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# Economic Efficiency of Crucian carp (*Carassius auratus gibelio*) Polyculture Farmers in the Coastal Area of Yancheng City, China

**Xiaolin Yin[1, 2], Aimin Wang[2], Hong Zhou[1,]*, Quanzhong Wang[1], Zhuyu Li[2], Peng Shao[3]**

[1] Nanjing Agricultural University, College of Economics and Management, Nanjing 210095, China.
[2] Yancheng Institute of Technology, Key Laboratory of Aquaculture and Ecology of Coastal Pool, Jiangsu Province, Yancheng 224051, China.
[3] Disease Prevention and Research Institute of Aquatic and Poultry, Yancheng city, Yancheng 224051, China.

* Corresponding Author: Tel.: +86.025 84396537; Fax: +86.025 84396537;
E-mail: zhouhong@njau.edu.cn

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## Abstract

Polyculture is commonly practiced in pond aquaculture where several fish species are reared together, creating a multi-output production structure. This study examines the technical (TE), allocative (AE) and economic efficiency (EE) of the most widely practiced fish-producing polyculture system in the coastal area of Yancheng city, China, which deals mostly with the production of crucian carp alongside silver carp and bighead carp. Data envelopment analysis is used to measure the efficiencies, while Tobit regression is applied to identify the factors affecting efficiencies. The estimated TE, AE and EEs are 0.92, 0.96, and 0.88 respectively. Crucian carp polyculture is characterized by moderate technical inefficiencies, necessitating the development and dissemination of new technology to increase the productivity of these farmers. On average, small ponds were found to be more technically efficient while large ponds were found to have higher allocative and scale efficiencies. Additionally, Tobit regression revealed a positive effect between farm size and efficiencies. These findings provide some support for the current standardized pond program in China. The use of hired labor decreased technical efficiencies of fish farmers. Fingerling size had a significant positive effect on efficiencies. In order to manage constantly expanding crucian carp polyculture, farmers should be provided with information on sizable fingerlings, economic pond sizes, and employee supervision, among other factors.

*Keywords*: Data envelopment analysis, economic efficiency, tobit regression, Crucian carp (*Carassius auratus gibelio*), Yancheng city.

## Introduction

Crucian carp (*Carassius auratus gibelio*) is an important triploid gynogenetic freshwater aquaculture species in China with many merits, such as rapid growth, large body size, and strong resistance (Gui, 1996; Yang *et al*., 1999; Zhou *et al*., 2000). According to the Chinese Fishery Statistical Yearbook 2012, the total quantity of crucian carp in the country is estimated to be 2,216,000 tons (Bureau of fisheries of the Ministry of Agriculture, 2012). Yancheng city, located in the eastern part of China, has a total aquaculture area amounting to 133,333 hectares (Yin *et al*., 2010), with 53,333 hectares dedicated to Crucian carp. With the rapid development of aquaculture in Yancheng city, many old ponds have been transformed to standardized ponds of about 12 hectares in this district. According to the Chinese Fishery Statistical Yearbook, the scale of freshwater aquaculture in China is divided into small groups (≤2 hectares) and scale groups (>2 hectares). Farm size is practically divided into three groups by the local aquaculture farmers: small farms (≤5 hectares)、medium farms (5-10 hectares) and large farms (>10 hectares) crucian . The most widely adopted system of crucian carp production in this district, crucian carp-bighead carp-silver carp polyculture, represents the highest level of crucian carp cropping in China. In this polyculture system, crucial carp is the main species, often cultured in varying ratios with some silver carps and bighead carps in order to prevent or reduce the negative impacts of fish or other animal wastes (Fu *et al*., 2010).

