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Shrimp Poly-Culture Development and Local Livelihoods in Tam Giang-Cau Hai Lagoon, Vietnam

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Abstract

This research was conducted to evaluate the efficiency level of shrimp poly-culture farms by using Data Envelopment Analysis. It also identified factors affecting the inefficiencies of shrimp poly-culture farms using Tobit regression model. The empirical results indicated that the mean of Technical, Allocative and Economic Efficiency were at 84.01%, 64.16%, 55.32%, respectively, hence there is a substantial room for improving the efficiency. DEA results recommended that inefficient farms need to minimize overfeeding of stocks in order to avoid the accumulation of uneaten feeds that further contributes to water pollution. The optimal stocking density ratio should be 8.15 for shrimps, 1.59 for crabs and 2.46 for fish per square meter of pond. The results also showed the presence of scale inefficiency. Smaller farms tend to be more efficient than larger farms. The optimal farm size should be less than 0.5 hectares. The results of Tobit regression model suggested that farm personal characteristics, farm ability to access to institutions, and water environment have significant effect on the efficiency of farms.

Keywords: sustainable livelihood, Data Envelopment Analysis (DEA), Tobit regression model

1. Introduction

Aquaculture has been found as one of the fastest growing food producing sectors of the world, contributing significantly to poverty alleviation, food security, and rural development. In Vietnam, aquaculture is identified as a key economic sector for the nation. According to Commercial Aquaculture Magazine, the total value of aquaculture production in 2011 was estimated at 99.432 billion dong, accounting for 3.92% of GDP (Commercial Aquaculture Magazine, 2011). Thua Thien Hue Province which locates in the middle of Vietnam is one of the potential provinces for aquaculture development. According to socio-economic report of Thua Thien Hue Province in 2010, economic structure has shifted towards Service, Industry, Agriculture-Forestry-Aquaculture of which Service accounted for 45.2%, followed by Industry and Agriculture-Forestry-Aquaculture with 39.7% and 15.1%, respectively (The Official Web Portal of Vietnam Central Coastal Region, 2011). Particularly, in the field of Agriculture-Forestry-Aquaculture, aquaculture is regarded as the leading-edge sector of socio-economic provincial development strategy. It is because Thua Thien Hue province is endowed with 22,000 ha of natural water surface, namely Tam Giang-Cau Hai lagoon. Aside from being considered as one of the largest lagoon systems in Southeast Asia, Tam Giang-Cau Hai has also been found to be a promising area for aquaculture activities since 1990s, because of its suitable condition for the development of many kinds of aquatic species. The livelihood of approximately 300,000 local residents which is estimated nearly one-third of the population in Thua Thien Hue Province, are entirely or partly dependent on aquaculture activities.

Shrimp monoculture system which farmers cultivate only single species (shrimp) in their ponds, has emerged as the prominent model in this lagoon. It brought a lot of benefits to local farms. Many farms could change their lives from being poor to becoming millionaires in the early years of twentieth century due to shrimp monoculture practices. Those who used to visit Tam Giang-Cau Hai Lagoon at that time, surely enough heard local people mentioned the term “the super profitable cultivation” in reference to shrimp monoculture model. Real success as well as the bright prospect of shrimp production became extremely persuasive proofs to thousands of farms settling around the lagoon, and hence, encouraged them to get involved with shrimp monoculture practices. As a result, within merely a year the total area of aquaculture in the whole lagoon reached 1000 ha by 1999, 1700 ha by mid-2000 and 1850 ha by the end of 2000 (Phap et al., 2002). According to Fishery Department of Thua Thien Hue Province, the corresponding number in 2010 was 5800 ha, which is nearly six times more than that in 1990s – the very early years of aquaculture development (Thua Thien Hue Province People's Committee, 2011).

The thriving period of shrimp monoculture practices, however, could not be maintained for a long time. In recent years, shrimp monoculture has been facing a number of risks owing to shrimp diseases, water pollution, and low productivity, pushing many farms further into an impoverished and vulnerable state. This worrying situation of shrimp production also occurred in other countries such as India, Thailand (Kutty, 2005). According to Chambers and Conway, a livelihood is considered to be sustainable if and only if people are able to cope with and recover from shocks and stresses, maintain and improve their living standard as well as provide for future generations without compromising the natural resource base (Chambers & Conway, 1992). Therefore, it is clear to see that the sustainability of local livelihoods has been threatened. Accordingly, the current situation presses the need of seeking the sound direction for aquaculture development in such a way that sustainable livelihoods of local people in Tam Giang-Cau Hai Lagoon could be achieved.

IMOLA (Integrated Management of Lagoon Activities) project which aims at assisting Thua Thien Hue Province to promote the livelihoods of local people through the sound and sustainable management of natural resources in the Tam Giang-Cau Hai Lagoon has encouraged farms to apply poly-culture model due to it merits compared to monoculture model (Van, 2010). In the current context, shrimp poly-culture has been found as a good solution to deal with risks arisen from shrimp monoculture. Shrimp poly-culture model is the model that farmers feed three kinds of species: shrimp, crab, and fish in their ponds. Accordingly, shrimp, fish and crab together create a good ecosystem in earth pond because fish can eat the algae, dung of shrimp, and uneaten feed. Hence, the water environment can be improved by the poly-culture system itself, thereby, lessening the danger of shrimp diseases (Phuoc, 2009). Moreover, the initial capital is allocated to three species instead of investing on only shrimp, thus the risk of dead loss, to some extent, could be overcome.

