Technical efficiency of prawn poly-culture in Tam Giang lagoon, Vietnam

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Abstract

This paper measured the mean technical efficiency of 91 percent in prawn poly-culture (prawn (*Peneaus monodon*)-rabbitfish (*Siganus oramin*)-others pattern) farms in Tam Giang lagoon, Vietnam, using an input-oriented VRS data envelopment analysis. The estimated technical super-efficiency was then regressed to the farmer characteristics, extension contacts, stocking density, and production environment to identify the determinants of technical efficiency of those farms. Experience of the operators, their attendance to aquaculture training courses were the factors positively influencing farm level efficiency, while prawn stocking density had negative relationship with their technical efficiency. The later results also revealed the problem of congestion in prawn poly-culture production process. Moreover, the positive coefficient of production environment dummy variable indicated the difference between two types of ecosystem: planned farms and unplanned farms. In addition, in comparison between the technical efficiency results of those two groups, the unplanned farms were less efficient than planned ones. A suggestion of planning aquaculture area in Tam Giang – Cau Hai lagoon system and cooperating between unplanned farms and governmental offices, as a result, were made to improve technical efficiency. Moreover, training more extension workers and conducting more aquaculture training courses were also suggested in order to have the desired increase in productivity. Finally is a hint of further study about the congestion problems which have not been dealt in this study.

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1. Introduction

1.1. Problems statement

Tam Giang – Cau Hai lagoon system, located mainly in Thua Thien Hue province in the central of Vietnam, is one of the twelve largest lagoons in Asia, and is the most typical lagoon system of Vietnam. It receives fresh water from most rivers in the province and discharges to the sea through two narrow tidal inlets. This dynamic brackish water, hence, is a good habitat for both freshwater and marine aquatic species. Therefore, in 1994, the policies of Thua Thien Hue province directed this lagoon system as the second strongest potential (after tourism) and supported aquaculture development (Nhung 2008). There has been, since then, a boom in aquaculture, especially in shrimp mono-culture in this lagoon area. Aquaculture area has increased significantly, uncontrollably, and spontaneously from 110 hectare in 1991 to more than 4000 hectare in 2004. Pollution, disease widespread, and finally poor crop were alarmed (Tuyen 2005; Xuan 2008) (Fisheries Department of Thua Thien Hue province, 2004).

Planning boomed aquaculture area and applying poly-culture have been considered as two main methods to solve those problems. Phap and Thuan (2002) recommended that shrimp poly-culture such as prawn (*Peneaus monodon*)-fish (*Siganus guttatus*)-crab (*Scylla serrata*)-seaweed (*Gracilaria tenuistipitata*) pattern, or prawn-seaweed pattern, or prawn-crab-fish pattern are more sustainable than prawn mono-culture. Moreover, the original purpose of those poly-culture patterns, since the past, was basing on living, feeding, and reproducing habits of aquatic animals to utilize the existing conditions in ponds and maximize physical production. In other words, shrimp poly-culture is believed to improve the efficiency of aquaculture. As a result, among many poly-culture experimented patterns, prawn (*Peneaus monodon*)-rabbitfish (*Siganus oramin*)-others has been applied widely in Tam Giang – Cau Hai lagoon area as one of the best ways to avoid and reduce the risk of losing the whole crop due to diseases in recent years (Agricultural Forestry and Fishery Extension Centre of Thua Thien Hue province). Is this prawn poly-culture an efficient pattern? What are their technical efficiency levels? How many inputs were actually used and should be used, especially in the situation of limited resources such as pond size, capital, available man power, skilled staff and worker, high quality seed and feed, infrastructure, and so on. Which factors should be controlled to improve technical efficiency? Are there any differences in level and determinants of technical efficiencies between planned and unplanned ponds? Those are the necessary and useful information for not only the farmers themselves, but also fisheries extension offices at both local and central levels, and policies makers.

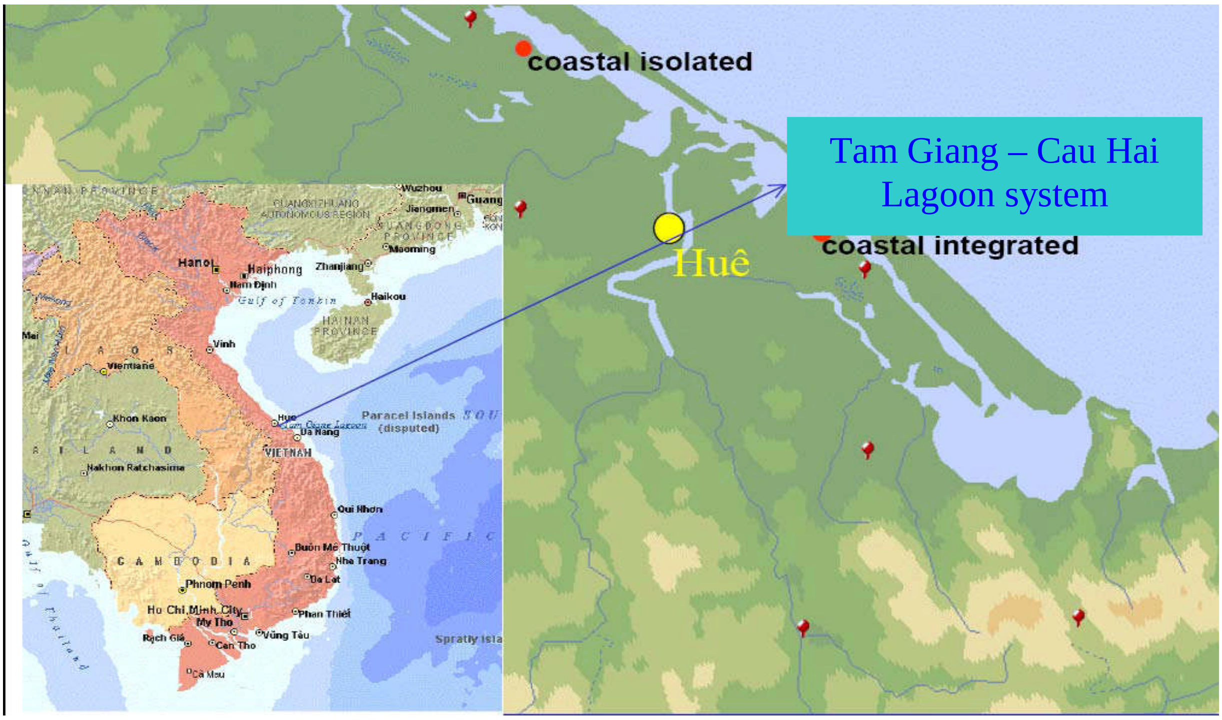


Figure 1: The allocation of Tam Giang - Cau Hai lagoon system in Vietnam

Source: (IUCN)

Up to now, some studies have officially reported about economic efficiency of aquaculture in Tam Giang – Cau Hai lagoon system, such as economic efficiency of shrimp-culture of Xuan and Hoa (2005), economic valuation of Tam Giang lagoon of Xuan (2008) and some other relevant studies at university level. However, so far no studies have estimated technical efficiency for aquaculture, especially for shrimp poly-culture in this area. Moreover, most of the studies about the technical efficiency of Vietnam aquaculture used stochastic production frontier approach (SPF) (Dey, Paraguas et al. 2005; Den, Ancev et al. 2007). No one has ever used data envelopment (DEA) in analyzing efficiency of aquaculture, to my knowledge. Meanwhile the data envelopment analysis (DEA) seems to be more appropriate than stochastic production frontier in poly-culture, which is able to produce more than one output (multi-output) from multi-input (Herrero 2003; Pascoe 2003; Timothy J. Coelli, D.S. Prasada Rao et al. 2005).

Based on above problems statement, this study aims to discover the technical efficiency of prawn (*Peneaus monodon*)-rabbitfish (*Siganus oramin*)-others pattern in Tam Giang lagoon by applying two-stage data envelopment analysis approach (DEA). The technical efficiency score of these prawn poly-culture farms are estimated in the first stage to identify how efficient those farms are, and which type of production environment, planned or unplanned farms, is more efficient. The estimated results are then regressed to some characteristics of the operators, their ability to access extension services, prawn and rabbit-fish stocking density, and ecosystem dummy variable to determine which factor affects on technical efficiency of those farms.

1.2. Objectives of the study

From above purpose, three specific objectives can be identified as follows:

1) To study the existing aquaculture production in Tam Giang lagoon;

2) To measure the technical efficiency of prawn-rabbitfish poly-culture in Tam Giang lagoon;

3) To investigate the main factors affecting the technical efficiency of prawn-rabbitfish poly-culture in Tam Giang lagoon.

1.3. Hypotheses of the study

1) Planned prawn-rabbitfish ponds have higher technical efficiency scores than unplanned ponds.

2) Individual characteristics of the farmer such as experience, education and their ability to access extension are significant factors affecting the technical efficiency of prawn-rabbitfish poly-culture production.

3) Differences in shrimp and rabbit-fish stocking densities have no effect on technical efficiency.

1.4. Organization of the study

The study contains 6 chapters. Chapter 1 is the introduction with problems statement, the objectives and hypotheses of this study. Then an overview of aquaculture in Tam Giang – Cau Hai lagoon system is presented in Chapter 2. This Chapter covers the whole picture of lagoon aquaculture including general introduction on the allocation and some characteristics of this lagoon system, aquaculture labor, aquaculture area, and aquaculture production.

Chapter 3 starts with some definitions of technical efficiency and its measurements. Then some empirical studies related to technical efficiency in aquaculture are reviewed.

In Chapter 4, how the data were collected is described in sampling method and sample sizes. Then the methods to analyze data such as data envelopment analysis in the first stage and ordinary least square regression in the second stage are mentioned.

Chapter 5 is the presentation of analysis result on estimated technical efficiency scores and the factors effecting on this efficiency. And those results are discussed later in this chapter.

Chapter 6 ends this study by some main conclusions about the analysis results. Based on those, some recommendations are made to improve the technical efficiency in the study area.

2. Overview of aquaculture in Tam Giang – Cau Hai lagoon system

Tam Giang – Cau Hai lagoon system is the biggest lagoon in South East Asia with highly diverse aquatic ecosystem. It is approximately 22,000 hectares in area, and 68 km in length from O Lau river mouth in the north-west to Vinh Long Mountain in the south-east. It is divided into 3 main regions, i.e. Tam Giang lagoon in the north; Sam Chuon, An Truyen and Thuy Tu lagoons in the central; and Cau Hai lagoon in the south. Its flow is from most of inland rivers and two narrow tidal inlets of Thuan An and Tu Hien. Therefore, this large brackish water course plays an important role in terms of environment, biodiversity, and economic development in the central region of Vietnam (Lan 2005; Nga 2006; Nhung 2008).

2.1. Aquaculture labor

Tam Giang – Cau Hai lagoon system comprises 33 communes and towns in 5 districts. In which, 2 communes are in Phong Dien district, 8 communes in Quang Dien district, 2 communes in Huong Tra district, 13 communes in Phu Vang district, and 8 communes in Phu Loc district (Table 1). More than 350,000 people, accounting for almost one-third of the population of Thua Thien Hue province, live on the margins of the lagoon.

Table 1: Distribution of communes and labors by district in Tam Giang – Cau Hai lagoon system

Districts	No. of communes	Distribution of labors	
		No. labors	Percent (%)
Phong Dien	2	15976	11.59
Quang Dien	8	24711	17.94
Huong Tra	2	15712	11.42
Phu Vang	13	45863	33.29
Phu Loc	8	35497	25.76
Total	**33**	**137779**	**100**

Source: Fisheries Department of Thua Thien Hue province, 2004

In which, it is estimated that about 100 thousand people depend on fishery and aquaculture, and 200 thousand have other livelihoods including part-time aquaculture and capture fisheries

(Tuyen 2005). The labor source makes up about 43 percent of total population (Fisheries Department of Thua Thien Hue province, 2004). Its detail distributions by district are shown in Table 1.

It is the fact that 3 districts in Tam Giang lagoon (Phong Dien, Quang Dien, Huong Tra) contributes more than 40 percent to the labor force of this lagoon system (Table 1). However, their education is mainly at primary level. The number of employed labor was 8356 people in 2004, accounting for 94% of labor force in this area. They mainly work in agriculture, fishery, and aquaculture sectors (Fisheries Department of Thua Thien Hue province, 2004).