Fu *et al*. (2010) investigated the production and consumption status of crucial carps of Jiangsu Province. Efficiency-oriented studies on Crucian carp have not been found. The produce of Crucian carp, like many other farming activities, is dependent upon the use of natural resources such as water, land, seed, and feed. As the demand for fish product rises with the improvement of living standards and the country's effort to increase aquaculture production, the demand for these resources will rise, resulting in increased competition for limited resources. The efficiency or inefficiency of utilization of available resources for fish farming has remained an unanswered question in the quest for increased pond production in Yancheng city in particular, as well as across China. The present study is undertaken to estimate the technical efficiency, allocative efficiency, and economic efficiency of a sample of the above mentioned polyculture system. In addition, it compares the efficiency measures of the three different farm size groups. It is expected that the study will generate meaningful insights in at least two aspects. First, the information provided in this report could facilitate increases in productivity through improving technical efficiency at the farm level. Second, the interplay between technical efficiency and pond size will offer certain policy insights to facilitate the development of Yancheng coastal aquaculture, with the aim to make the most of the vast areas of this district.

The present study covered the period from April 2011 to May 2012. The Department of Statistics (DOS), Bureau of Fisheries of the Ministry of Agriculture, Statistical Yearbook in each province and other related sources were the secondary data sources for this study.

## Materials and Methods

### Data Sources and Sample Characteristics

Practice of crucian carp polyculture is concentrated in three districts of Yancheng city: Dafeng, Sheyang and Dongtai. During the 2011-2012 aquaculture cycle, cross-sectional data were collected from the three major crucian carp-growing districts. We have chosen 7 counties from the three districts, 3 counties from Dafeng, 2 counties from Sheyang and 2 counties from Dongtai. More counties were selected from Dafeng district because the total level of crucian carp production in Dafeng was greatest. Fifteen samples from each of the selected counties (105 in total) were randomly chosen from the list of crucian carp farmers collected from the Department of Fisheries of the respective districts. After careful scrutiny, 14 samples were dropped as the collected data in the questionnaires were dubious. Therefore, a total of 91 sample crucian carp polyculture farmers were retained and analyzed for this study. A pre-tested questionnaire designed by the first author was used to collect data from the selected famers during June-July 2012. Data included mainly prices and quantities of inputs and outputs, feeding and characteristics of farms and farmers.

The farmers surveyed in this study practiced polyculture dominated by crucian carp , with some silver carp and bighead carp. For the purpose of this study, fish outputs are measured in kilogram per hectare as follows:

$y_1$ represents crucian carp (*Carassius auratus gibelio)* ;

$y_2$ represents bighead carp(*Aristichthys nobills*);

$y_3$ represents silver carp (*Hypophthalmichthys molitrix*).

The inputs involved in fish polyculture are aggregated into four categories, all expressed on an annual basis, as follows:

seed ($x_1$) represents the total amount of seeds (fry) of all three species released to the pond, measured in kilograms per hectare.

feed ($x_2$) represents the total dry weight of feed, measured in tons per hectare (with no green feed).

fertilizers and medicine ($x_3$) represent the expenses of fertilizers and medicine, measured in Yuan per hectare.

labor ($x_4$) represents the total expenses for family and hired labor used in fish farming, measured in Yuan per hectare (because number of hours worked per year was difficult to calculate).

The output price data needed to calculate economic efficiency are measured in Yuan per 500 g. Average pond size of the sample fish farms is 8.74 hectares ranging from 2 to 33.33 hectares. The average length of culture period is 259 days varying from 120 to 515 days. The mean age of the farmers is 47.7 years while experience is 10 years. Summary statistics for the important variables in practice of crucian carp polyculture and farm-specific factors are presented in Table 1.

### Choice of Methods

The stochastic frontier production function approach involving econometric techniques (Aigner *et al.*, 1977; Meeusen and van den Broeck, 1977) and data envelopment analysis (DEA; Charnes *et al*., 1978) are the two most popular analytical tools to measure the efficiency of a firm or decision-making unit (DMU) in various industries. The main advantage of the stochastic frontier model is that it can decompose the deviation from the frontier or best practice into its stochastic noise and technical inefficiency components. However, this method needs to impose a particular functional form for underlying technology. DEA is deterministic and all deviations from the frontier are attributed to inefficiencies. A frontier estimated by this technique is likely to be sensitive to stochastic noise and other measurement errors in the data. DEA is widely employed in efficiency analysis of various areas, among which agriculture constitutes an important area (Coelli *et al*., 2002; Bayarsaihan and Coelli, 2003; Rahman, 2003; Kelvin *et al*., 2007; Alam, 2011). However, its application to aquaculture is still limited. Previous studies of the efficiency of aquaculture in China were scarce and focused mainly on the entire fresh aquaculture (Chen *et al*., 2007; Gao *et al*., 2012) and on the culture of tilapia (Dai *et al*., 2012).

