrated control of water environment of Wuli lake, Lake Taihu J. Lake Sci. 16 56-60
[9] Wang Y, Liu L S, Shu J M, Zhu Y Z, Li L and Zhou J 2013 Purification effect of different biological chains on eutrophic water in Baiyangdian lake Wetr. Sci. 11 499-504
[10] Zhou Q, Xie P, Xu J, Ke Z X and Guo L G 2009 Seasonal variations in stable isotope ratios of two biomanipulation fishes and seston in a large pen culture in hypereutrophic Meiliang Bay, Lake Taihu Ecol. Eng. 35 1603-1609
[11] Ke Z X, Xie P and Guo L G 2009 Impacts of two biomanipulation fishes stocked in a large pen on the plankton abundance and water quality during a period of phytoplankton seasonal succession Ecol. Eng. 35 1610-1618
[12] Lu H, Yuan Y, Campbell D E, Qin P and Cui L 2014 Integrated water quality, energy and economic evaluation of three bioremediation treatment systems for eutrophic water Ecol. Eng. 69 244-254
[13] Aiazki M 1981 Application of modified Carson’s trophic state index to Japanese lakes and its relationships to other parameters related to trophic state Res Rep Environ Stud 23 13-31
[14] Goda T 1981 Comprehensive studies on the eutrophication of freshwater areas XI: Summary of researches Environ. Stud. 27 59-71
[15] Xi Y G and Qin P 2009 Emergy evaluation of organic rice-duck mutualism system Ecol. Eng. 35 1677-1683
[16] Zhu H G, Qin P, Wan S W and Xie M 2001 Emergy analysis of two models of wetland utilization on seashore in Jiangsu Province Chin. J. Ecol. 20 38-44
[17] Lu H F, Campbell D, Chen J, Qin P and Ren H 2007 Conservation and economic viability of natural reserves: An energy evaluation of the Yancheng Biosphere Reserve Biol. Conserv. 139 415-438
[18] Bastianoni S and Marchettini N 2000 The problem of co-production in environmental accounting by emergy analysis Ecol. Model. 129 187-193
[19] Xi H Z and Kang W X 2008 Evaluation and analysis of emergy-emdollar value for wetland resources of Dongting Lake J. Econ. Water Res. 26 37-44
[20] Li L J, Lu H F, Ren H, Kang W L and Chen F P 2011 Emergy evaluations of three aquaculture
systems on wetlands surrounding the Pearl River Estuary, China *Ecol. Indic.* **11** 526-534

[21] Qin P, Wong Y S and Tam N F Y 2000 Emergy evaluation of Mai Po mangrove marshes *Ecol. Eng.* **16** 271–280

[22] Brown M T, Green P, Gonzalez A and Venegas J 1992 *Emergy Analysis Perspectives, Public Policy Options, and Development Guidelines for the Coastal Zone of Nayarit, Mexico* vol 1-2 (Gainesville, FL: Center for Wetlands, University of Florida) Vassallo P, Bastianoni S, Beiso I, Ridolfi R and Fabiano M 2007 Emergy analysis for the environmental sustainability of an inshore fish farming system *Ecol. Indic.* **7** 290-298