Nevertheless, according to results investigated by Mohan and others, the technical efficiency of freshwater pond poly-culture farms in Vietnam was found to be considerably lower compared to that of China, India, and Thailand (Mohan Dey et al., 2005). The results achieved from poly-culture models in Vietnam so far have not been compatible with the potentials it has. The same story could be found in Tam Giang-Cau Hai Lagoon. Poly-culture techniques are still new to local farms that are used to solely practice shrimp monoculture, hence shrimp poly-culture model is currently characterized as a spontaneous practice performed by the minority farmers in this study area. Even for those who have been applied bravely this new model, the limited knowledge on poly-culture techniques hinders farmers from obtaining the high efficiency and productivity. Therefore, the need for improving efficiency of poly-culture production has become a crucial issue for the improvements of local farms' livelihoods, and consequently to achieve aquaculture sustainability development in Tam Giang – Cau Hai Lagoon, Thua Thien Hue Province.

Technical efficiency of shrimp monoculture has been extensively studied in Vietnam. Recently, there were several authors (Den et al., 2007; Akter, 2010) who studied on technical efficiency of shrimp farming. Meanwhile, there are currently few studies which were conducted related to shrimp poly-culture farms. Au (2009) researched on the technical efficiency of prawn-rabbit fish poly-culture. The estimated technical efficiency score was relatively high, approximately 0.9. The results showed that farms doing aquaculture in planned zone got technical efficiency higher than those outside the planned zone. However, the analysis of economic efficiency of shrimp poly-culture farms in Tam Giang-Cau Hai Lagoon has so far not been addressed yet.

Stemming from that reality, this paper aims to fill this gap. First, it evaluated the productive efficiency level of shrimp poly-culture farms by applying Data Envelopment Analysis (DEA) approach in order to help farms identify sources of inefficiency, and reallocate resources to obtain efficiency improvement. Secondly, it investigated factors affecting the inefficiencies of shrimp poly-culture farms by using Tobit regression model to handle the underlying causes of farm inefficiency. Results derived from this research can provide useful information for local farms to meet the sustainable livelihood goals and for policy makers to have the right orientation for the aquaculture development in the long-term.

This paper is structured as follows. Section 2 will describe materials and methods used in this study. In section 3, the empirical results are presented and discussed. Section 4 encompasses recommendation and policy implication.

2. Materials and Methods

2.1 Data Envelopment Analysis

2.1.1 Analytical Framework

The unknown production frontier is needed to estimate in order to obtain efficiency measures. There have been many different methods which were used to estimate frontier over the past 40 years. Among of those methods, the two principal methods are stochastic frontier analysis (SFA) and data envelopment analysis (DEA). The former is parametric method and bases upon econometric programming, while the latter involves mathematical programming and is considered as a non-parametric method (Coelli et al., 2005).

SFA and DEA have been extensively applied to many studies of various fields. The utilization of SFA in aquaculture could be found in the numerous studies such as Iinuma et al. (1999), Irz et al. (2003), Chiang et al. (2004), Mohan Dey et al. (2005), Kareem et al. (2008), Singh et al. (2009), Asamoah et al. (2012), Bukenya et al. (2013). However, the application of DEA to aquaculture is still limited compared to SFA. Sharma et al. (1999), Cinemre et al. (2006), Kaliba et al. (2006), Ferdous Alam et al. (2008), Cuong (2009), Nielsen (2011) employed DEA to evaluate the efficiency of aquaculture production.

Both parametric and non-parametric methods have their corresponding advantages and disadvantages. Although parametric method calls for an explicit form of the relation between inputs and outputs, one of its advantages is that statistical inferences could be drawn from the results. Parametric method uses statistical techniques to estimate parameters of production function, in which output is a function of a set of inputs, inefficiency, and random errors. On the contrary, relaxing the requirements for specifying the production form, DEA utilizes the linear programming methods to construct a piecewise linear frontier and compares each producer with the virtual producer in the data set. However, in DEA, all deviations from the frontier are attributed to inefficiency. It ignores random effects. Instead of being able to test hypothesis statistically as parametric method does, the DEA method concentrates on individual farms. One striking advantage of DEA over SFA is that DEA method can deal with multiple inputs and multiple outputs situation, while SFA only handles one output and multiple inputs situation. Because of that, DEA is favored measuring productive efficiency of shrimp poly-culture farms in this study.