Table 2: Distribution of labors by economic sectors in Tam Giang – Cau Hai lagoon system

Economic sectors	No. labors	Percent (%)
1. Agriculture	73309	56.6
2. Fisheries	36820	28.4
- Sea fishing	17035	46.3
- Lagoon fishing	9726	26.4
- Aquaculture	5838	15.8
- Seafood processing and services	4221	11.5
3. Small scale industry	7797	6.0
4. Service	3556	2.8
5. Others	7953	6.1
Total	**129423**	**100**

Source: Fishery Department of Thua Thien Hue province, 2004

The Table 2 of labor distribution by sector also shows the structure of lagoon economy. In the past, local residents mainly lived on agriculture and natural resource exploitation or small scale fishing. Since the introduction of aquaculture in 1987, due to the high economic returns, more and more people have joined in aquaculture in this area. The total labors working for fisheries sector accounted for more than 28 percent in 2004. Of which aquaculture labor was more than 15 percent (Table 2).

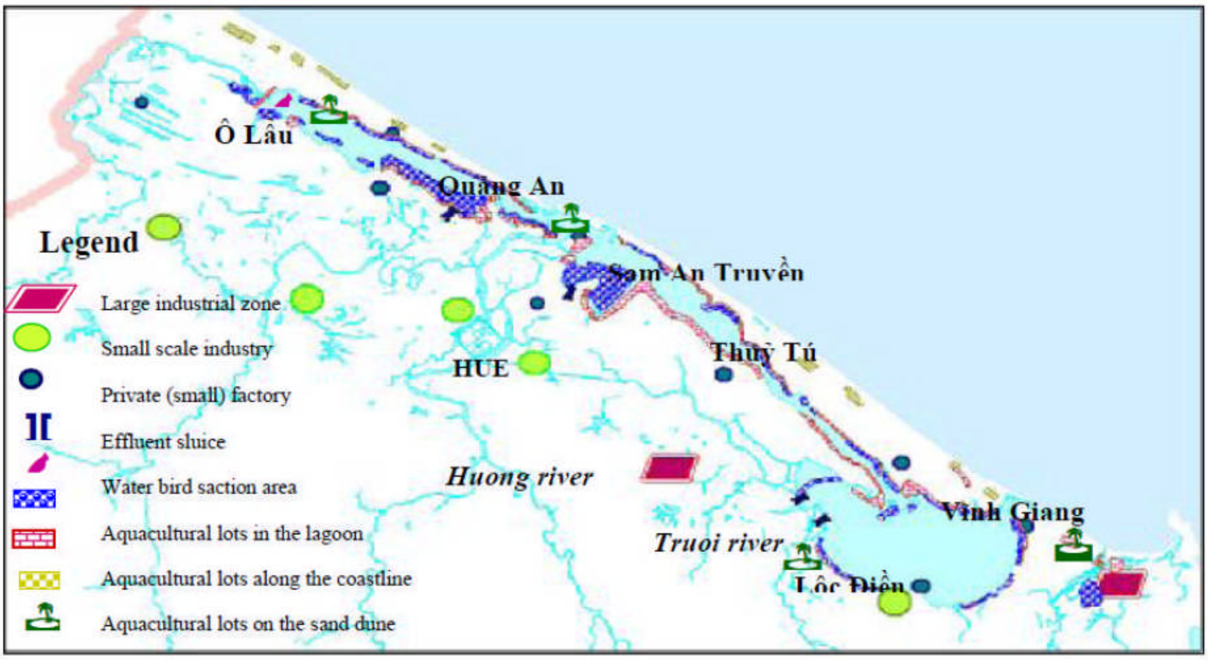


Figure 2: Distribution of major economic activities in Tam Giang - Cau Hai lagoon area

Source: (Nga 2006)

2.2. Aquaculture area

Tam Giang – Cau Hai lagoon system makes up 48.2% of total area of all coastal lagoons of Vietnam with about 22000 hectares of water surface area. This is most typical in typology of coastal water bodies, form and structure, in complexity of water dynamics and environment, in nutrition and diversity of aquatic resources and high biodiversity. Hence, main likelihoods of local residents are not only fishing in lagoon but also doing aquaculture in lagoon and both sides of this lagoon system. However, before 1990, aquaculture had not been introduced in Tam Giang – Cau Hai lagoon area, the main lagoon resource-used likelihood was traditionally natural fishing. As a result, aquaculture area in Tam Giang – Cau Hai lagoon system was only about 110 hectares of net-enclosure, which integrated pen culture and natural fishing, in 1991 (Figure 3) (Tuyen 2005). However, since the introduction of aquaculture in 1987 and its adoption in 1990s, aquaculture has expanded rapidly. There was, especially, "a boom" due to the claimed lagoon areas by individual households without clear regulations from local government.

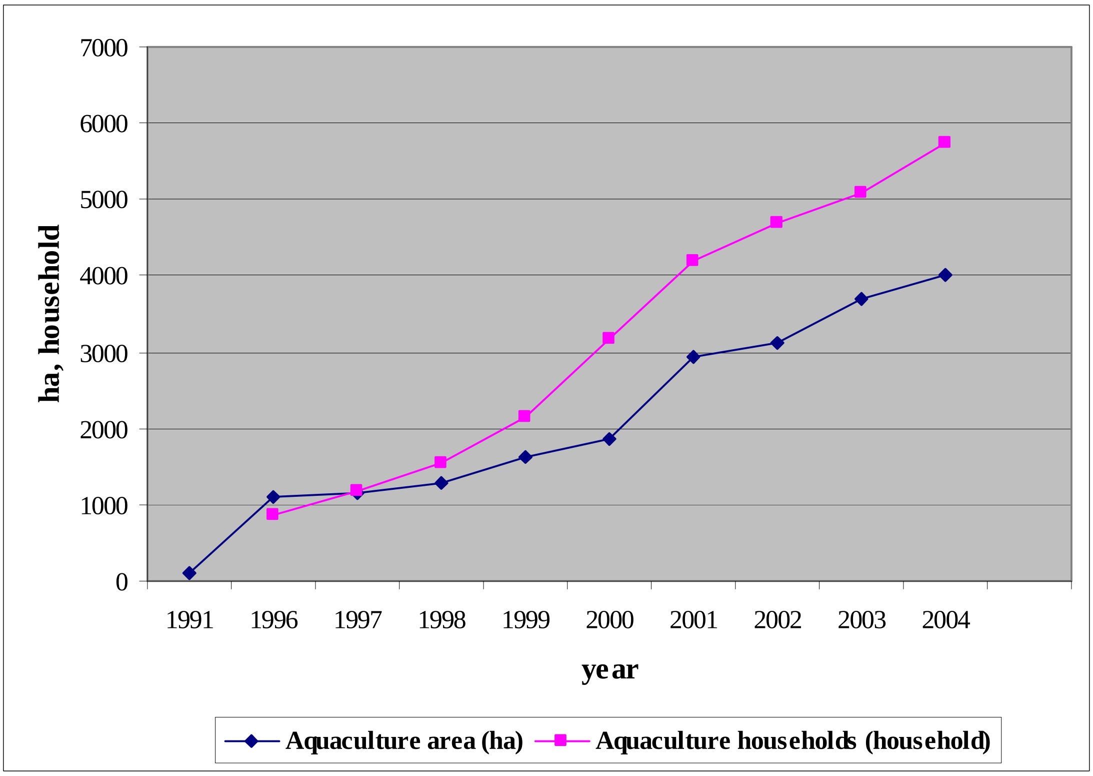


Figure 3: Aquaculture area and households in Tam Giang – Cau Hai lagoon system

Source: Fishery Department and People's Committee of Thua Thien Hue Province

Aquaculture area around this lagoon system, hence, increased sharply to more than 4000 hectares of both ponds and net-enclosures in 2005. The number of households doing aquaculture also increased rapidly from 867 in 1996 to more than 5700 in 2004 (Figure 3 and Appendix 2). That was also due to an increase in aquatic price between 1995 and 2004, and initially high economic returns from shrimp cultivating. However, the rapid and widespread extension of aquaculture area was spontaneous due to the unplanned claims of exclusive right by individuals. This was one of the causes of the substantial prevention of water flows, the pollution and lagoon environment degradation (Phap and Thuan 2002; Tuyen 2005; Xuan 2008).

Unplanned area

Since the encouragement in developing aquaculture of central and local government by the Decree No 64 and Land's Law in 1993, the privatization of lagoon surface has become common. The fishers who located their fixed gears on lagoon in the past could now replace with permanent fish net enclosures as their individual process. Moreover, any other fishers and local landowners also could also stake out private aquaculture areas in the lagoon. Fishers and farmers were stimulated to convert water surface and land around lagoon into aquaculture area. Therefore, by the end of 1990s, about 75 percent of lagoon water territory was covered by aquaculture net-enclosures and another 20 percent of water surface was occupied by shrimp ponds built out from flooded rice fields on the low-lying shore. With the privatization of lagoon surface, the fishers tried to get as high economic returns as possible without considering the sustainability and environment. That resulted in the decline of water quality and current flow. Water pollution led to disease widespread. Hence, lost and unstable aquaculture crops were common. (Tyler; Phap and Thuan 2002; Tuyen 2005; Xuan 2008).

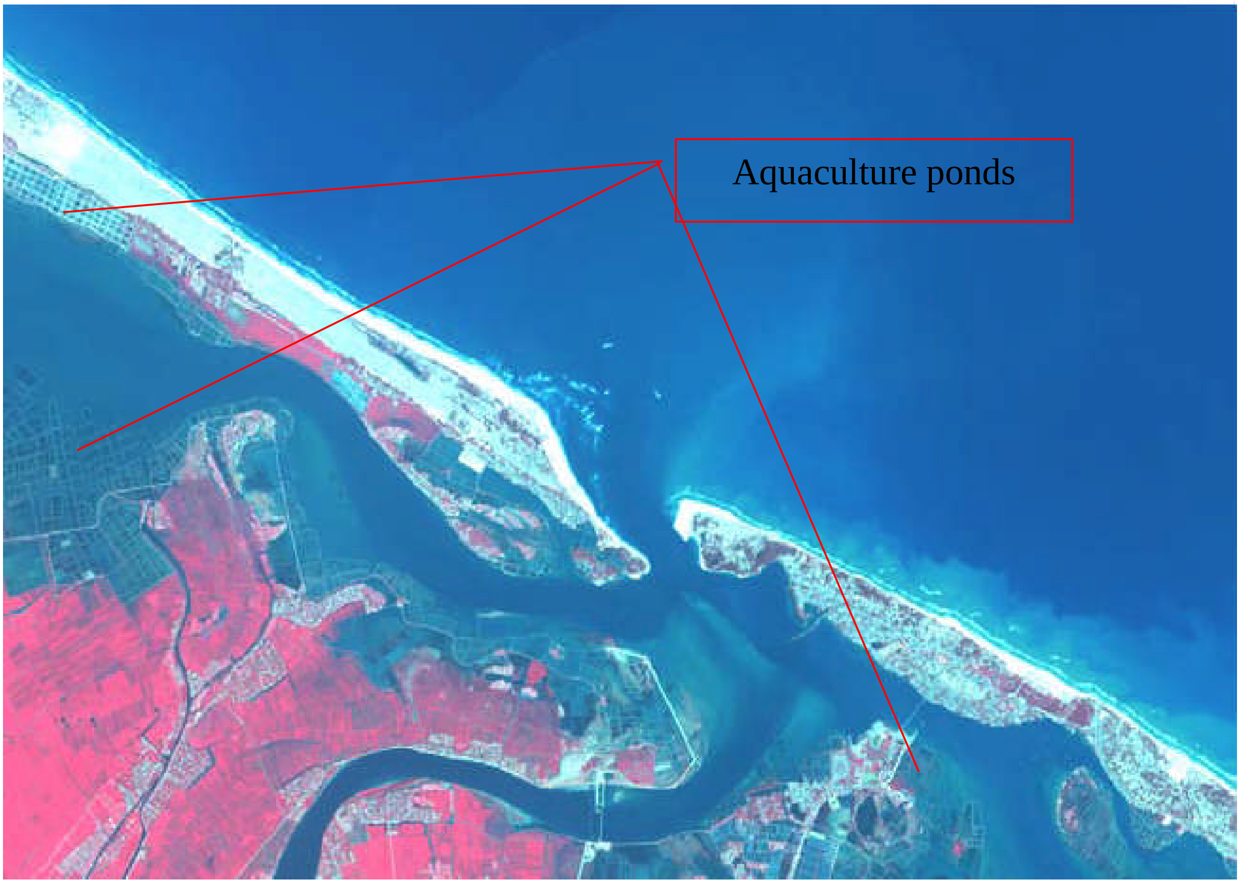


Figure 4: Aquaculture area on the edge of Tam Giang – Cau Hai lagoon from satellite

Source: (Anh 2005)

Planned area

In order to solve those problems and ensure sustainable access to lagoon resources, local people and governments together with many GO and NGOs programs have made enforcement to open water ways by removing parts of net-enclosure in some area around Tam Giang – Cau Hai lagoon system in recent years. Some projects supported by IDRC/CIDA applied participatory management in planning the lagoon resource governance in some area, such as a pilot participatory planning in Quang Thai commune in the north of Tam Giang – Cau Hai lagoon system in 2003; a replication in Quang Loi commune, Quang Dien district in 2003-2004; and a scale up participatory planning in Sam Chuon lagoon in 2004-2005.