The present study chooses DEA for two reasons. First, for a sample of DMUs, DEA distinguishes between efficient and inefficient units and computes

**Table 1.** Descriptive statistics of the Included Farms

| Variables | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Outputs (kg $ha^{-1}$) | 27091.8 | 7179.4 | 1723.3 | 42000 |
| Crucian carp | 10659.6 | 2669.8 | 725.0 | 17625.0 |
| Fingerlings (g) | 67.2 | 24.9 | 2.8 | 150.2 |
| Bighead carp | 1084.4 | 422.0 | 300.0 | 2125.0 |
| Silver carp | 891.0 | 475.5 | 60.0 | 2750.0 |
| Prices of outputs (Yuan 500 $g^{-1}$) | | | | |
| Crucian carp | 6.53 | 0.80 | 3.80 | 8.60 |
| Silver carp | 5.00 | 0.76 | 3.90 | 7.10 |
| Bighead carp | 2.76 | 0.43 | 2.00 | 4.50 |
| Inputs | | | | |
| Seed (kg $ha^{-1}$) | 2180.7 | 863.1 | 332.0 | 4504.1 |
| Feed (ton $ha^{-1}$) | 16.8 | 4.4 | 4.5 | 27.0 |
| Fertilizers and medicine (Yuan $ha^{-1}$) | 6444.2 | 2937.9 | 1765 | 15600 |
| Labor (Yuan $ha^{-1}$) | 6001.3 | 3404.6 | 1049 | 16666.7 |
| Farm specific variables | | | | |
| Pond size (hectare) | 8.74 | 5.62 | 2 | 33.33 |
| Age of operator (years) | 47.7 | 6.5 | 28 | 69 |
| Experience of operator (years) | 10 | 3.1 | 2 | 20 |
| Length of culture period( day) | 259 | 80.2 | 120 | 515 |

Note: Yuan, Renminbi; Fingerlings , stocking size of crucian carp

the efficient input and output levels for inefficient units in terms of linear combinations of input and output levels of efficient units. For polyculture farms, this information can be used to calculate optimum output combinations as well as the corresponding stocking densities of different fish species (Sharma *et al.*, 1999). The second issue is that the accuracy of the study data, obtained by trained graduates and feed salesmen through face-to-face interviews with farmers, ensures the successful use of DEA. Feed salesmen, as the farmers' fixed and main technical consultants, play an important part in the practice of fish cropping in the study area. Fish polyculture, with its multi-output feature, provides a promising setting for applications of output-based efficiency measurement techniques, especially DEA. Under the output-based approach, performance is judged by the ability to produce the maximum output(s) achievable from a given set of inputs (technical efficiency) or to maximize revenue given output prices and input quantities ("revenue" or overall economic efficiency) (Färe *et al.*, 1994). The ratio of economic and technical efficiencies provides a measure of allocative efficiency. Under the output-based approach, allocative efficiency reflects the ability of the firm to produce optimum combination of different outputs. As revenue maximization is a more appropriate behavioral assumption to aquaculture farmers, this study will use DEA to empirically estimate technical, economic and allocative efficiencies, as described by Farrell (1957).