DEA has received the wide attention since the paper of Charnes et al. (1978) was published. Economic Efficiency (EE) is the composition of two components: Technical Efficiency (TE) and Allocative Efficiency (AE) (Farrell, 1957). Technical Efficiency reflects the ability of a farm to either obtain the maximum output from a given set of inputs or to produce a given level of output by using the minimum amount of inputs for a given technology. Two ways for approaching DEA, thereby, are known as output-oriented and input-oriented models. According to Banker et al. (1984), orientation is selected based on which factors farmers have most control over. Meanwhile, Fare et al. (1993) pinpointed that farmers tend to have more controls over the inputs than over the amount of outputs. Therefore, input-oriented models were chosen in this study. Cinemre et al. (2006) who evaluated the cost efficiency of trout farms, and Nielsen (2011) who investigated green and technical efficient growth in Danish fresh water aquaculture applied DEA under input orientation. Allocative Efficiency is defined as the ability of farm to use the inputs in optimal proportions given their respective prices.

We assume that there are *N* shrimp Poly-culture farms. Each farm produces *M* kinds of outputs by using *K* kinds of inputs. The column vectors x_i and y_i are denoted the input and output data of *i*th farm, respectively. The data for all farms are represented by input matrix *X (KxN)* and output matrix *Y (MxN)*.

The input-oriented DEA model used to calculate **Technical Efficiency (TE)** is specified as follows:

$$\begin{aligned}
&\text{Min}_{\theta,\lambda} \quad \theta \\
&\text{s.t.} \\
&-y_i + Y\lambda \geq 0 \\
&\theta x_i - X\lambda \geq 0 \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \geq 0
\end{aligned}$$

λ denotes an $Nx1$ vector of constant weights which defines the linear combination of the peer of ith farm. $Y\lambda$ is the output vector of the theoretically efficient farm. The first constraint forces that the theoretically efficient farm has to produce the amount of output more than or at least equal to that of farm ith. $X\lambda$ is the minimum input of the theoretically efficient farm used, given the actual quantity of output produced by ith farm. θ is the proportional decrease in input that can be achieved by farm to produce the given output. θ measures Technical Efficiency score and ranges from 0 to 1. The second constraint shows how much inputs the ith farm could be reduced. The third constraint is convexity constraint which is added in order to make sure that the theoretically efficient farm and the ith farm are similar in scale size. The linear programming problem will be solved N times to attain θ for each farm. If the solution of linear programming problem turns θ out to be equal to 1, the ith farm is technical efficient, otherwise it is technical inefficient. This is because if θ is equal to 1, the ith farm uses the same amount of inputs as theoretically efficient farm does to produce the same given quantity of outputs. In case, θ is less than 1, there is still room for the ith farm to reduce inputs usage further as low as the minimum of inputs used by theoretically efficient farm so that the existence of technical inefficiency of the ith farm could be found.

Economic Efficiency (EE) could be derived from solving the additional cost minimization DEA problem:

$$\text{Min}_{\lambda, x_i^*} \; w_i x_i^*$$

$$\text{s.t.}$$

$$-y_i + Y\lambda \geq 0$$

$$x_i^* - X\lambda \geq 0$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0$$

Where w_i is a vector of input prices for the ith farm and x_i^* which is calculated by the model is the cost-minimizing vector of input quantities for the ith farm, given the input price w_i and the output levels y_i. Then the ratio of minimum cost to observed cost of the ith farm defines its Economic Efficiency.

$$EE = \frac{w_i' x_i^*}{w_i' x_i}$$

Allocative Efficiency (AE): Economic Efficiency is the multiplication of Technical and Allocative Efficiency (Farrell, 1957). Allocative Efficiency, thereby, is calculated as:

$$AE=EE/TE$$

2.1.2 Data and Variables

Source of data:

Every year, Thua Thien Hue Province has to cope with some serious floods around October to November. Accordingly, the period time from February to July is chosen for aquaculture cultivation because that time creates the best condition for the development of aquatic species. The cross-sectional data was caught through questionnaire interview. 70 shrimp poly-culture farms in Tam Giang-Cau Hai Lagoon were randomly selected and face to face interviewed in order to get detailed information on various aspects of shrimp poly-culture production. Moreover, farm socio-economic characteristics and farm practices information were also collected.

Variables:

Five inputs to produce three kinds of output were identified. Farm size represents the cultured area of farm, measured in m^2. Labor denotes the number of person-days per m^2. Shrimp seed, Crab seed, Fish seed respectively indicate the amount of shrimp, crab, and fish fingerlings released per m^2. Feed is expressed as the volume of feed used per 10,000 fingerlings. Chemicals represent the quantity of lime and antibiotics used to deal with diseases and water pollution, measured in kilograms per m^2. Table 1 presents the summary statistics of inputs and outputs of shrimp poly-culture farms. The most striking feature, as can be seen, is the large variability of outputs and inputs among farms. These considerable variations reveal that there exist inefficiencies on inputs usage among farms, indicating the need for managerial efficiency.