Moreover, the government at district levels agreed with commune authorities to develop planning of lagoon area and then allocate aquaculture ponds to individual households or enterprises by land using contracts (Tuyen 2005). Those planned area might have less effects of disease or water pollution on productivity thanks to opening water ways.

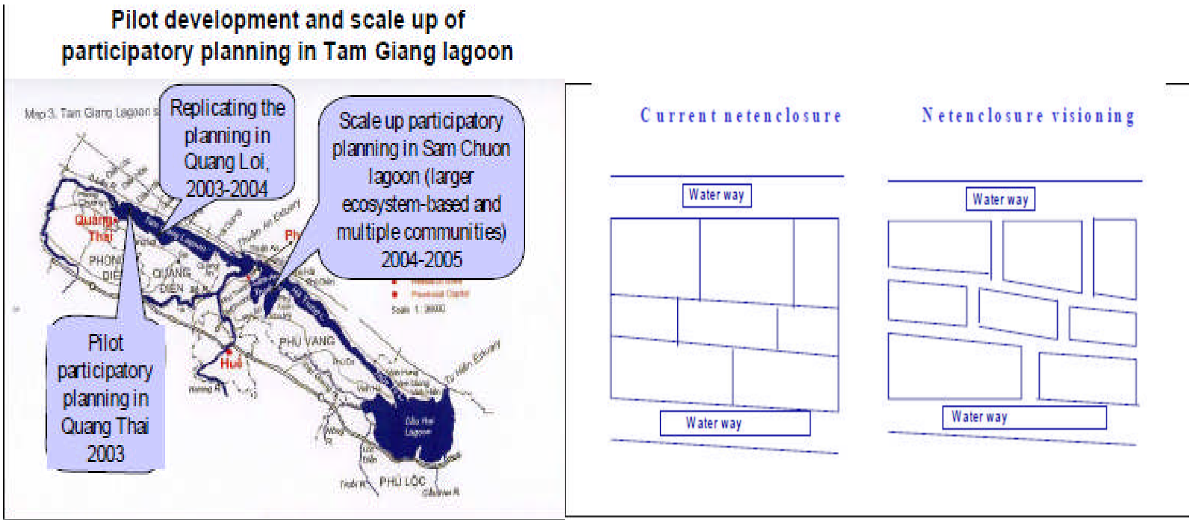


Figure 5: Some of participatory planning programs in Tam Giang – Cau Hai lagoon system

Source: (Tuyen 2005)

2.3. Aquaculture production

Thanks to its initially high economic returns, aquaculture had good contributions to local socio-economic development and to local government budget.

In 1992, aquaculture production in Tam Giang – Cau Hai lagoon was only about 500 tons. Thanks to the sharing of basic aquaculture techniques from many training courses, aquaculture production increased steadily to more than 1000 tons in 1996 (Phap and Thuan 2002). Then, it has experienced rapid development after a heavy flood in 1999, particularly since the encouragement of local government and the increase in aquatic price in 1995-2004. In 2007, aquaculture production in Tam Giang – Cau Hai lagoon was 7 times as much as in 1999. In which, shrimp production was the main contribution.

However, due to disease in shrimp mono-culture and the application of low stocking density and poly-culture instead of shrimp mono-culture, the quantity as well as the proportion of shrimp production tended to decrease since 2004 (Figure 6 and Appendix 2).

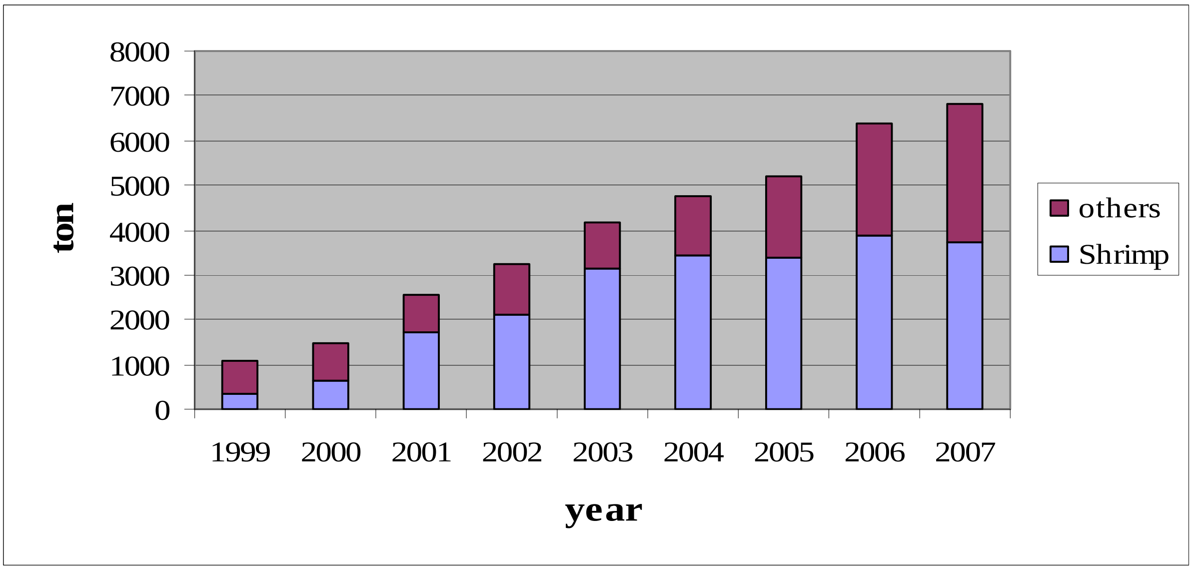


Figure 6: Aquaculture production in Tam Giang – Cau Hai lagoon system

Source: Fishery Department and People's Committee of Thua Thien Hue Province

3. Theory: Literature Review on efficiency of aquaculture

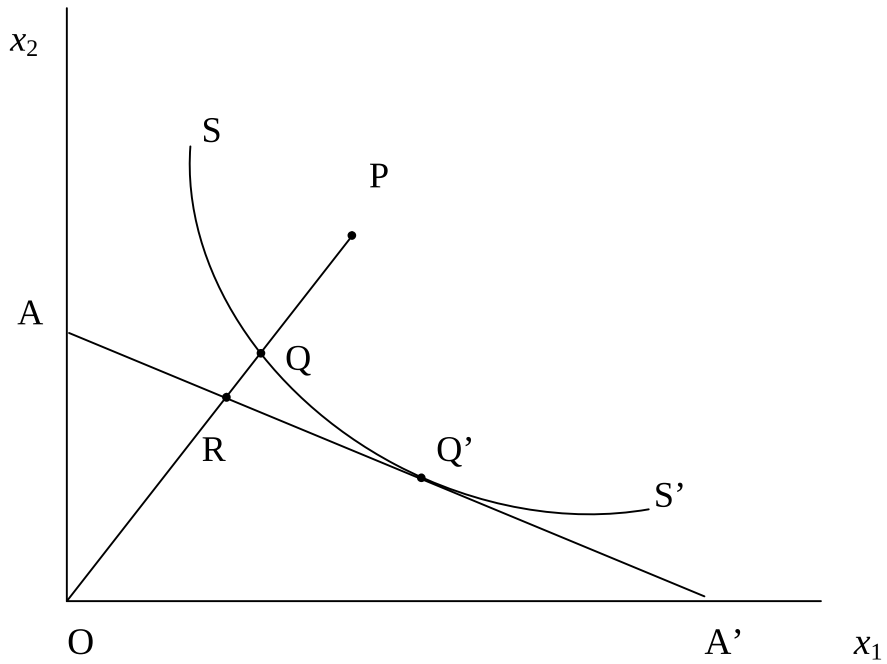
3.1. Definition of technical efficiency

Technical efficiency

The modern efficiency was firstly studied by Farrell in 1957 based on the work of Debreu (1951) and Koopmans (1951). Farrell (1957) used a simple model with 2 inputs and single output under constant return to scale in this study. He proposed that technical efficiency and allocative efficiency are two components of the efficiency. Technical efficiency is the ability of a farm in producing a maximum output from a given set of inputs and available technology. Allocative efficiency (or price efficiency) is the ability of a farm in using the inputs in optimal proportions, given their respective prices. And the combination of those two components provides a measure of overall or economic efficiency. Therefore, technical efficiency can be considered as an indispensable component to obtain economic efficiency.

Efficiency can be considered in term of input-orientation or output-orientation. In which, input-orientated efficiency finds out a target point maximizing the proportion reduction in inputs or produces a given level of output from an optimal combination of inputs. Meanwhile output-orientated efficiency finds out a target point that maximizes the proportional augmentation in outputs or produces the optimal output from a given set of inputs. These concepts are illustrated in Figure 7.

Figure 7: Input-orientated measures



Input-oriented measure

Input-oriented technical efficiency is to address the question: "By how much can input quantities be proportionally reduced without changing the output quantities produced?"

Based on the simple model with 2 inputs and 1 output, input-oriented efficiency is illustrated in Figure 7. From this figure, the technically efficient firms are those that lay on the curve SS'. Hence, Q and Q' are technically efficient points. Meanwhile, P is technically inefficient point. And the inefficiency of that firm could be represented by the distance OQ/OP when it is less than one. It means that the firm could reduce the use of both inputs from P to Q without the reduction in output. In other words, in order to obtain technically efficient production, that firm need reduce all inputs proportionally by QP/OP. And the technical efficiency (TE) of a firm is most commonly measured by the ratio:

$$\mathbf{TE_I = OQ/OP}$$

The technical efficiency value will be between zero and one. A firm is fully technically efficient if its technical efficiency score is equal to one, and vice versa.

If unit costs of inputs are available, AA' represents an iso-cost line. Hence, R or Q' have the same total cost. However, the output at R point production is lower than at Q', which is the intersection between AA' iso-cost and SS' iso-quant (production frontier). Therefore, Q' is said to be technical efficient as well as allocative efficient. And the cost efficiency can be estimated by the ratio:

$$\mathbf{CE_I = OR/OP}$$

Then allocative efficiency and technical efficiency can also be calculated by using the iso-cost line:

$$\mathbf{AE_I = OR/OQ}$$

$$\mathbf{TE_I = OQ/OP}$$

From those equations, the relation between technical, allocative, and cost efficiency can be explored:

$$\mathbf{TE_I * AE_I = (OR/OQ)*(OQ/OP) = OR/OP = CE}$$

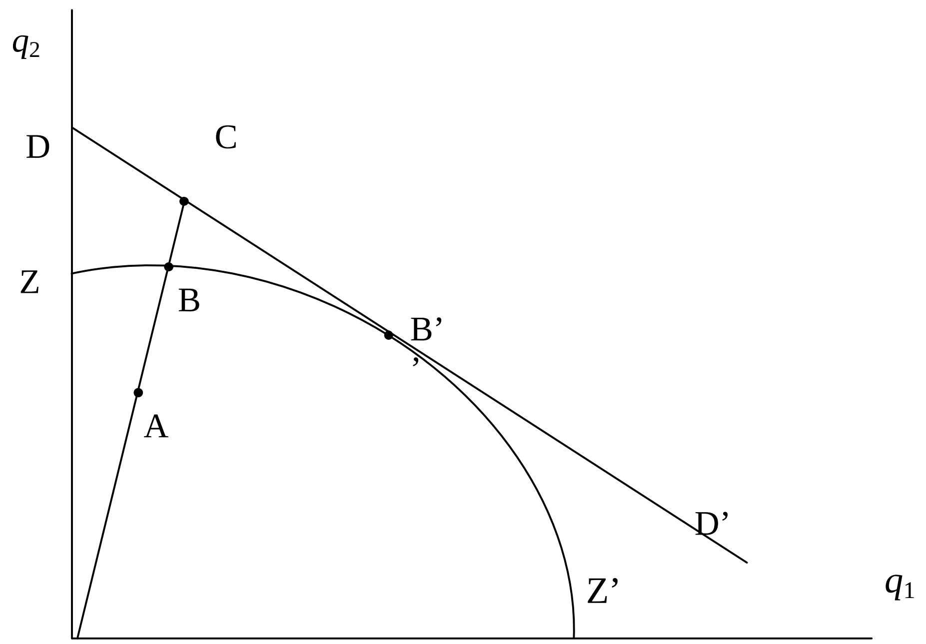
Output-oriented measure

On the contrary, output-oriented technical efficiency is to answer the question: "By how much can output quantities be proportionally expanded without altering the input quantities used?"