## DEA Model for Crucian Carp Dominant Pond Systems

DEA was first introduced by Charnes *et al.* (1978) and a general introduction to DEA can be found in Coelli *et al.* (2005). DEA is based on the estimation of a non-parametric distance function, which measures the distance between the actual production and the best practice production on the estimated production frontier. In this study, a common (i.e. for a homogenous technology) output-oriented model DEA was used, assuming variable returns-to-scale, to compute the technical efficiency of a farm. Each farm j out of N farms can produce s outputs with m inputs. Efficiency scores are then computed by running a linear programming model (1) for each farm in the data set:

$$\begin{aligned} &\text{Maximize}_{\Phi_j,\lambda}\ \Phi_j && (1)\\ &\text{Subjective to: } -\Phi_j y_j+Y\lambda \geq 0 \\ &x_j-X\lambda\geq 0 \\ &e'\lambda=1. \\ &\lambda\geq 0 \end{aligned}$$

For each firm j, the model aims at maximizing a scalar $\Phi_j \geq 1$, which is multiplied by the observed output $y_j$ (s×1 vector) to represent the maximum output that is feasible for firm j. Thus, as $\Phi_j$ increases, firm j is less efficient. The maximum output is represented by a convex linear combination of the observed outputs of all other firms $Y\lambda$ (s×N matrix) where $\lambda$ is an N×1 vector of non-negative weights which must sum to one (assumption of a variable returns-to-scale technology), and e is a N×1 vector of ones. The maximum output must be produced with no more input than observed for firm j. In other words, the inputs corresponding to the maximum output are represented by a convex linear combination of inputs $X\lambda$ (m×N matrix) of all firms that do not exceed the observed input $x_j$ of firm j. The technical efficiency index of farm j can be computed as follows:

$$TE_j=\Phi_j^{-1} \quad (2)$$

Allocative inefficiency in output-mix selection can be accounted for in a similar manner. For the case of VRS revenue maximization, technical efficiencies are calculated by solving the model (1) and model (2) (Coelli *et al.*, 2005). The following revenue maximization DEA problem is then solved:

$$\begin{aligned} &\mathrm{Max}_{\lambda,y_j^*} p_j' y_j^* \quad (3)\\ &\text{subject to } -y_j^* + Y\lambda \geq 0\\ &x_j - X\lambda \geq 0\\ &I1'\lambda = 1\\ &\lambda \geq 0 \end{aligned}$$

where $p_j$ is M×1 vector of output prices for the j-th farm and $y_j^*$ (which is calculated by the LP) is the revenue-maximizing vector of output quantities for the j-th farm, given the output prices $p_j$ and the input levels $x_j$. The total revenue efficiency (RE) of the j-th farm is calculated as

$$RE= p_j' y_j / p_j' y_j^* \quad (4)$$

which is the ratio of observed revenue to maximum revenue. Following Farrell (1957) and Färe *et al*. (1994), the output-based allocative efficiency index for the j-th farm ($AE_j$) can be derived using Eqs. (2) and (4) as:

$$AE_j = RE_j / TE_j$$

These three measures (TE, AE and RE) can take values ranging from 0 to 1, where a value of 1 indicates full efficiency.

The measurement of scale efficiency in the multi-input、multi-output case is a generalization of the above concepts. For a particular firm using an input vector x to produce an output vector y, the concepts of TOPs relates to finding a point of maximum productivity on the production frontier, subject to the constraint that the input and output mixes cannot be altered, while the scale of these vectors can (Coelli *et al*., 2003). Scale efficiency can be deduced by dividing the technical efficiency score from the CRS DEA with the score obtained from the VRS DEA.

$$SE_j = TE_{j,crs} / TE_{j,vrs}$$

The jth farm is scale efficient if SE=1, where SE<1 indicates scale inefficiency.

On the basis of the above efficiency measures, farms are categorized by farm size in order to investigate the existence of an inverse relationship (IR) between farm size and efficiencies in Yancheng crucian carp aquaculture. In addition, some previous studies have shown that feed level appears to have a significant correlation with AE and CEs (Alam and Jahan, 2008; Alam, 2010). Hence, for the purpose of examining the influence of feed level on the efficiencies of farmers, the farms are divided into three different groups according to feed application.