Table 1. Summary statistics of the inputs and outputs of shrimp poly-culture farms

Variable	Unit	Mean	Std.Dev	Min	Max
Inputs					
Farm size	m^2	5882.800	2551.100	1500.000	12000.000
Labor	person- day/ m^2	0.054	0.032	0.009	0.015
Shrimp seed	fingerlings/ m^2	19.700	9.296	5.000	40.000
Crab seed	fingerlings/ m^2	1.283	1.044	0.125	6.000
Fish seed	fingerlings/ m^2	3.958	3.485	0.625	17.500
Feed	kg/10,000 fingerlings	162.840	67.766	14.268	305.049
Chemicals	kg/ m^2	0.035	0.010	0.010	0.060
Outputs					
Shrimp	kg/ m^2	0.129	0.080	0.003	0.344
Crab	kg/ m^2	0.115	0.009	0.001	0.050
Fish	kg/ m^2	0.082	0.268	0.002	1.805

2.2 Tobit Regression Model

Efficiency scores vary between at 0 and 1. In other words, the distribution of efficiency scores will be censored by the left to a zero value and the right to one value if analyzed. For these reasons, Tobit regression (Tobin, 1958) is preferable to the Ordinary Least Square (OLS) regression in assessing factors affecting on technical efficiency, allocative efficiency and economic efficiency. If the Ordinary Least Square regression has applied, it could not have identified difference among the censored and continuous observation, resulting in potential bias and inconsistent parameter estimation problem. Tobit regression, meanwhile, can deal with that weakness of the OLS regression and generates consistent parameters. The model is defined as:

$$y_j^* = \beta_o + \sum \beta_m X_{jm} + \varepsilon_j$$

$$\varepsilon_j \sim N(0, \sigma^2)$$

$$y_j = \begin{cases} 1 & \text{if} \quad y_j^* \geq 1 \\ y_j^* & \text{if} \quad 0 \leq y_j^* \leq 1 \\ 0 & \text{if} \quad y_j^* \leq 0 \end{cases}$$

Where y_j^* is the latent variable representing the efficiency of farm *j*

X_{jm} is a vector of explanatory variables *m* (*m*=1,7) for farm *j*

ε_j is an error term that is independently and normally distributed, with mean zero and a constant variance.

The empirical model is presented in the form as following:

$$EFFICIENCY=\beta_0 + \beta_1 EDU + \beta_2 EXPERIENCE + \beta_3 TRAIN + \beta_4 EXTENSION + \beta_5 COOP + \beta_6\, POLLUTION + \beta_7 TIMES + \varepsilon_i$$

EFFICIENCY is the technical efficiency or allocative efficiency or economic efficiency of farms calculated by DEA method.

Table 2. Definition and descriptive statistics of variables used in Tobit regression analysis

Variable	Description	Mean	Std. Dev	Min	Max
TE	Technical Efficiency	0.840	0.200	0.343	1.000
AE	Allocative Efficiency	0.642	0.238	0.214	1.000
EE	Economic Efficiency	0.553	0.276	0.084	1.000
EDU	1 if farmer's education level is high school or higher education level, 0 otherwise	0.386	0.490	0	1
EXPERIENCE	Experience years in aquaculture (years)	18.414	11.281	2	40
TRAIN	1 if farmer joins training courses, 0 otherwise	0.571	0.498	0	1
EXTENSION	The number of times that aquaculture extension staffs visit farm per year (times)	0.714	0.705	0	2
COOP	1 if farmer joins Fish Association, 0 otherwise	0.586	0.496	0	1
POLLUTION	1 if water quality based on farm's perception is polluted, 0 otherwise	0.557	0.500	0	1
TIMES	The number of times that farmer changes water per crop (times)	4.500	2.957	1	10

The descriptive statistics of sample variables are summarized in Table 2. The percentage of farmers who finish high school or university, accounts for only 38.6%. Although their education level is low, their experience in aquaculture activities is relatively high with nearly 18.5 years. Local government organizes annual periodic training course for providing farmers with knowledge on aquaculture activities. The proportion of farms who attend those training course is approximately 57.1%. Fish Association is established with the aim of sharing experience in aquaculture activities among farms. Moreover, Fish Association also helps farms timely and sufficiently approach market information, and prevent from information interference, which leads to buy inputs with high price but sell products with low price. Until the interview time, 58.6% farms have already joined in the Fish Association. Water environment has been in the state of pollution is the evaluation of most farmers when they were asked about the water quality of their cultivation area.

The hypotheses to be statistically tested are farm personal characteristics (education level, experience), access to institutions (attending training course, member of the Fish Association, contacting with aquaculture extension staff), and water environment (water quality, the number of changing water in cultivation ponds per crop) are determinants, which have relationship with efficiency estimates.

3. Results and Discussion

3.1 Productive Efficiency of Shrimp Poly-Culture Farms

The software DEAP version 2.1 (Coelli, 1996) is utilized to estimate three efficiency measures. The frequency and the percentage distribution of efficiency measures are reported in Table 3. The empirical results indicate that the mean of Technical Efficiency, Allocative Efficiency and Economic Efficiency are 84.01, 64.16, and 55.32 percent, respectively. This proves that there is still room for improvement the efficiency of shrimp poly-culture production. Regardless of input prices, farms mix inputs used quite efficiently since their average Technical Efficiency is fairly high at 84.01 percent. However, farms have potentials to reduce their physical inputs used by 15.99 (= 100 – 84.01) percent, and still maintain their production levels. The wrong combination of inputs used, given their prices lead the cost to be 35.84 (= 100 – 64.16) percent higher than the cost minimizing level. It seems that farms mostly apply inputs based on their experience rather than market information. The mean of Economic Efficiency is 55.32 percent with the range of 8.4 percent to 100 percent. This implies that farms could save average of 44.68 (= 100 – 55.32) percent of production cost without affecting the existing output levels.