Consider the case of producing two outputs from a single input, output-oriented efficiency is showed in Figure 8. In this figure, the firms which are on the frontier curve ZZ' are technically efficient. A lies below the ZZ' curve. Hence, A is an inefficient point. And the distance AB represents technical inefficiency that outputs could be expanded without requiring extra inputs. Therefore, output-oriented technical efficiency is measured by the ratio of OA and OB

$$\mathbf{TE_O = OA/OB}$$

Figure 8: Output-orientated measures



Similar to the input-oriented case, if the unit prices are available, DD' represents the iso-revenue line. Hence, the intersection between the ZZ' technical efficient curve and DD' iso-revenue line, B', is said to be revenue efficient. And the revenue efficiency can be defined as the ratio:

$$\mathbf{RE_O = OA/OC}$$

Then allocative efficiency and technical efficiency can also be measured by the ratio:

$$\mathbf{AE_O = OB/OC}$$

$$\mathbf{TE_O = OA/OB}$$

The relation between technical, allocative, and cost efficiency, hence, can be defined:

$$\mathbf{TE_O*AE_O = (OA/OB)*(OB/OC) = OA/OC = RE}$$

In summary, the level of technical efficiency of a firm can be defined as the relationship between observed production and the best practice production. A firm is technical efficient if its production point is on the frontier. On the contrary, it is technical inefficient if the production point of that firm lies below the frontier.

3.2. Measurements of efficiency

Based on the study of Farrell in 1957 and the specific research on efficiency measurement for production units of Charnes, Copper, and Rhodes in 1978 and the contribution of Banker in 1984, the two approaches of non-frontier and frontier have been developed to measure the technical efficiency in production. In which, non-frontier measures the technical efficiency by comparing the actual output and the standard frontier which is estimated from the experimental data. Therefore, although one can separate and examine the interaction between conventional and non-conventional inputs by the former, it is too cost to conduct experimental study. Moreover, the real condition in production might not be represented by experimental condition.

The later approach describes the maximum output can be produced from any given combination of inputs by an efficient firm. It has been classified into various methods. And Data envelopment analysis (DEA) and stochastic frontier analysis are two most popular approaches. Both approaches have advantages and disadvantages

Stochastic Production Frontier (SPF)

Stochastic frontier analysis (SPF) is a parametric and econometric approach. This approach constructs a production function based on “average” values of the observed data.

The advantage of this approach is taking into account the stochastic variation. This will be important if the output is affected by random noise. However, this method it requires a specific functional form such as Cobb-Douglas, translog or quadratic function to estimate the production function. And it is necessary to have some distributional assumptions to separate the stochastic component from inefficiency component. Moreover, it can not be applied to multiple output case. Therefore, it will be a disadvantage for any production function with more than one output.

Data envelopment analysis (DEA)

In 1957, Farrell firstly studied about the efficiency based on the construction of hypothetical firms as a weighted average of some of observed firms. Since then, some literatures have analyzed the efficiency based on his idea. Charnes et al. (1978) construct the efficient frontier as an envelopment of the data by using Linear programming methods. The resulting model is called Data Envelopment Analysis, DEA.

Unlike stochastic production approach, data envelopment analysis measures the relative efficiency in the presence of not only single input-output but also multiple input and output factors at farm level or decision making units (DMUs). When the weights are restricted, efficiency of DMUs could be defined as the ratio of the weighted sum of outputs over the weighted sum of inputs

$$\text{Efficiency} = \frac{\text{Weighted sum of outputs}}{\text{Weighted sum of inputs}}$$

Hence, although missing taking into account the random error due to the deterministic nature, the major advantage of DEA approach is that DEA can be applied in multi input – multi output situation. Moreover, Data envelopment analysis (DEA) is a non-parametric method. It constructs the efficient frontier based on extreme values of the observed data. It uses the linear programming techniques to measure the efficiency. Therefore, it is unnecessary to assume in advance any specific functional form or any assumption on distributions of error. DEA can also identify sources and amounts of inefficiency in each input and each output for each farm, and identify the benchmark members of the efficient set.

In this study the data envelopment analysis method to measure efficiency is chosen over stochastic frontier production approach for three reasons. First, data envelopment analysis is able to deal with multi-outputs of shrimp poly-culture pattern of the sample farms, which can not be deal with stochastic production frontier. Second, it is unnecessary to apply any functional form or any assumption on distribution of error, which is very necessary in stochastic frontier production. And third, this is the first study, to my knowledge, that used data envelopment analysis to measure technical efficiency of shrimp poly-culture at farm level in Tam Giang – Cau Hai lagoon system, Vietnam. Moreover, using data envelopment analysis two-step approach can also identify the factors that influence technical efficiency results.

3.3. Empirical studies on technical efficiency of aquaculture

Kareem, Dipeolu et al. (2008) estimated the economic efficiency of fish farming in Ogun, Nigeria using stochastic frontiers production approach. Cross section data of 85 fish farms grouped into concrete and earthen pond type in this area were used. The analysis was based on the Cobb Douglas production function involving fish production in kilogram and 6 inputs including pond area, feed, lime, fingerlings, labor, and other materials. The technical inefficiency function involved experience, age and education of the operators and his/her household size. The empirical results revealed that the mean technical efficiency of concrete pond and earthen pond type were almost the same, about 0.88-0.89. And experience of the operators had negative effect on inefficiency of concrete pond. (Kareem, Dipeolu et al. 2008).

Alam and Murshed-e-Jahan (2008) evaluated the resource allocation efficiency of prawn-carp poly-culture systems in Bangladesh using data envelopment analysis (DEA) approach. Cross section data of 105 prawn-carp farms in this country were used. The efficiency estimation was based on two outputs (prawn and carp) and four inputs (labor, fingerlings, inorganic fertilizers, organic fertilizer and feed). And the main results showed that the mean technical, allocative, cost and scale efficiency of prawn-carp poly-culture in Bangladesh were 0.85, 0.58, 0.49, and 0.88, respectively. Moreover, pond size was found to have positive effect on technical and cost efficiency. And there was a negative relationship between pond size and allocative efficiency, and between feed application and technical, allocative and cost efficiency (Alam and Murshed-e-Jahan 2008).

Amos (2007) examined the productivity and technical efficiency of crustacean in Nigeria using stochastic production frontier (SPF) approach. Data of 100 crustacean farms in five villages in Ilaje Local Government Area of this country were used. The analysis was based on Cobb-Douglas frontier production function with one output of the value of crustacean produced per hectare and five inputs: labor, cost of feed, equipment, foundation stock, and other cost. In which, feeds and equipment cost were found to significantly affect technical efficiency. The empirical results showed that the mean technical efficiency of producers was 0.7. Moreover, it was found that age of producers had negative effect while family size had positive effect on technical efficiency (Amos 2007).

Den et al. (2007) examined the technical efficiency of prawn farms in the Mekong Delta in Vietnam using stochastic production frontier (SPF) approach. Cross section data in 2004 of 193 prawn farms classified into extensive and intensive farms in this area were used for analyzing. The analysis was based on the Cobb Douglas production function in the first step involving one output of kilogram prawn per hectare per year and seven inputs: fingerlings, feed, chemical inputs, fuel, hired labor, type of prawn (dummy) and the farm specific technical inefficiency in the second step involving four inputs: farm area, and experience, age, education of the operators. The main results showed that the mean technical efficiency was 46 percent. In which, extensive farms were technically more efficient than intensive farms with

0.48 and 0.35, respectively. Furthermore, there was a positive relationship between experience and technical efficiency. However, it was found that the younger the operators were, the more technically efficient the farms were (Den, Ancev et al. 2007).

Cinemre et al. (2006) investigated the cost efficiency of trout farms in the Black Sea Region, Turkey using two-stage data envelopment analysis (DEA) approach. Cross section data of 73 trout farms were used. The analysis was based on a two inputs (feed and labor), a single output (trout) framework in the first stage, and Tobit model with personal characteristics (education level and experience of the operators), farm characteristics (pond size and off-farm income), and accessing to institutions/public goods (credit and extension services) in the second stage. The results revealed that the mean technical, allocative and cost efficiencies were 0.82, 0.83 and 0.68, respectively. Furthermore, pond tenure, farm ownership, experience as well as education level of the operators, contact with extension services, off-farm income and credit availability were found to have positive effects on cost efficiency. Meanwhile, there was a negative relationship between cost efficiency and feeding intensity, pond size, and capital intensity (Cinemre, Ceyhan et al. 2006).

Kaliba and Engle (2006) measured the productive efficiency of catfish farms in Chicot, Arkansas using a weight-restricted data envelopment analysis (DEA) approach. Cross section data in 2001 of 32 catfish farms in this area were used. The efficiency analysis was based on one output of live catfish in kilogram per hectare and five inputs: labor, energy, quantity of fingerlings/stockers, quantity of feed, and other costs. Besides, size of operation, experience of operator, extension services and land lessee were included in the two Tobit models in the second stage of the study. The results revealed that the mean technical efficiency under constant return to scale (CRS) and allocative, scale efficiency were 0.57, 0.67, and 0.77, respectively. Meanwhile, the technical and cost efficiency under variable return to scale (VRS) were 0.73 and 0.49, respectively. Moreover, operators' experience, extension contacts were found to have positive effects on the level of efficiency of those farms (Kaliba and Engle 2006).

Mussa (2006) investigated the technical efficiency of smallholder farmers in Southern Malawi using stochastic frontier production (SPF) function. Cross section data in 2003 of 150 farms adopting and 150 farms non-adopting integrated aquaculture-agriculture. The analysis was based on the Translog production function first. It was then tested against a Cobb Douglas functional form. Those production frontier involved farming system output value in Malawi Kwacha and some inputs such as land, assets, labor, and others and the technical inefficiency function involving age and education of the farmers, availability of credit, extension services, membership of a association, number of plots and recycling of materials. The results show that non-adopters were technically less efficient than adopters, with 0.49 and 0.63, respectively. And there was a positive relationship between education, extension services, recycling of materials, number of plots and technical efficiency of adopting integrated aquaculture-agriculture farms (Mussa 2006).

Dey et al. (2005) estimated the technical efficiency and its determinants of freshwater pond poly-culture in selected Asian countries using stochastic production frontier (SPF) approach. The data of 300 samples from China, 409 samples from India, 180 samples from Thailand, and 120 samples from Vietnam collected by WorldFish and its partner institution were used. Those freshwater pond poly-culture farms were classified into extensive, semi-intensive and intensive system. The production frontiers were Cobb Douglas function. The output included was farm yield in kilogram per hectare. The inputs used in those production frontiers were not only the common inputs, such as: stocking density, feed, labor, chemicals, but also the specific inputs, such as: energy, protein, nitrogen, phosphorus, fertilizer and its dummy variables. The farm-specific variables included age, education, experience of the farmer operator, the farm size, privately owned (dummy), distance from seed supplier/market and regional variable (dummy). The results showed that technical efficiencies of extensive and semi-intensive system were 0.77 and 0.84 in China, 0.65 and 0.86 in India, 0.72 and 0.91 in Thailand, 0.42 and 0.48 in Vietnam, respectively. The technical efficiency of intensive system in China had the highest score with 0.93. Moreover, a relationship between regional dummy, farm size, distance to seed supplier in China, education, farm size, pond owner dummy in India, farm area, pond owner dummy, distance to seed supplier/market in Thailand, age, education of operator, farm area, distance to nearest market in Vietnam and technical inefficiency (Dey, Paraguas et al. 2005).

Chiang et al. (2004) analyzed the technical efficiency of milkfish in Taiwan using stochastic frontier production function (SPF) approach. Data of 433 aquaculture milkfish farms between 1997 and 1999 were used. Both Translog and Cobb Douglas frontier production models were estimated using the maximum likelihood estimation method. The production frontier based on the output of milkfish production quantity and five inputs: pond area, fry cost, feed cost, water and electricity cost and other costs. And inefficiency factors included the data collecting time (dummy), monoculture farm (dummy), fresh water (dummy), location (dummy), pond size (dummy), education (dummy), experience, labor. The empirical results showed that the mean technical efficiency was 0.84 in the Translog model, and that milkfish farming in Taiwan diminished return to scale. Furthermore, there was a positive relationship among fresh water, location variables, education, experience and labor and technical inefficiency. Meanwhile, data in 1998, monoculture farm, reading ability of the farmer had negative effects on technical inefficiency (Chiang, Sun et al. 2004).