### Tobit Regression Explaining Determinants of Efficiency

Efficiency scores so obtained from the solution of the DEA problem at the first stage have been regressed on farm and farmer characteristics at the second stage using a Tobit regression. Alam (2011) has made use of such an approach in estimating efficiencies and factors affecting efficiencies in pangas fish farmers of Bangladesh. The Tobit regression takes the following form:

$$EFF = \beta_0 + \beta_1 AGE + \beta_2 EXP + \beta_3 PSIZ + \beta_4 FNSIZ + \beta_5 CULP + \beta 6 HIRED + \delta_D DAF + \ell$$

where EFF are the efficiency scores (ranging from 0 to 1) of the farms obtained from the DEA, AGE is the age of the operator measure in years, EXP is the carp culture experience of the operator measured in years, PSIZ is the size of carp ponds of the farmers measured in hectares to examine the dilemma as to whether small ponds are efficient or not, FNSIZ is the average crucian carp fingerling size released in ponds, measured in gram, CULP is the crucian carp period measured in number of days. HIRED is a dummy to indicate whether fish farmers have hired laborers or not (HIRED=1, NO HIRED=0). DAF is a location (Dafeng district) dummy variable (DAF=1, 0= Otherwise).

### Statistical Analysis

The DEA model for computing technical efficiency (Eq.(1)) was solved using DEAP 2.1 and the equation for economic or “revenue’ efficiency (Eq.(3)) was solved using a general linear programming package, LINGO (Sharma *et al.*, 1999). A maximum likelihood estimate was made to estimate the Tobit model. STATA was used to run the Tobit regression.

Statistical analyses on different groups were conducted using SAS 9.0 software. Data among farm groups were compared using one-way analysis of variance (one-way ANOVA) and Fisher’s LSD test; a P value <0.05 was considered to indicate a statistically significantly difference. All results were presented as mean values ± standard deviation (mean ±SD).

## Results

### Efficiency Estimates

Estimates of mean efficiencies are presented in Table 2. The distribution of VRS TE is skewed towards the right. Technical efficiency under VRS ranged from 0.59 to 1 with an average of 0.92 and a standard deviation of 0.09 (Table 2). Thus, on average, carp production could potentially be increased by roughly 8% using the same level of inputs if all farms produced in a technically efficient way. The mean AE was 0.96. The average EE score was 0.88, indicating that fish farmers could make use of the same level of input to increase the output revenue by 12% had they been operating at a fully technically and allocatively efficient level. Scale efficiency was 0.92 on average, with a standard deviation of 0.08. Individual analysis of the farms indicated that 12.1% operate at their optimal level (CRS), 7.69% at above optimal level (increasing returns to scale) and 80.22% below optimal level (decreasing returns to scale). The mean overall TE (CRS TE) is 0.85. The returns to scale figures suggest that an increase in overall technical efficiency can be improved by solving the problem of operating at increasing returns to scale. Eliminating the problem of operating at decreasing returns to scale would increase overall technical efficiency to a lesser extent.

## Factors Affecting Efficiencies

The result of the Tobit regression is presented in Table 3. Technical efficiency scores presented in Table 2 show that the overall technical efficiencies vary across crucian carp farmers, but the average level of overall efficiency is high (only 15% below full efficiency). This might be one of the reasons for the presence of insignificant variables in the efficiency (TE) model. The average age of the operators is 47.7, and although younger operators seem to have higher TE scores, experience also has a positive effect on TE scores. However, both age and experience are not statistically significant. Coelli *et al*. (2002) and Alam (2011) found similar results. Dey *et al*. (2005) also did not find any significance of age in explaining inefficiency for India, Vietnam, Thailand and China. However, pond size turned out to be a very significant variable explaining the TE of the carp farms. Fingerling size is also found to have significantly positive effects on TE scores, which is in line with Alam (2011). Results of hired labor dummy variables indicate that the TE of the farmers who have hired laborers is significantly lower than those who completely depend on family labor. Results of location dummy indicate that TE scores in the study area do not have significant variance.