As we known, under DEA framework, each farm self-evaluates its efficiency relative to the other farms in the data set. Jaforullah and Whiteman (1999) mentioned that in the absence of environmental differences and errors in measurement of inputs and outputs, inefficiency could be derived from the best practice farm management. Adopting the best practice of efficient farms, thus, is the crucial way to eliminate inefficiency. Therefore, it is worthwhile to distinguish the input usage between the economically efficient farms and inefficient ones in an attempt to detect the sources of inefficiency.

Table 3. Frequency and percentage distribution of TE, AE and EE

Efficiency Level (%)	TE		AE		EE	
	No[a]	%[b]	No[a]	%[b]	No[a]	%[b]
<20	0	0.0	0	0.0	4	5.7
20-30	0	0.0	4	5.7	9	12.9
30-40	1	1.4	9	12.9	12	17.1
40-50	7	10.0	6	8.6	10	14.3
50-60	4	5.7	13	18.6	10	14.3
60-70	6	8.6	13	18.6	5	7.1
70-80	7	10.0	4	5.7	3	4.3
80-90	4	5.7	6	8.6	2	2.9
90-100	9	12.9	4	5.7	4	5.7
100	32	45.7	11	15.7	11	15.7
Mean (%)	84.01		64.16		55.32	
Minimum (%)	34.30		21.40		8.40	
Maximum (%)	100.00		100.00		100.00	

Note: [a] indicates the number of farms, [b] indicates the percentage of total farms.

According to the results presented in Table 3, 11 farms among 70 farms are economically efficient on account of achieving Economic Efficiency score of unity. In order to discriminate the input combination between economically efficient and inefficient farms, a non-parametric rank sum test - Mann-Whitney U test is implemented (Table 4). Mann-Whitney U test indicates that there is significant difference in farm size between economically efficient and inefficient farms at 5 percent significance level. On average, economically efficient farms operates at roughly 4990 m^2, while the corresponding farm size of economically inefficient farms is around 6049 m^2. Table 4 also sheds the light on the difference in quantity of feed used between economically efficient and inefficient farms. Mann-Whitney test reveals that there is significant difference in the volume of feed at 10 percent significance level. On average, efficient farms feed their stocks less than inefficient farms do, 125.93 kg/10,000 fingerlings compared with 169.73 kg/10,000 fingerlings.

Table 4. Comparing inputs used between economically efficient and inefficient farms

EE	Unit	Efficient Farms	Inefficient farms	P-value
Farm size	m^2	4990.91	6049.15	0.038**
Feed	kg/10,000 fingerlings	125.93	169.73	0.065*
Shrimp seed	fingerlings/m^2	13.09	20.93	0.007***
Crab seed	fingerlings/m^2	2.31	1.09	0.004***
Fish seed	fingerlings/m^2	4.92	3.78	0.194

Note: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively.

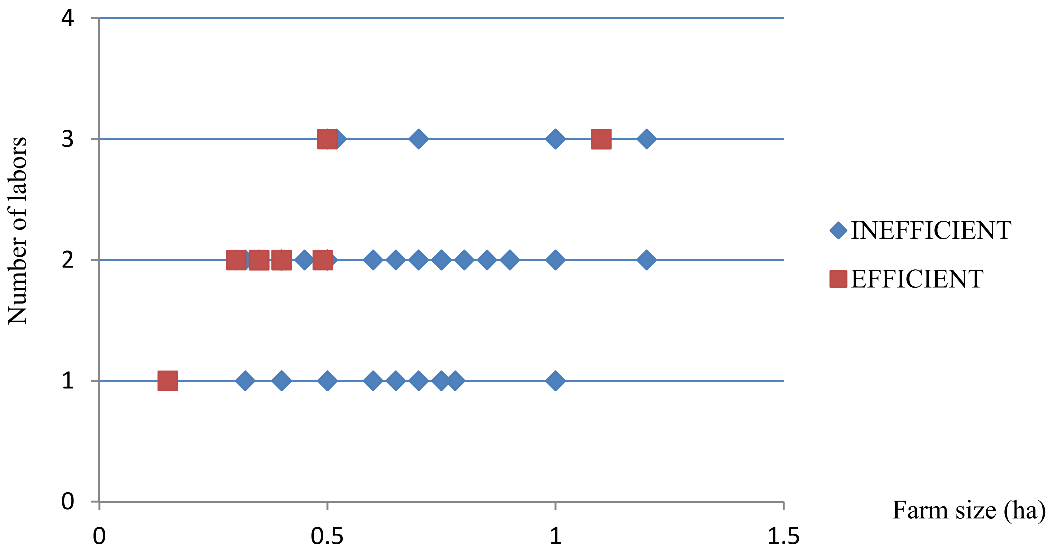

Figure 1. Farm size and number of family labors involved in Poly-Culture practices

The larger farm size is, the more labors are needed to manage and oversee farm production. Despite of lacking labors, many farms still operate at large farm size, resulting in unsupervised work and poor aquaculture practices. The relationship between number of labors and farm size provides information for farms to choose the farm size properly, based on their existing labor force. The interesting point could be observed from Figure 1 is that most of economically efficient farms operate at farm size of less than 0.5 ha. It is suggested that farms which have no more than two labors should operate at small farm size (less than 0.5 ha); otherwise farms tend to be inefficient due to beyond their management ability. If farms are capable of enhancing their labor force by utilizing their family labors or hiring more labors, they could enlarge their production scale.