Pantzios et al. (2004) implemented the input-oriented Malmquist productivity index to aquaculture farms in Greek using stochastic frontier approach and translog input distance function. Panel data set of 14 sea-bass and sea-bream farms between 1995 and 1999 were used for analysis. Its translog input-distance function was based on two outputs: the total annual production of sea-bass and sea-bream measured in tons, and four inputs: labor, stocking rate, fish feed and cages area. The empirical results showed that the mean technical efficiency of sea-bass and sea-bream farms seemed to be unchanged at approximate 0.7 over the time (Pantzios, Tzouvelekas et al.).

Sharma and Leung (2000) measured the technical efficiency of carp production in India using stochastic frontier analysis (SPF) approach. Since then its levels and determinants in carp pond in this country were examined. Cross section data of 906 carp farms in India classified into semi-intensive/intensive and extensive were used. The analysis was based on the Cobb Douglas production frontier involving one output of aggregated quantity of fish production in kilogram per hectare and six inputs: seed, labor, chemical fertilizer, organic manure, feed, and other input and technical efficiency model including primary activity (dummy), farmer's experience, owner operated, pond area, fish management index, water management index, feed management index and location variables (dummy). The main findings were 0.805 and 0.658 of technical efficiency score for semi-intensive/intensive and extensive respectively. Moreover, the former was found technically more efficient than the later. In addition, fish, water and feed management practices had positive effect on technical efficiency. In particular, there was a negative relationship between technical efficiency of extensive system and aquaculture as primary activity, semi/intensive farms' technical efficiency and farmers' experience (Sharma and Leung 2000).

Iinuma, Sharma and Leung (1999) assessed the technical efficiency of carp pond culture in Peninsula Malaysia by using stochastic production frontier (SPF) approach. The technical efficiency was estimated to give some policy implications for promoting carp production in this area. 94 carp pond farms classified into intensive/semi-intensive and extensive cultures were used for analysis. The analysis was based on the production frontier, which was in Cobb Douglas functional form, involving output of total quantity of fish harvested in 1994 production year measured in kilograms per hectare and six input variables including seed, seed ratio, feed, feed ration, labor and other inputs and technical efficiency model that includes five farm-specific variables such as: culture intensive, ownership, carp farming as a primary activity, pond area, and pond age. The main results reveal that the mean technical efficiency was 42%. In which, intensive/ semi-intensive system was more technically efficient than extensive one with 0.565 and 0.236 on average respectively. Moreover, age and ownership were found to have positive effects on technical inefficiency. Meanwhile, there was a negative relationship between intensive culture and technical inefficiency (Iinuma, Sharma et al. 1999).

Sharma et al. (1999) measured the economic efficiency of fish poly-culture in China using output-based data envelopment analysis (DEA) approach. Then the optimum stocking densities for those farms were suggested. Cross-section data of 115 fish poly-culture farms from eight provinces in China were used. The analysis was based on four output categories of fish, including: black carp, grass carp, silver carp and common carp and the combination of inputs such as: seed, feed, and labor. The main results showed that the sample average technical, allocative, and economic efficiencies were 0.83, 0.87, and 0.74, respectively. Moreover, the technical and economic efficiency had negative relationship with farm size. The large farms (> 10 ha) and those from the underdeveloped provinces were technically less efficient than the small ones (< 0.5 ha) and those from the developed provinces (Sharma, Leung et al. 1999).

Jayaraman (1997) analyzed the economics analysis of carp culture in Thanjavur district, Tamil Nadu state, India, and identified the reasons for yield variations by using probabilistic frontier production function model (PFPF). Cross section data of 40 carp farms were used for the analysis. The analysis was based on the average production function estimated by Ordinary Least Square method and PFPF involving the mean yield of carp and five inputs: pond size, stocking ration, labor, feed cost, and average price of fish. The results reveal that 23 out of 40 farms had technical efficiency of less than 0.5, only one farm was technical efficiency (Jayaraman 1997).

In summary, data envelopment analysis and stochastic frontier analysis have been used in most of the above studies. In which, Stochastic production frontier measures the efficiency by using econometric techniques. Hence, the studies using this method had their specific production functional forms such as Cobb Douglas function, translog function, and quadratic function. Moreover, they imposed the specific assumption on the error term. While data envelopment analysis measures the efficiency by using the linear programming techniques. It therefore requires specific orientation and returns to scale assumptions on the analysis instead of functional form and error term assumption.

In general, regardless of the used estimation method, the mean technical efficiency of aquaculture in the above studies varied from more than 50 percent to 91 percent, except the cases of Malaysia, Malawi, and especially Vietnam. The poly-culture seemed to be more efficient, except Vietnam. Therefore, this study also targets to re-estimate the technical efficiency of poly-culture in a part of Vietnam, it is Tam Giang lagoon.

In addition, those studies also showed that human capital (age, education, experience, and extension contacts) affect technical efficiency and, through it, productivity. Based on that, one of the objectives of this study is to test whether some of those characteristics such as education, experience of farmers and their ability to access extension services have any effect on technical efficiency of shrimp poly-culture farms in this study area or not.

Some of the above studies used stocking density and regional variable as inputs in measuring efficiency or forming the production frontier. However, to my knowledge, the relationship between stocking density, ecosystem variable and technical efficiency has not been explored in any studies about the technical efficiency of aquaculture. Therefore, this study targets to test whether the differences in prawn and rabbit-fish stocking densities and the production environment (planned or unplanned ponds) have any effects on technical efficiency of shrimp poly-culture farms in this study area.

4. Research Methodology

4.1. Data collection

4.1.1. Secondary data

Secondary data for this study were collected from various sources such as books, journals, research reports, statistical yearbook 2007 of Thua Thien Hue Statistical office with relevant information on efficiency analysis and production of aquaculture. In addition, data of district and community levels in this lagoon were gathered from bureau of statistics of districts.

4.1.2. Primary data

Tam Giang lagoon in Tam Giang – Cau Hai lagoon system located in the central of Vietnam was selected as the study area. Primary data of this research were based on farm level cross-section data of shrimp poly-culture crop year 2008. The survey was implemented in February 2009.

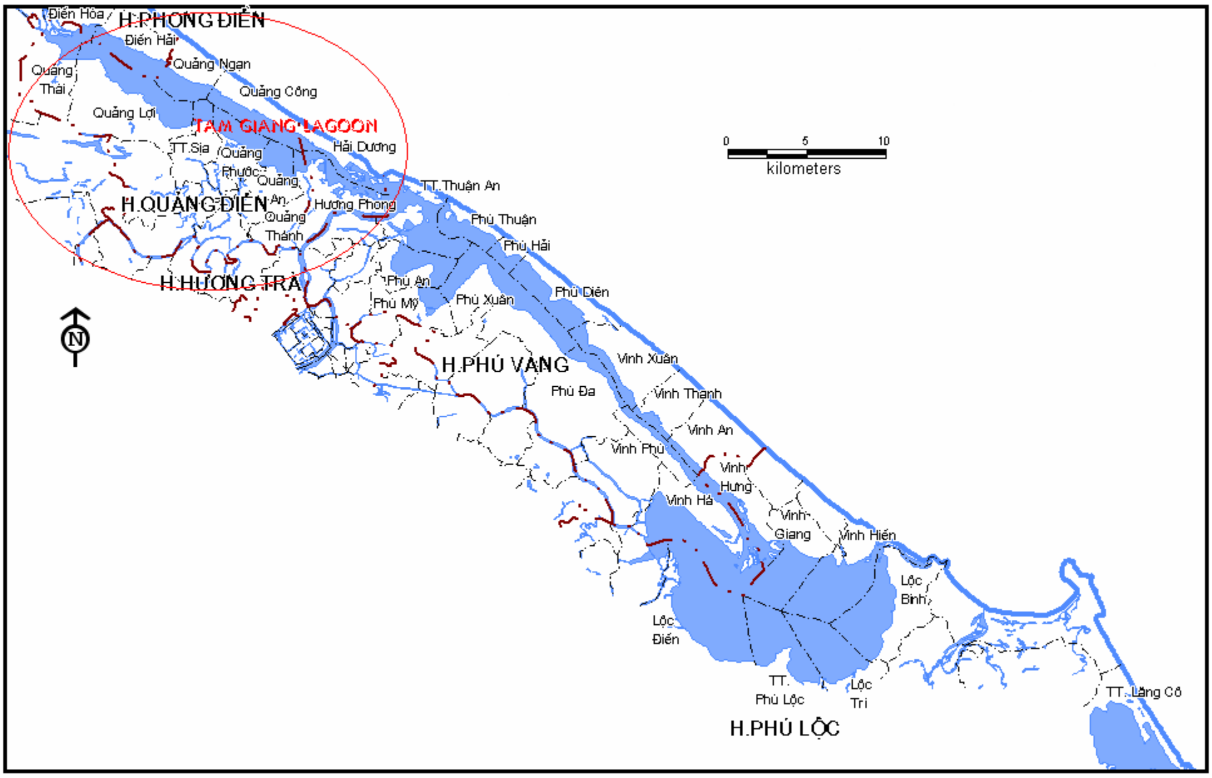


Figure 9: Location of the study area

Source: Fisheries Department of Thua Thien Hue Province

Sampling method

Tam Giang – Cau Hai lagoon system includes four sub-lagoons from the North to the South: Tam Giang, Sam Chuong, Thuy Tu, and Cau Hai lagoons, in which the study area is Tam

Giang lagoon with three districts: Phong Dien, Quang Dien, and Huong Tra which is accounting for 23% of total area for aquaculture of system.

A preliminary survey was conducted to get the basic information about aquaculture in this area. From this survey, it is known that shrimp is cultivated in all three districts in this lagoon. In which, shrimp poly-culture has been applied widely in Quang Dien and Huong Tra districts. Meanwhile, there is still shrimp mono-culture in Phong Dien district. Therefore, Quang Dien and Huong Tra were selected as primary sampling units. Then, a focus group discussion was done in January 2009 to identify the key outputs and input variables of this production. Some other variables considered as effecting factors of technical efficiency were also identified in this stage.

Based on those results, the structured questionnaire was made. And the pre-testing of this structured questionnaire was done for five households in both Quang Dien and Huong Tra districts. Then the edited version of questionnaire was used for interviewing the prawn-rabbitfish poly-culture farmers in Quang An and Quang Thanh communes in Quang Dien district, and Huong Phong commune in Huong Tra district in February 2009.

The following lists of information were included in the structured questionnaire:

1) Household characteristics: age, gender, education, experience,
2) Labor in prawn-rabbitfish poly-culture: number of labor, total working days, total working hours
3) Basic information of ponds: the number of ponds, area, pond tenure, the disease status of ponds in recent years, the number of operating crops, pond lease, capital construction cost, maintenance cost
4) The source, density and cost of all kind of seeds were reared.
5) The amount and cost of industrial and fresh feed were used in prawn-rabbitfish poly-culture.
6) The amount and unit price of outputs.
7) Farmers' ability to access credit and extension services.

Sample size

The prawn-rabbitfish poly-culture households from three villages in three communes of Quang Dien and Huong Tra districts were randomly selected and interviewed. The actual sample size was 48 farm households. However, data of only 44 samples were used for analyzing. In which, 19 households were from Huong Tra and 29 households were from Quang Dien district.

Table 3: Sample size of aquaculture household survey

Study area	Communes	Sampling size	Planned ponds	Unplanned ponds
Quang Dien	Quang Thanh	10	10	0
	Quang An	19	0	19
Huong Tra	Huong Phong	19	0	19
Total		48	10	38

Source: Field survey

4.2. Data analysis

The primary data were the main information for analyzing. In this study, there was a descriptive analysis of the observations at first. And then, technical efficiency at farm level of those observations was measured by data envelopment analysis (DEA) approach. Finally, ordinary least square was used to investigate the factors affecting the technical efficiency of shrimp poly-culture.