## Relationship of Pond Size and Feed Level with Efficiency

Analysis of variance results on size groups and feed application groups are respectively presented in

**Table 2.** Distribution of farms according to efficiency level

| Efficiency level | Percent of farms | | | | |
|---|---|---|---|---|---|
| | $TE_{crs}$ | $TE_{vrs}$ | SE | AE | EE |
| <0.5 | 1.1 | | | 1.1 | 1.1 |
| 0.50 0.6 | 3.3 | 2.2 | | | 2.2 |
| 0.6 0.7 | 1.1 | 1.1 | | | 1.1 |
| 0.7 0.8 | 23.1 | 5.5 | 9.9 | | 8.8 |
| 0.8 0.9 | 36.3 | 22.0 | 24.2 | 3.3 | 34.1 |
| 0.9 1.0 | 24.2 | 40.7 | 53.8 | 79.1 | 36.3 |
| 1 | 11.0 | 28.6 | 12.1 | 16.5 | 16.5 |
| Mean | 0.85 | 0.92 | 0.92 | 0.96 | 0.88 |
| Standard deviation | 0.11 | 0.09 | 0.08 | 0.08 | 0.12 |
| Minimum | 0.45 | 0.59 | 0.72 | 0.3 | 0.2 |
| Maximum | 1 | 1 | 1 | 1 | 1 |

Note: TE, technical efficiency; SE, scale efficiency; AE, allocative efficiency; EE, economic efficiency; VRS, variable returns to scale; CRS, constant returns to scale.

**Table 3.** Tobit Estimates of the Technical Inefficiency (TEcrs) of Fish Farmers

| Variables | Coefficient | Standard Error | T-Statistics |
|---|---|---|---|
| Constant | 0.886 | 0.111 | 8*** |
| AGE | -0.003 | 0.002 | -1.14 |
| EXP | 0.006 | 0.005 | 1.24 |
| PSIZ | 0.009 | 0.002 | 4.17*** |
| FNSIZ | 0.003 | 0.002 | 1.85* |
| CULP | 0.000 | 0.000 | 0.42 |
| HIRED | -0.113 | 0.032 | -3.56*** |
| DAF | -0.0003 | 0.027 | -0.01 |
| log likelihood | 61.04 | | |

$^{***}$Significant at the 0.01 level. $^{**}$Significant at the 0.05 level. $^{*}$Significant at the 0.1 level

Table 4 and Table 5. Different superscripts indicate that the pair-wise differences between different groups for each of the four efficiency indices are significant at the 0.05 level. As shown by Table 4, small farms (≤5ha) are technically more efficient than the large ones (>10ha), but the mean AE and EE levels across size categories do not suggest any significant difference. The SE scores are found to have increased significantly as the pond size increased. Table 5 displays distributions of mean efficiency scores according to quantity of feed application. Feed level has a strong positive and significant effect on VRS TE and EE. This means that operators applying larger feed quantities achieve relatively higher technical and economic efficiencies. The SE scores decline as feed application increases.

### Actual Versus Economically Efficient Input Applications and Output Productions

Since we are interested in sustainability of the industry, the optimum input levels (i.e. input levels at full economic efficiency) were estimated. Accordingly, the mean actual and optimum usage of labor, feed and seed by pond size are presented in Table 6. As to the gap between actual and optimal inputs, all the figures presented within parentheses are >1 indicating that observed input usages are higher than economically efficient levels except for feed use. The input dosage that crucian carp farmers currently apply is 7% higher for fingerlings, 17% for labor, and 49% higher for fertilizer and medicine. As far as pond size is concerned, we can find that the actual feed application per hectare of the small farms (17.97 kg) is apparently higher than medium (16.34 kg) and large ones (16.14 kg). Similar results are obtained when actual labor application and actual fertilizer and Medicine applications are compared among farm size groups. However, fingerling use is the largest for large ponds. As to the gap between actual and optimal outputs, the production of dominant crucian carp is nearest to the optimal level. In general, farmers should release more accompanying species. It is in line with the demand for ecologic breeding to add filter feeding fish (bighead carp and silver carp ).

Table 7 provides the average deviations from the optimum production for the sample farms that are economically inefficient. The majority of inefficient farms are producing less of every species as compared to economically optimum levels. On average, 72 of 76 inefficient farms could increase crucian carp production by 1607.6 kg per hectare, and 4 of 76 inefficient farms should reduce crucian carp production by 534 kg. 52 of the 76 inefficient farms could add 503.3 kg bighead carp per hectare, and 24 of the 76 inefficient farms should reduce 280 kg bighead carp per hectare. 57 of the 76 inefficient farms could add 636.4 kg silver carp per hectare, and 19 of the 76 inefficient farms should reduce silver carp production by 560.6 kg.