Table 5. Effect of farm size on technical, allocative and economic efficiency

Farm size	Number of farms	TE	AE	EE
<0.5 ha	27	0.928	0.815	0.765
0.5-1 ha	33	0.786	0.552	0.428
>1 ha	10	0.780	0.470	0.395
Chi_square		7.002	25.533	28.408
Sig		0.030**	0.000***	0.000***

Note: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively.

A non-parametric Kruskal-Wallis test indicated that efficiency scores are substantial difference across farm size (Table 5). The smaller farms are likely to be more efficient than the large ones, indicating the existence of diseconomies of scale in this study area. This result is consistent with findings of Ali et al. (1994), Sharma et al. (1999), Engle et al. (2004), Cinemre et al. (2006) who explored that small farms tended to be more efficient than large farms, but differ from the results of Dey et al. (2000), Sharma et al. (1997), Singh et al. (2009) who found that farmers with larger pond area attained higher efficiency. With respect to the current situation of shrimp poly-culture farms, the optimal farm size should be less than 0.5 ha. The negative relationships between farm size and efficiency measures are perhaps not surprising because the number of family labors involved in shrimp pond practices, on average, is only 1.93 people per farm. Furthermore, most of farms mainly rely on family labors, resulting in the limitation of farm management ability. Farmer's ability to manage shrimp poly-culture production activities decreases with the increase of farm size. Operating at small farm size enables farmers to control pond maintenance, feeding, and to supervise the health of three kinds of species better than operating at large farm size. The diseconomies of scale probably occur because the gain from the economies of scale could not compensate for the loss caused by such management inefficiencies.

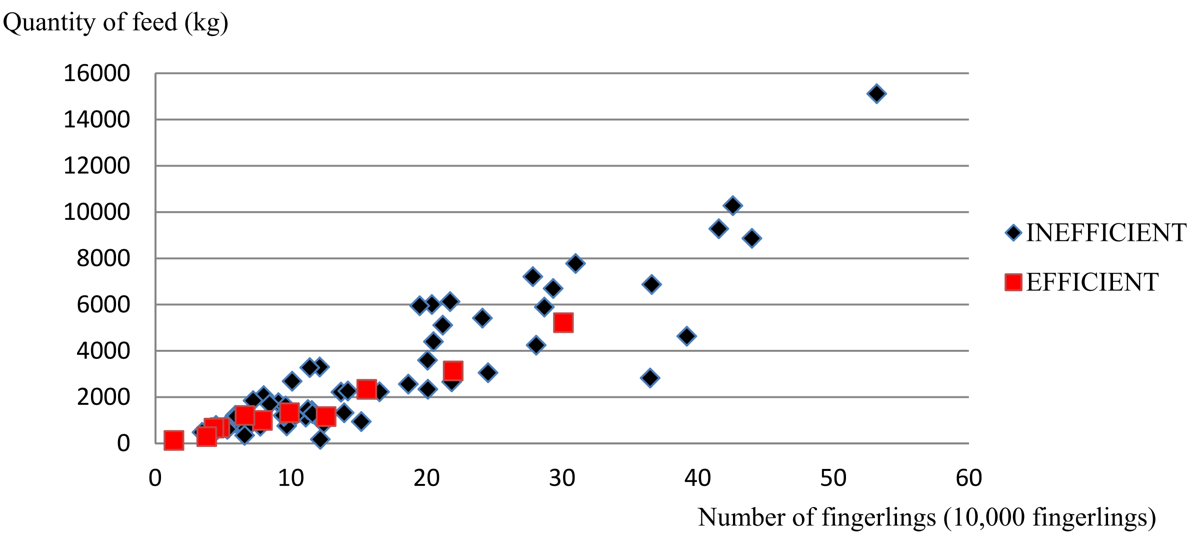

Figure 2. The quantity of feed and number of fingerlings used by Poly-Culture Farms

Figure 2 shows the distribution of poly-culture farms according to the quantity of feed and number of fingerlings released. Despite of releasing the same amount of fingerlings with efficient farms, most of inefficient farms over-feed their species. The considerable redundancy of feed causes production cost to rise substantially. Production efficiency, thereby, is not as high as farms expect. Furthermore, feed surplus also results in degrading the water quality due to the sediment made by the accumulation of uneaten feed, which had negative effect on production later. Therefore, properly feeding is a necessary requirement to improve farm performance. DEA results recommend economically inefficient farms that the amount of feed should be 118.18 kg per 10,000 fingerlings (Table 6). By applying this recommendation, economically inefficient farms could reduce production cost, and use cost-savings for others purposes as well as diminish water pollution.