4.2.1. Descriptive statistic analysis

This part dealt with simple descriptive statistic analysis, including: mean, variance, standard deviation, maximum, minimum, percentage. And descriptive analysis was done in both stage of the study. First, some main inputs and outputs which were used in estimating technical efficiency were described. Then, the summary of significant characteristics of the shrimp poly-culture farmers which were used in the OLS stage was included. In the later part, because the differences in some characteristics between planned and unplanned groups were small, a t-test was done to test whether it is different from zero or not. The t – value to test for significance of difference is estimated by below formula:

$$t = \frac{\left(\overline{Y_1} - \overline{Y_2}\right) - \left(\mu_1 - \mu_2\right)}{\sqrt{\left[\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\right] \cdot \left(\frac{n_1 + n_2}{n_1 \cdot n_2}\right)}}$$

$$\text{Degree of freedom is}: df = (n_1 + n_2 - 2).$$

Where:

$\overline{Y_1}$ is the mean value in planned group, and
$\overline{Y_2}$ is the mean value in unplanned group
μ_1 is expected value in planned group, and
μ_2 is expected value in unplanned group
s_1^2 is variance in planned group
s_2^2 is variance in unplanned group
n_1 obervations in planned group, and
n_2 observations in unplanned group,

The test statistic includes:

1. The null hypothesis is H_0: $\overline{Y_1} - \overline{Y_2} = 0$. The alternative hypothesis is H_1: $\overline{Y_1} - \overline{Y_2} \neq 0$

2. The test statistic $t \sim t_{(n1 + n2 - 2)}$ if the null hypothesis is true

3. Let select the level of significance $\alpha = 0.05$. In a two tail test $\alpha / 2 = 0.025$ of probability is allocated to each tail of the distribution. The critical value is $t_{(0.975,42)} = 2.02$ with $n_1 + n_2 - 2 = 42$ degrees of freedom. Thus we will reject the null hypothesis in favor of the alternative if $t \geq t_{(0.975,42)}$ or if $t \leq -t_{(0.975,42)}$

4.2.2. Technical efficiency analysis: Data Envelopment Analysis

DEA Method

As mention above, Farrell was the first one who studied about the efficiency measurement by using the simple model of two inputs - single output under constant return to scale. Based on that, Charnes, Cooper, and Rhodes (CCR) (1978) extended, developed and proposed the data envelopment analysis (DEA).

DEA is used to measure the relative efficiency or performance at the firm level. It constructs a non-parametric piece-wise frontier over the data by using the linear programming methods. Its calculation bases on the comparison output and input used with the production frontier. The efficiency score is 1 (one) when the production point of a decision making unit (DMU) is on the frontier and smaller than 1 when the production point of a DMU is inside (or outside, depending on how you see this) the frontier.

Efficiency can be defined in input-orientation or output-orientation. In input-orientation, technical efficiency can address the question: “By how much can inputs be proportionally reduced without changing the output quantities produced?”. Meanwhile, output-oriented technical efficiency focuses on maximizing the output quantities and addressing the question:

"By how much can outputs be proportionally increased without changing the inputs quantities used?" (Farrell 1957).

DEA concepts have developed into four models: CCR (Charnes, Cooper, and Rhodes) ratio model, BCC (Banker, Charnes and Cooper) returns to scale model, additive model and multiplicative model (Roland 2003). Charnes et al. (1978) proposed the CCR model to find out radial reduction in input or radial expansion in output based on the restrictions of constant return to scale (CRS), strong disposability[1] of inputs and outputs, and convexity of feasible input-output combinations. But as Timothy J. Coelli et al. mentioned in *An Introduction to efficiency and productivity analysis,* "CRS assumption is only appropriate when all farms are operating at an optimal scale". Meanwhile "imperfect competition, government regulations, constraints of finance, etc. may cause a firm to be not operating at optimal scale". Then Banker, Charnes, and Cooper in 1984 continued to extend the model by turning to the problem of returns to scale (Banker, Charnes et al. 1984; Timothy J. Coelli, D.S. Prasada Rao et al. 2005; Alam and Murshed-e-Jahan 2008; Kiatpathomchai 2008).

In prawn-rabbitfish poly-culture in Tam Giang lagoon, due to the limitation of resource, such as infrastructure, canal systems, good quality seeds and environmental protection for aquaculture areas, capital, availability of man power, skilled staff and workers for investment and especially the restriction of expanding pond size, input-oriented DEA approach is appropriate to describe the production possibility situation. The input-oriented measure is to answer the question what the most efficient combinations are among the limited inputs those poly-culture patterns with the unchanged output. Hence, the reduction of inputs use can be applied to avoid wasting resources, improve farm technical efficiency, reduce the producing cost or increase the gross margin from prawn-rabbitfish poly-culture. Moreover, due to the existence of imperfect competition, limited finance and socioeconomic limitations of farmers in this study area, almost farms are not operating at optimal scale. Hence, VRS DEA model seems to be more suitable for analyzing technical efficiency than CRS in this study.

Therefore, the standard BCC-DEA model under input-oriented approach was used to measure technical efficiency of prawn-rabbitfish poly-culture in this study. Moreover, in order to identify the exogenous factors effecting on farm technical efficiency, two-stage DEA methodology of efficiency analysis was applied. In the first stage, technical efficiency scores were calculated. Then the results of the first stage were used as dependent variables in the second stage by regress the technical efficiency scores against a set of explanatory variables.

[1] Strong disposability of inputs is defined when an increase or un-change in inputs would not lead to a decrease in outputs. On the contrary, weak disposability of inputs is defined if x can produce y, and a proportional increase in inputs which is larger than one, could also produce y (Fare 2000)

And Tobit is the standard method which has been used in many studies as I mentioned in literature review part. OLS model has been used in very few studies due to the biased estimates. OLS model, hence, was chosen instead of Tobit in this study. However, because the dependent variables are restricted to be between zero and one, it effects on the regression stage. Hence, super efficiency was also measured in the first stage. And this super efficiency scores were used as dependent variables in OLS regression in the second stage.

Model specification of technical efficiency

Consider the case of *n* prawn-rabbitfish poly-culture farms or decision making units (DMUs), *n* are equal to 46 in this study. Each farm uses *K* inputs to produce *M* different types of fish species. The inputs are total seed cost, labor working hours, and the quantity of feed which each household used to cultivate prawn-rabbitfish in 2008. M outputs are the quantity of prawn, rabbit-fish, and other kinda of fish per household which were harvested in the same year. Input and output vectors are represented by the vectors x_{it} and y_{it}, respectively, for the i-th farm. The data for all firms may be denoted by the KxN input matrix (X) and the MxN output matrix (Y). The envelopment form of the input-oriented VRS DEA model is specified:

$$\min_{\theta,\lambda_j} \theta$$

Subject to

$$Y\lambda \geq y$$

$$\theta x_i \geq X\lambda$$

$$\sum_{i=1}^{N} \lambda_i = 1$$

$$\lambda_i \geq 0$$

Where θ is the technical efficiency (TE) score having value ranging from zero to one ($0 \leq \theta \leq 1$). The farm is technically efficient and on the frontier if θ is equal to one. The vector λ is an Nx1 vector of weights (constants) which defines the linear combination of the peers of the i-th farm. Y is a vector of output quantities and X is a vector of observed inputs. $-y_i$ is the vector of output of the i-th farm compared to the output vector of the theoretically efficient farm (Yλ). Xλ is the minimum input of theoretically efficient farm, given the actual level of output produced by the i-th farm. x_i is the actual level of inputs of i-th farm. If θ is equal to one, the farm is technically efficient because the level of input of that farm is as small as the quantity of input utilized by the theoretically efficient farm in producing the same level of output. On the contrary, if θ is less than one, the farm is technically inefficient. That farm can still reduce further the level of input used to as low as Xλ in producing the same level of output.

Super efficiency

Super efficiency method was originally proposed by Andersen and Petersen in 1993. This is the term of efficiency score larger than one. That is because each firm is not permitted to use itself as a peer. Although one of its drawbacks is infeasible results of some samples, it is normally used in sensitivity testing, identifying the outliers, and OLS regressing in the second stage instead of Tobit regression (Timothy J. Coelli, D.S. Prasada Rao et al. 2005).

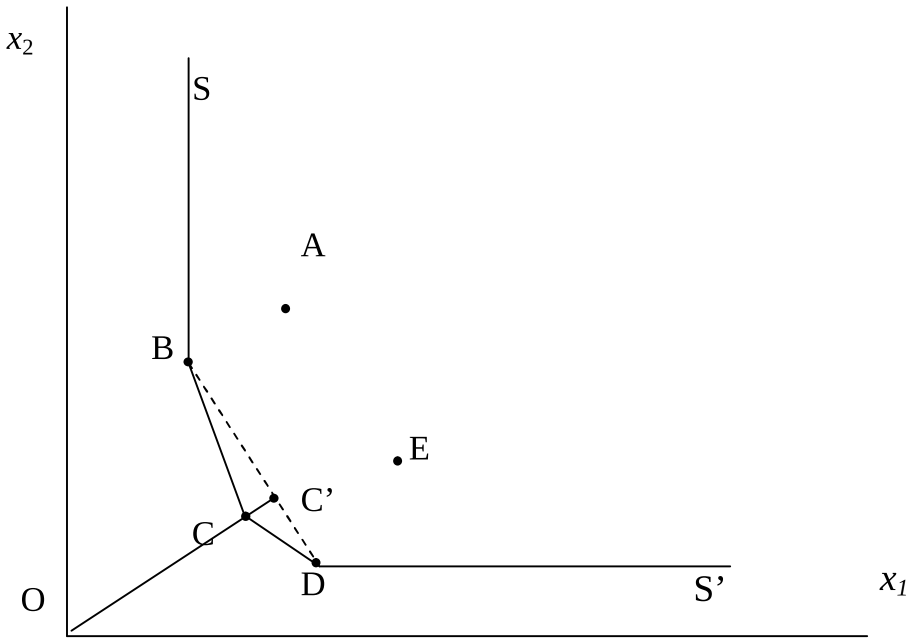


Figure 10: Super efficiency

Consider the case of using two inputs to produce a particular output, if the standard DEA is applied, firms B, C and D are on the frontier and have technical efficiency score of one. However, considering the case of firm C, if super efficiency DEA is applied, C itself will no longer form a part of the frontier. B and D are two firms forming the new frontier. And the projected point of C is C'. The super-efficiency score of C is the ratio of OC' and OC.

A and E are inefficient firms. And their original technical efficiency scores do not change when the super efficiency method is used (Timothy J. Coelli, D.S. Prasada Rao et al. 2005).

4.2.3. Ordinary Least Square regression (OLS)

In order to identify factors affecting on technical efficiency scores which were measured in the first stage, a second stage OLS model was used. It regressed the first stage index on some discretionary and non-discretionary factors in this stage. However, because the upper limit on the efficiency index from the first stage is 1, OLS regression can produce biased estimates. The solutions to this potential problem are to use Tobit instead of OLS regression or to use super-efficiency scores instead of normal-efficiency for OLS regression in the second stage. The later method was chosen to solve above problem in this study.