## Discussion and Conclusion

The mean measures of technical and economic efficiency in carp polycultures (92%, 88%) are at a high level. As referred to in some other aquaculture studies, Sharma *et al.* (1999) reported a CRS TE of 0.83 for Chinese fish farms and Alam (2011) reported a mean VRS TE of 0.86 for pangas fish farmers of Bangladesh. Irz and Mckenzie (2008) also found that freshwater farms are substantially more efficient than their brackish water counterparts in the Philippines. While 28.6% (26 farmers) of the sampled carp farmers displayed full TE, only 16.5% (15 farmers) of them were able to be fully allocatively and economically efficient, and the rest of the 12.1% of technically efficient farmers failed to achieve full allocative and economic efficiency. The observed technical inefficiency could be eliminated by eliminating the problem of decreasing returns to scale, as about 80% of carp farmers operated below optimal levels (decreasing returns to scale). It is worth noting that technical inefficiency, rather than allocative inefficiency, accounted for most of the economic inefficiency in the present study. On the average, fish farms in this study area had adjusted quite well to the prices of the different species in the market in selecting the proper species combination.

**Table 4.** Effects of farm size on technical, allocative, and economic efficiency levels

| farm size | $TE_{vrs}$ | AE | EE | SE |
|---|---|---|---|---|
| ≤5 ha(n=31) | $0.94 \pm 0.08^a$ | $0.95 \pm 0.13^a$ | $0.90 \pm 0.15^a$ | $0.90 \pm 0.11^b$ |
| 5≤10ha(n=26) | $0.91 \pm 0.11^{ab}$ | $0.97 \pm 0.05^a$ | $0.88 \pm 0.12^a$ | $0.95 \pm 0.07^a$ |
| >10 ha(n=34) | $0.90 \pm 0.07^b$ | $0.97 \pm 0.02^a$ | $0.87 \pm 0.08^a$ | $0.95 \pm 0.06^a$ |

**Table 5.** Effects of feed quantity on technical, allocative, and economic efficiency levels

| Feed qty. level (kg/ha) | $TE_{vrs}$ | AE | EE | SE |
|---|---|---|---|---|
| ≤15000 （n=33） | $0.89 \pm 0.10^b$ | $0.95 \pm 0.12^a$ | $0.85 \pm 0.15^b$ | $0.97 \pm 0.03^a$ |
| 15000-20000 (n=35) | $0.91 \pm 0.09^{ab}$ | $0.97 \pm 0.03^a$ | $0.89 \pm 0.10^{ab}$ | $0.93 \pm 0.06^b$ |
| Above 20000(n=23) | $0.96 \pm 0.07^a$ | $0.97 \pm 0.04^a$ | $0.93 \pm 0.09^a$ | $0.84 \pm 0.08^c$ |