There are substantial distinctions in shrimp and crab stocking density at 1% significance level while fish stocking density is not significant difference (Table 4). DEA results recommend inefficient farms that the optimal stocking density is 8.15 for shrimp, 1.59 for crab and 2.46 for fish per m^2 (Table 6). Comparing with the optimal stocking density, 59 economically inefficient farms out of 70 farms are divided into 2 groups: below optimum group and above optimum group.

Table 6. Actual and Economically optimal quantity of feed and stocking density for economically inefficient farms

EE	Unit	Efficient farms (n=11)	Inefficient farms (n=59)	
		Actual	Actual	Optimal
Feed	kg/10,000 fingerlings	125.93	169.73	118.18
Shrimp seed	fingerlings/m^2	13.09	20.93	8.15
Crab seed	fingerlings/m^2	2.31	1.09	1.59
Fish seed	fingerlings/m^2	4.92	3.78	2.46

Table 7. Average deviations from optimal stocking density of economic inefficient farms

Species	Unit	Stocking density			
		Below optimum		Above optimum	
		Average deviation	No[a]	Average deviation	No[a]
Shrimp seed	10,000 fingerlings/m^2	-2.82	2	13.33	57
Crab seed	10,000 fingerlings/m^2	-0.79	47	0.65	12
Fish seed	10,000 fingerlings/m^2	-0.87	22	2.62	37

Note: [a] indicates the number of farms.

Table 7 indicates that 57 farms out of 59 economically inefficient farms over-stock shrimp, meanwhile 47 of the 59 economically inefficient farms under-stock crab. This results stems from the fact that despite of transforming from monoculture into poly-culture techniques, most of farms do not dare to make a big change in the combination of 3 species. This is because local farms have a long history attaching to shrimp monoculture, while just accustomed to poly-culture techniques for a short time. Shrimp, thus, is still the main species, accounting for a high stocking density relative to other species. The results suggested that farms should decrease the stocking density of shrimp and increase that of crab. By doing this, farms can diversify their outputs and reduce risks of mono-cultivation. In addition, crab market is one of potential markets where farms still earn more income because the supply does not meet its demand yet. Accordingly, once farms bravely adjust the composition of 3 kinds of species, they could further improve their production efficiency.

3.2 Factors Affecting Farmer's Efficiency

The likelihood ratio test (Table 8) pinpoints that the hypothesis, which all variables included in the Tobit model are statistically insignificant is rejected at 1 percent significance level.

Table 8. Estimated results of Tobit regression for Technical Efficiency (TE), Allocative Efficiency (AE), and Economic Efficiency (EE) of farms

Variable	TE		AE		EE	
	Coefficient	Std.Error	Coefficient	Std.Error	Coefficient	Std.Error
EDU	0.034***	0.069	0.208***	0.060	0.204***	0.046
EXPERIENCE	0.014***	0.003	0.001	0.002	0.004**	0.002
TRAIN	0.011***	0.061	0.171	0.059	0.155***	0.046
EXTENSION	0.072	0.055	0.106	0.052	0.038	0.040
COOP	0.038	0.034	0.007**	0.028	0.009*	0.022
POLLUTION	-0.196***	0.071	-0.005	0.065	-0.090**	0.050
TIMES	0.027**	0.011	0.009	0.010	0.016**	0.008
INTERCEPT	0.674***	0.094	0.391***	0.085	0.274***	0.065
Likelihood ratio test	78.73		73.67		124.28	
Sig	0.000		0.000		0.000	

Note: ***, **, * indicate statistical significance at the 0.01, 0.05, and 0.1 level respectively.

As shown in Table 8, the estimated coefficients of *EDU* have positive statistically significant effect on technical, allocative and economic efficiency. This indicates that farmers with higher education level tend to be more technical, allocative, and economic efficient than those with lower education level. Higher education level helps farmers to acquire aquaculture techniques more easily, and sufficiently catch market information. Therefore, their input combination is more optimal and input cost could be reduced substantially to attain the same volume of output. However, as mentioned above, the educational level of shrimp poly-culture farms is still low. Through our survey, we recognize that local people in this study area do not fully understand the role as well as the benefits that an education can bring. This can be considered as the deep-rooted cause of the poverty circle. Therefore, improving farm's educational level should be the top concern of local government.

EXPERIECE is found to have positive statistically significant connection with TE and EE at 1% and 5% significance level. This indicates that the more years involved in aquaculture activities the more efficient household is. In other words, past experience with aquaculture cultivation increase farm skills, hence improving the management efficiency of shrimp poly-culture practices.

Results concerning *TRAIN* suggested that farmers, who join training courses which are organized by local government, are likely to be more efficient than farmers who do not join. It has a robust and positive relationship with TE and EE. Through these training courses, aquaculture experts provide farmers with aquaculture techniques and raise awareness for natural resources conservation, environmental and biodiversity issues. By this way, understandings of farmers about aquaculture are upgraded which, in turn, will help them to use optimal inputs.

COOP has positive contribution to AE and EE considerably. Fish Association proves its important role in improving allocative efficiency for farms because the striking merit of Fish Association is that it helps farms fully approach market information. Furthermore, the Fish Association also provides good opportunities for inexperienced farms that have just started their cultivation in recent years to learn practical experiences and to acquire the necessary know-how for their cultivation from experienced farms.