However, this stage requires a priori specification of functional form. Hence, a Cobb Douglas model was used to identify the relationship between super efficiency and some inputs variables such as education level and experience of shrimp poly-culture farmers, their ability to access extension service, the aquatic stocking density and the production environment.

$$\mathbf{SUPEFF = \alpha\ EDU^{\beta 1}\ EXP^{\beta 2}\ EXT^{\beta 3}\ SDEN^{\beta 4}\ RADEN^{\beta 5}\ e^{ECO}}$$

where **SUPEFF** is super-efficiency scores, which were measured in the first stage. **EDU** and **EXP** are education level and experience of the prawn-rabbitfish poly-culture operators (year). **EXT** is the times that farmers attended in aquaculture training courses which were operated to enhance aquaculture knowledge and skill for farmers by some projects as well as local extension service office (times). **SDEN** and **RADEN** are the densities of shrimp and rabbitfish that the farm applied for the aquaculture crops in 2008 (unit per m^2). And **ECO** is the dummy variable of production environment. **ECO is** equal to 0, if shrimp poly-culture was done in unplanned area or unplanned ponds. And **ECO is** equal to 1, if it was done in planned area (planned ponds). Above function would be transferred to:

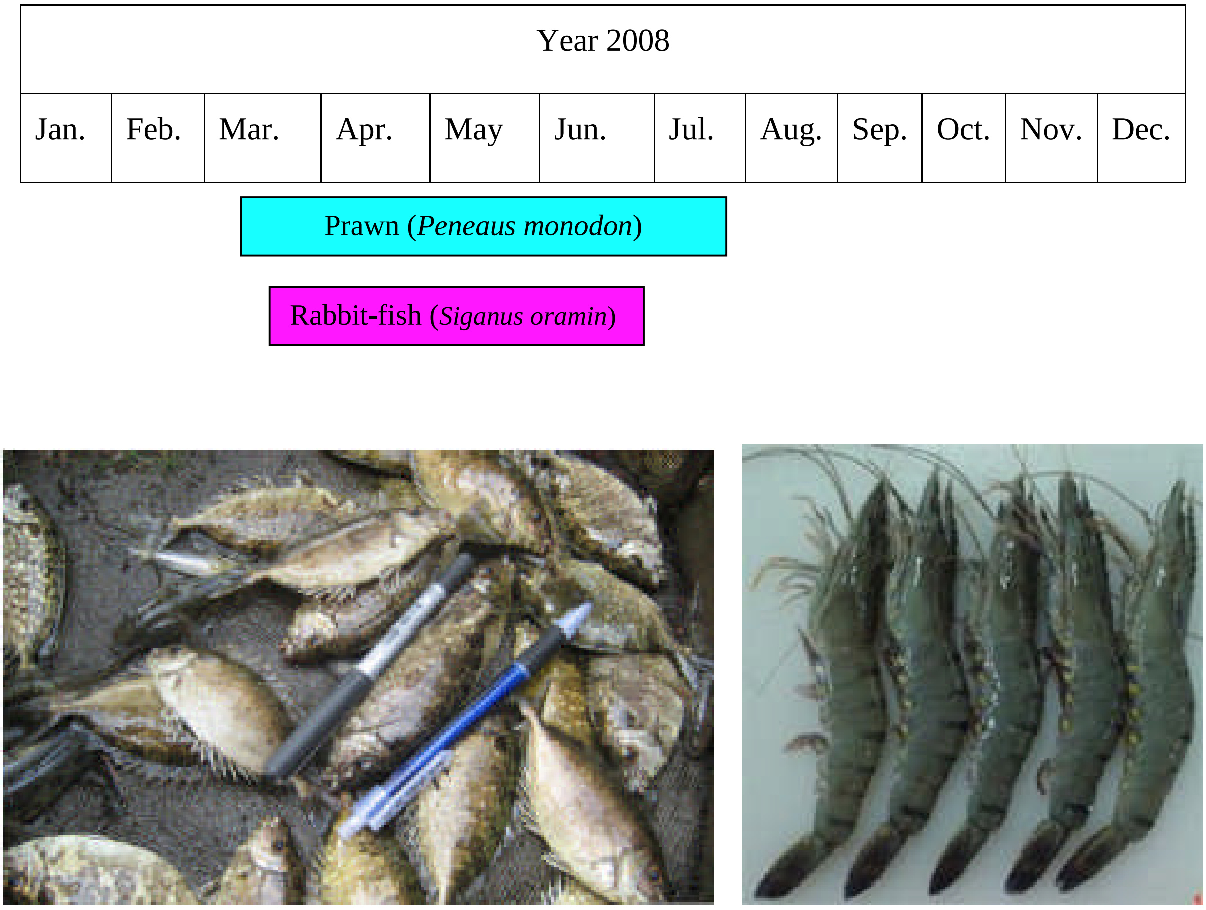
$$\mathbf{LnSUPEFF = Ln\alpha + \beta_1 LnEDU + \beta_2 LnEXP + \beta_3 LnEXT + \beta_4 LnSDEN + \beta_5 LnRADEN + ECOLne}$$

4.2.4. Variables

Since DEA two-stage method was used in this study, two groups of outputs and inputs were categorized.

DEA stage

Outputs used in estimating technical efficiency score were the quantity of three kind of aquatic products including prawn (*Peneaus monodon*), rabbit-fish (*Siganus oramin*), and crab (*Scylla serrata*) which were harvested during the 2008 production year measured in kilogram. Because the poly-culture model was applied all of those outputs were not harvested at the same time. Based on the local seasonal timetable, prawn was wholly harvested between July and August, while rabbit-fish was harvested selectively and gradually from April to June. The harvest time of crab was unfixed and depended on its releasing seed time. However, similar to rabbit-fish, crab was harvested selectively and gradually after releasing crab seeds. It was partly due to the size of seeds released.



a) Rabbit-fish (*Siganus oramin*)   b) Prawn (*Peneaus monodon*)

Figure 11: The seasonal timetable shrimp poly-culture and the illustrated images of rabbit-fish and prawn cultivated

Source: Field survey, google images, and Agricultural, Forestry and Fisheries extension Centre of Thua Thien Hue province

Inputs used to calculate technical efficiency score were seed, labor and feed:

- Seeds used in shrimp poly-culture are seeds of prawn, rabbit-fish and crab. Thus, the quality and size of seeds are different. Moreover, defining the seed for each kind of aquatic product might increase the number of constraints lead to the frontier become tighter. Therefore, seed in this analysis was expressed as total seed cost of all aquatic products measured in VND.

- The feed feeding to prawn, rabbit-fish and crab are different. Besides the available feed in the ponds, the farms used industrial feeds to feed prawn, grass to feed rabbit-fish and small fresh trash fish to feed crab. However, the kind and amount of feeds also depended on each growth stage of each kind of fish species. In this study, the green feed was converted to dry weight equivalent by multiplying it by 0.2 (Sharma, Leung et al. 1999; Sharma and Leung 2000). And feed variable in this analysis was measured in kilogram.

- Labor, in this study, is expressed as total working hours included both household farm and hired labor who might work full-time or part-time. The type and number of workers employed by the farms were up to each stage of cultivating crop and farm size. In the beginning and the end of crop, it was necessary to work in full-time to improve and maintain the ponds and to harvest. Hence, in those stages, the farms often employed from 2 to 5 workers, depending on the farm size, including both hired and household farm labors. The larger farm tended to hire labor and work in full-time rather than part-time. During the crop time, the family members mainly spent about 2 hours per day on average to take care of and feed fish.

OLS stage

Output in this stage refers to technical super efficiency score which was estimated in the first stage, while inputs are some others variables which were not used in the first stage including both discretionary and non-discretionary variables. They were categorized into 4 groups: some main characteristics of the shrimp poly-culture farmers; their ability to access to public services; the aquatic stocking densities; and the production environment.

- Farmer characteristics

+ EDU refers to the education level of shrimp poly-culture farmers in year.

+ EXP is the experience of shrimp poly-culture farmers in year.

Those two variables were expected to have positive relationship with super efficiency in this study.

- Ability to access the extension services

The extension services were often distributed by fisheries department at province and district levels associated with some NGOs projects. They mainly organized aquaculture training courses for the farmers. Therefore, how many times a farmer could attend aquaculture training course was considered as his/her ability to access extension services in this analysis. EXT, hence, refers to the attending times of shrimp poly-culture farmers to aquaculture training courses. It was expected to have positive sign in this study.

- Stocking density

+ SDEN refers to prawn stocking density measured in unit per square meter.

+ RADEN refers to rabbit-fish stocking density measured in unit per square meter.

Those two variables were expected to have no effects on super efficiency in this research.

- Production environment

It was expected that there was difference in super efficiency between two kinds of ecosystem: planned and unplanned ponds. Hence, ECO is a dummy variable used to refer planned area when ECO equals to 1, and unplanned area when ECO equals to 0.

5. Results and Discussion

5.1. Results

5.1.1. Technical efficiency analysis

5.1.1.1. Data set of technical efficiency analysis

Table 4 presents the summary statistics per hectare of the variables used in the efficiency analysis at farm level of planned and unplanned ponds in 2008. In general, a planned farm used less input but produced more prawn output per hectare than an unplanned one.

On average, a farm spent about 6.5 million VND per hectare of pond on aquatic seeds. The range of this input variable was from 2 to 14.5 million VND. In which, an unplanned farm spent almost 7.2 million VND per hectare on seeds, while planned one spent only 4.3 million VND on this.

Table 4: Descriptive statistics of the sample variables per hectare

	All farms				**Planned ponds**		**Unplanned ponds**	
	Mean	**S.D**	**Min**	**Max**	**Mean**	**S.D**	**Mean**	**S.D**
Outputs/Ha								
Prawn (kg/ha)	273.5	259.6	24.0	1300.0	270.0	240.1	191.7	241.3
Rabbit-fish (kg/ha)	189.0	129.5	10.0	658.0	118.0	85.9	169.6	168.9
Others (kg/ha)	38.7	36.1	0.0	130.0	21.0	22.8	38.9	43.7
Inputs/Ha								
Seed (1000 VND/ha)	6567.9	3049.1	2080.0	14517	3357.0	1805.2	6059.6	3738.3
Feed (kg/ha)	1102.9	930.7	213.0	5306.0	444.3	206.1	1020.6	923.6
Labor (man hours/ha)	1531.4	739.3	376.0	4280.0	1193.8	457.2	1037.8	295.9

Source: Field survey

The results also show that feed used per hectare of pond averaged approximately 1103 kg in total. The minimum was only 213 kg, while the maximum was 24 times higher (more than 5300 kg per hectare). Similarly, the range of labor variable was so large from 376 to almost

4300 working hours, while the average man hours per hectare was more than 1.5 thousand hours. That was due to the effects of flood-tide in some farms in the study area in 2008.

In 2008 crop, there were 2 flood-tides in Tam Giang lagoon area. One happened just some weeks after releasing aquatic seeds. The aquatic seeds of some farms, hence, were drifted downstream. Those farms, therefore, almost stopped feeding and working in hopeless to save and wait for new coming crops. However, the results were unexpected. Some farms could still harvest considerable aquatic outputs in the end of crop. That might be the reason why some cases had very favorable feed ratio and some had very little labor input.

It would be more interesting to consider the descriptive statistic of sample variables in total in appendix 3. It is clearer in some cases having very favorable feed amount with only 138 kg feeds and very little working hours with only 680 hours, while the average feed and labor input a farm used was almost 890 kg and 1073 hours, respectively. However, that might also be due to the production scale such as pond size, seed stocking density.

The average outputs per hectare of all farms were more than 273 kg prawn, 189 kg rabbit-fish, and about 39 kg others, mainly crab. The minimum quantity of prawn, rabbit-fish, and crab were 24, 10, and zero kg per hectare, while the maximum were 1.3 thousand, almost 660, and 130 kg per hectare respectively. The planned farms tended to produce more prawn but less rabbit-fish and crab than unplanned ones, although the total quantity of outputs was almost the same for both groups.

5.1.1.2. Technical efficiency results

Table 5 gives information on the range and the mean technical efficiency scores of samples which were categorized into planned and unplanned-pond groups.

The analysis shows that there were 18 out of 44 farms or more than 40 percent of the whole samples being VRS technically efficient. The technical efficiency under VRS ranged from 0.58 to 1, with the mean measure of 0.91. Of these 13 farms or more than 72 percent of the VRS efficient farms were unplanned, only 28 percent (5 out of 18 farms) were planned ponds. The range of VRS technical efficiency of unplanned group (from 0.58 to 1) was also larger than that of planned group (from 0.79 to 1). However, the mean value of technical efficiency score under VRS was higher in planned farms than in unplanned ones with 0.95 and 0.89, respectively.

Table 5: Average technical efficiency scores

		Mean	Efficient farms No. farms	Efficient farms %	Min	S.D
Total	VRSTE	0.9063	18	40.9	0.578	0.11029
	CRSTE	0.7662	14	31.8	0.191	0.22695
	SCALE	0.8291	14	31.8	0.322	0.18916
Planned ponds	VRSTE	0.9523	5	27.8	0.789	0.72501E-01
	CRSTE	0.8794	4	28.6	0.600	0.12826
	SCALE	0.9238	4	28.6	0.648	0.11668
Unplanned ponds	VRSTE	0.8928	13	72.2	0.578	0.11656
	CRSTE	0.7329	10	71.4	0.191	0.24001
	SCALE	0.8013	10	71.4	0.322	0.19849

Source: Field survey

14 out of 44 samples or almost 32 percent were CRS technically efficient. The estimated technical efficiency under CRS efficiency ranged from 0.19 to 1, while VRSTE ranged from 0.58 to 1. The mean CRS technical efficiency was about 0.77. About 71 percent or 10 out of 14 CRS technically efficient farms were unplanned, while only 28.6 or 4 out of 14 CRSTE farms were planned. However, the average score of unplanned group was much less than that of planned one.

The difference between VRS and CRS technical efficiency indicates the existence of scale inefficiency in the sample farms. Average scale efficiency was about 0.83. There were still about 30 scale inefficient farms in the whole samples. Although the number of scale efficient farms in unplanned group (more than 71 percent) was more than in planned one (only 28.6 percent), the mean scale efficiency score of the latter group (0.92) was still higher than that of the former (0.8).