**Table 6.** Gaps Between Per Hectare Actual and Economic Efficient Input Applications and Fish Production

| Output/Inputs | Less 5 | 5-10 | Above 10 | All Sizes |
|---|---|---|---|---|
| Actual crucian carp production (kg) | 11265.3 | 10211 | 10449.8 | 10605 |
| Optimum crucian carp production (kg) | 12850 | 11354 | 11472.9 | 11908 |
| | 0.88 | 0.90 | 0.91 | 0.89 |
| Actual bighead carp production (kg) | 1212.2 | 1124.6 | 937 | 1084 |
| Optimum bighead carp production (kg) | 1398.5 | 1286 | 1216 | 1298 |
| | 0.87 | 0.87 | 0.77 | 0.84 |
| Actual silver carp production (kg) | 990.9 | 915.6 | 781.1 | 891 |
| Optimum silver carp production (kg) | 1115.9 | 1242.7 | 1170.6 | 1172 |
| | 0.89 | 0.74 | 0.67 | 0.76 |
| Actual fingerling use (kg) | 2113.7 | 2077.2 | 2321 | 2180.7 |
| Optimum fingerling use (kg) | 2011.2 | 1945.2 | 2144 | 2042 |
| | 1.05 | 1.07 | 1.08 | 1.07 |
| Actual feed use (kg) | 17.97 | 16.34 | 16.14 | 16821.57 |
| Optimum feed use (kg) | 17.97 | 16.35 | 16.14 | 16822.20 |
| | 1.00 | 1.00 | 1.00 | 1.00 |
| Actual fertilizer and medicine use (yuan) | 7307.7 | 5679.8 | 6241.4 | 6444 |
| Optimum fertilizer and medicine use (yuan) | 5772.6 | 3427 | 3724.8 | 4337 |
| | 1.27 | 1.66 | 1.68 | 1.49 |
| Actual labor use (yuan) | 9422.7 | 4859.3 | 3755 | 6001 |
| Optimum labor use (yuan) | 7085.7 | 4735.5 | 3638.2 | 5126 |
| | 1.33 | 1.03 | 1.03 | 1.17 |

Note: Figures within parentheses indicate the ratio of observed inputs/outputs levels to model suggested levels according to pond size

**Table 7.** Average deviations below (-) and above (+) the economically optimum production for the economically inefficient farms (n=76). Figures in parentheses denote the numbers of inefficient farms in each category

| Species | Economically optimum production (kg ha$^{-1}$) | |
|---|---|---|
| | Below optimal | Above optimal |
| Crucian carp | -1607.6(72) | 534.1(4) |
| Bighead carp | -503.3(52) | 280(24) |
| Silver carp | -636.4(57) | 560.6(19) |

As far as pond size is concerned, significant differences in pure technical efficiency (VRS TE) were observed between the small farms (≤5ha) and the large farms (>10 ha). Sharma *et al.* (1999) also found that TE and EE scores of fish polyculture in China decreased as pond size increased. There are also authors who found at least a slightly positive relationship between efficiency and farm size (Heshmati and Kumbhakar, 1997; Wilson *et al*., 1998; Helfand and Levine, 2004). The negative relationship between farm size and technical efficiency in our study seems to contradict the institutional arrangement of farm size in recent years. If small farms are more technically efficient, why are more and more farms getting larger? However, large pond operators have higher scale and allocative efficiency relative to their small pond counterparts. The large farm group (>10 ha) was operating at an almost optimal scale (0.95), while the smallest farms could improve slightly (0.90). Similar results are obtained with allocative efficiency, although they are not statistically significant. These findings reinforce the fact that within the context of production, it is economic efficiency that should be of prime concern in the long run, and not technical efficiency.

As the production condition is closely related to the environment surrounding the farm, externality problems such as organic waste, antibiotics, chemicals and escapement have been successfully internalized to a large extent in farmers' production decisions over time (Tveterås *et al*., 2002). If producers affect the environmental condition negatively by using too much feed, chemical and antibiotics, it can have negative feedback effects such as decreased productivity and increased risk of disease (Asche *et al*., 1999, 2009; Tveterås *et al*., 2002). The average optimum feed, fertilizer and medicine of the small ponds are higher than their counterparts and the overall average level (Table 6). Differences in feed consumption reflect different feed coefficients. The condition of dissolved oxygen is usually better in large and medium ponds than in small ones, resulting in higher utilization ratios of feed and lower waste material. The regression results (Table 3) also showed that bigger pond owners are more efficient in general, recalling the existing resource-saving potential that results from scale effects.

This research was aimed at identifying potential ways of increasing productivity. Crucian carp polyculture farmers, on average, are quite efficient in utilizing their existing resources and technology. There is a need to develop and disseminate new technology to increase the productivity of these farmers. There is some evidence of the existence of positive relationships between farm size and efficiencies. These findings provide some support for the current standardized pond program in China. Hence, it is likely that government reform on the standardized pond model is the key to unlocking the productive potential of aquaculture in China. In order to manage the constantly expanding crucian carp polyculture, farmers should be provided with information on sizable fingerlings, economic pond sizes and other factors which can increase overall efficiency.

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