The statistically strong significant effect of *POLLUTION* with TE and EE points out that the more polluted water quality is, the more technically and economically inefficient the farm is. Water quality is the most important factor to determine the productivity in aquaculture because the survival rate of species depends almost on water quality. If species are raised in polluted water, they are in danger of contracting diseases. Thus, keeping water purify is essential work that farmer should concentrate. However, one of the characteristics of shrimp poly-culture farms is that they use the same water sources from Tam Giang-Cau Hai Lagoon. Most of farms directly discharge waste water of their aquaculture activity into the lagoon without any prior treatment. Consequently, shrimp diseases easily spread over farms, lowering efficiency of farms.

EXTENSION is found to be not significant effect on efficiency. Results indicate that aquaculture extension staffs have not exerted themselves to increase production efficiency of shrimp poly-culture farms yet. Extension staffs have not been in close co-operation with farmers. Although extension staffs visited farms, they did not carefully collect information associated with current situation of farms. As a result, they cannot promptly support farms in solving problems which farmers encounter during their production process. This result indicates the need of improving the contact between extension staffs and farmers in this study area. The study of Engle et al. (2004), Cinemre et al. (2006) emphasized the role of extension contacts to improve farm efficiency, and that the more frequent contact with extension staffs resulted in a decrease in inefficiency of farms.

The estimated coefficients of *TIMES* demonstrate that *TIMES* has positively significant effect on TE and EE. Carefully overseeing water environment and carrying out timely change of water upon observing signs of water pollution contribute to ensure the existence of a healthy environment for the development of species, and thereby, result in positive contribution to efficiency.

4. Conclusions and Policy Implications

This paper applied DEA to analyze productive efficiency of shrimp poly-culture farms in the first stage, and then, the effect of factors on farm efficiency were extrapolated from Tobit model regression in the second stage.

DEA results show the existence of a great scope for improving the efficiency of shrimp poly-culture production in Tam Giang-Cau Hai Lagoon. In fact, most of economically inefficient farms overuse inputs and do not apply the proper inputs mix. By learning from the best practice performance, the economically inefficient farms should take both economic and environmental issues into consideration by reducing the amount of feed to 118.18 kg/10,000 fingerlings. Moreover, farms need to make good another point in term of farm size or scale production. Because of the current labor force limitation, the optimal farm size for shrimp poly-culture farms should be less than 0.5 ha. However, this recommendation is only suitable in short-run because farms could not immediately change their current resources. In long-run, farms should enlarge their farm size in order to shift aquaculture production from small scale to large scale. By such a way, aquaculture could become a big industry, contributing more to the economic development of Thua Thien Hue province. Additionally, it is important to bring some adjustments of the composition of three kinds of species to the notice of farms in order to meet demand market and alleviate risks.

Tobit results explain the effect of farm socio-economic characteristics, farms practices and water quality on the variation of the efficiency. The results prove that education positively contributes to farm's efficiency production. Local government should increase more investment on education to better farm performance. Farm practices such as joining training courses and Fishing Association, are found to have positive effect on efficiency. Training courses mainly enhance technical efficiency, while Fish Association further improves allocative efficiency of farms. Therefore, training courses, together with Fishing Association could remedy the existing shortcomings of shrimp poly-culture farms, which lack the market information concerning input prices, output prices, and techniques of poly-culture production. It is suggested that local government should organize adequate training courses, and then, propagandize the importance of attending training courses and joining Fish Association to farms since those can improve farm's efficiency. Regarding aquaculture extension staffs, they should further promote their roles by fulfilling their duties more diligently. Farmer-extension staff relationship can be strengthened through regular visits to farm cultivation area, which keep the staffs informed about farm problems and promptly assist these farms into attaining a solution. Furthermore, DEA is regarded as a useful extension tool because it can segregate efficient and inefficient farms. Extension staffs can utilize the information related to operating practices of efficient farms to diffuse the good practices in term of farm management throughout aquaculture farms. The dissemination of these practices could be conducted by various ways such as broadcasting media of local area, group activities, farm visits or field trips on efficient farms, thus farmers can easily catch the information of the good operating practices. Water environment has strong effect on technical and economic efficiency. Therefore, water pollution is the urgent problem needed to be tackled with the aim of obtaining higher efficiency of shrimp poly-culture production. According to the findings of this study, a good solution to deal with this problem is to minimize the quantity of food surplus, which not only contributes to alleviate water pollution but also enables farmers to reduce their production cost. Furthermore, it is also recommended that waste water from aquaculture activities should be properly treated before discharging into the lagoon in order to prevent the spread of shrimp diseases because all farms use the same water resource from Tam Giang-Cau Hai Lagoon for their aquaculture activities. It is strongly believed that once these solutions are implemented, they can prove effectiveness to reduce water pollution, and to achieve sustainable livelihood for local farmers in long-term.

In sum, this paper provides farms as well as local authority with useful information and recommendation in the process of solving the hard "mathematical exercise", namely "sustainable livelihood" for local farms in Tam Giang-Cau Hai Lagoon. It is emphasized that success can only be achieved if farms are educated about shrimp poly-culture production, along with proper care from local government.

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