The Figure 12 depicts the frequency distributions of estimated technical efficiency scores under CRS and VRS and scale efficiency scores. Almost 40 percent of sample farms had one score of VRS and CRS technical efficiency, and scale efficiency. Just 5 percent of the samples had pure technical efficiency score from 5 to 6. There was no farm having VRS technical efficiency scores less than 0.5. About 12 percent and only 7 percent of total shrimp poly-culture farms had less than or equal to 0.5 CRS technical efficiency and scale scores, respectively.

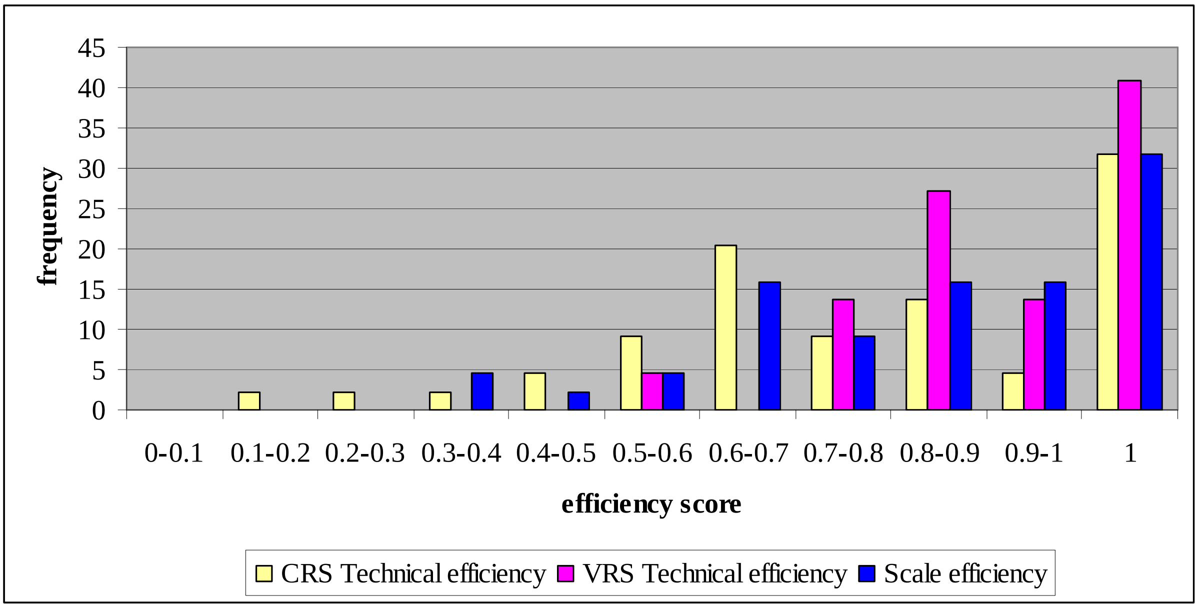


Figure 12: Frequency distribution of technical efficiency

Source: Field survey

Moreover, individual analysis of farms indicated that most of the samples (about 65.9% or 29 out of 46 farms) had increasing returns to scale. About 14 farms, accounting for 35% of the whole samples, were scale efficient. Only one out of 46 farms, accounting for 2.3 percent of total samples had decreasing return to scale (Table 6)

Scale efficiency refer to the optimal size that a certain percentage increase in inputs would lead to the same proportion expand in outputs. The below table includes pond size and total production of outputs as farm size variables.

The Table 6 shows that, on average, 14 scale efficient farms had large pond size with about 1.15 hectare and produced more than 610 kg of total outputs. However, a farm that had decreasing return to scale produced only 350 kg in one hectare of pond. Meanwhile an increasing return to scale farm could produce more than 305 kg from 0.69 hectare of pond.

Table 6: The results of return to scale and mean value of total production and pond size

Return to scale	Group	Efficient farms		Total production (kg)	Pond size (ha)
		No	%		
IRS	All	29	65.9	305.5	0.69
	Planned	6	20.7	321.7	0.67
	Unplanned	23	79.3	301.2	0.70
CRS	All	14	31.8	615.6	1.15
	Planned	4	28.6	540.0	1.09
	Unplanned	10	71.4	645.8	1.17
DRS	All	1	2.3	350.0	1.00
	Planned	0	0	0	0
	Unplanned	1	100	350.0	1.00

Source: Field survey

5.1.2. Factors affecting the technical efficiency of prawn poly-culture farms

5.1.2.1. Descriptive statistic of variables used in OLS stage

OLS regression was applied to identify the relationship between technical super-efficiency and some main factors which were grouped into three categories: farmer characteristics (EDU, EXP), accessing ability to credit and extension services (CRED, EXT), stocking density (SDEN, RADEN), and production environment (ECOSYSTEM). The mean values of these variables are shown in Table 7. In general, the mean values of independent variables of unplanned-pond groups were higher than that of planned-pond groups, except the investment in maintaining the ponds and shrimp stocking density, while super-efficiency of planned farms was larger than that of unplanned.

On average, an operator was from the 6^{th} to 7^{th} grade and had more than 10 years of experience. In which, unplanned farmers had about 6.6 years of schooling and more than 11 years of experience, while planned ones had only 5.4 years of education and 8.4 years of experience. However, the t-test results, which test whether the differences in mean values of education and experience between two groups different from zero or not, show that the value of test statistic of only experience variable was less than the critical value if 5 percent level of significance was selected (t = -2.32 < $-t_{(0.975,42)}$ = -2.02). It means that the null hypothesis that there is no difference in mean experience between planned and unplanned farmers was rejected.

Table 7: Mean value and standard deviation of variables used in OLS regression

Variable	**All farms n = 44**		**Planned ponds N = 10**		**Unplanned ponds n = 34**		**Differences**
	Mean	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**t-test**
DEPENDENT VARIABLE							
SUPEFF	0.91	0.46	1.01	0.29	0.89	0.50	0.72
INDEPENDENT VARIABLES							
Farmer characteristics							
EDU	6.5	2.6	5.4	2.3	6.8	2.7	-1.48
EXP	10.6	3.5	8.4	1.3	11.2	3.7	-2.32**
Accessing ability to extension services							
EXT	15.1	21.6	14.1	5.3	15.4	24.5	-0.17
Stocking density							
SDEN	11.9	6.3	12.4	4.8	11.7	6.7	0.31
RADEN	1.4	0.9	1.3	1.1	1.4	0.8	-0.32
Production environment							
ECO = 1	10	-	-	-	-	-	-
ECO = 0	34	-	-	-	-	-	-

Source: Field survey *Note: **Significant at 5 %*

The results also show that the average stocking density of shrimp and rabbit-fish were almost 12 and 1.4 units per square meter of pond, respectively. And similarly, rabbit-fish stocking density of unplanned groups was a bit more than that of planned ones. It was inversely for shrimp stocking density. A planned farm released about 12.4 units of shrimp per meter of pond, while an unplanned one raised only 11.7 units. However, those differences are not different from zero based on the test statistic results. It means that at 5 percent of level of significance, the mean values of prawn and rabbit-fish stocking densities are almost the same for those two groups.

In terms of farmers' ability to access extension services, it was not much different between those two groups. Both groups were exposed to about 14 aquaculture training courses on average.

5.1.2.2. OLS results

Table 8 shows the estimate of the parameters of Cobb Douglas model in OLS regression. The individual coefficient of explanatory variables differs with respect to planned and unplanned ponds.

These coefficients imply that percentage change in independent variables might lead to percentage change in dependent variables, in which the positive coefficients mean that an increase in such variables would lead to an increase in technical super-efficiency of shrimp poly-culture farms. Meanwhile the negative coefficients mean that an increase in those variables would lead to a decrease in technical super-efficiency of the farms.

All farms

Table 8 analysis results show that about 44.5 percent of the variation in technical super-efficiency was explained by the variation in farmer characteristics, their ability to access extension services, stocking density and the production environment. Moreover, the table 8 shows that the experience of shrimp poly-culture farmers, their accessing ability to extension services, the differences in shrimp densities, and the production environment were significant factors affecting technical efficiency of the whole samples. This means that the In contrast, the education level of shrimp poly-culture farmers and rabbit-fish stocking density per square meter of pond had no explanatory effect on technical super-efficiency.

In general, LnEXP (experience of the farmers), LnEXT (ability to access extension services), and production environment, which was expressed by ecosystem variable (ECO), had statistically significant positive effects on technical super-efficiency of all shrimp poly-culture farms at 10 percent level. However, LnSDEN (shrimp density) had negative relationship with technical super-efficiency at 1 percent of significant level.

Table 8: Parameter estimates and standard error values of the efficiency determinants for a sample of farms

Explanatory Variable	Total		Planned ponds		Unplanned ponds	
	Coefficient	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**
Constant	-1.1001	0.6980	-1.9955	1.963	-1.1594	0.8372
Farmer characteristics						
- LnED	0.83364E-01	0.1525	-0.13668	0.2765	0.11859	0.1937
- LnEXP	0.50542*	0.2603	0.64888	0.8528	0.53883*	0.3048
Accessing ability to extension services						
- LnEXT	0.12622*	0.6499E-01	0.23266	0.3299	0.11733	0.7185E-01
Stocking density						
- LnSDEN	-0.32607***	0.8828E-01	0.86811E-01	0.3219	-0.35238***	0.9763E-01
- LnRADEN	-0.19775	0.1202	-0.12026	0.1702	-0.23542	0.1633
Production environment						
- ECO	0.34782*	0.6980	-	-	-	-
R^2	44.5		32.07		46.21	

Notes: ***Significant at 1% ** Significant at 5% * Significant at 10%

Source: Field survey

Planned farms

The planned-pond results show that all variables including farmer characteristics, their accessing ability to extension services, the stocking density of shrimp and rabbit-fish, and the production environment had no statistically significant effect on technical super-efficiency for planned-pond group. This means that there are not any variables effecting on technical super-efficiency of planned farms.

Unplanned farms

For unplanned group, experience of the shrimp poly-culture and shrimp stocking density had statistical effects at 10 and 1 percent of significant level respectively, while other variables such as education level of farmers, their ability to access extension services and rabbit-fish density had no effects on technical super-efficiency.

In which, the experience of shrimp poly-culture farmers had statistically positive relationship with technical super-efficiency. Conversely, the stocking density of prawn impacted negatively on technical super-efficiency.

5.2. Discussion

The mean technical efficiency for the whole samples cultivating prawn-rabbitfish-crab under VRS was estimated to be about 91 percent. This means that approximately 9 percent of inputs were used inefficiently by shrimp poly-culture farms. In fact, the farms could potentially decrease the current level of all inputs by 9 percent in producing the current level of outputs (Table 5). This estimate compared fairly well with the mean technical efficiency estimate of Nigeria (from 88 to 89 percent), Bangladesh (85 percent), Thailand (72 percent for extensive and 91 percent for intensive), and Taiwan (84 percent). However, this result is much higher comparing with the mean technical efficiency estimate reported by some other frontier applications to Vietnam aquaculture. For example, Den et al. (2007) reported a mean technical efficiency of 46 percent in prawn mono-culture in Mekong Delta, Vietnam. By analyzing data collected by World-Fish and its partner institution in Vietnam involved in the "Genetic improvement of carp species in Asia" project, Dey et al. (2005) estimated the mean technical efficiency of freshwater pond poly-culture in Vietnam to be 42 percent for extensive and 48 percent for intensive culture. However, it is easy to see the difference in production environment of those study areas although all of them are in Vietnam. Moreover, the results of this study may only be the case for data collected in Tam Giang lagoon. It can not be representative of Vietnam aquaculture.

Under constant return to scale, the mean technical efficiency of the whole sample was approximately 77 percent. This means that those farms could reduce the use of all inputs by 23 percent without changing the current level of outputs when operating at an optimal scale. The difference between VRS and CRS technical efficiency scores shows that scale inefficiency was the main cause of the CRS technical inefficiency. More than 62 percent of total samples were scale inefficiency indicating that those farms should change their farm size to improve their productivity (Table 5**)**

The individual analysis reveals that the unplanned-pond group used the combination of inputs more inefficiently than planned one. They could potentially save all their inputs by 11 percent under VRS and more than 27 percent under CRS without changing the output quantities produced. While planned farms could reduce about 5 percent of inputs to produce the current level of outputs (Table 5). The impacts of production environment were clearer in the relationship with technical super-efficiency, which was shown in Table 8. The statistically significant coefficient of 0.34782 indicated that there was a 37.57 percent differential between cultivating prawn-rabbitfish-others in planned and unplanned ponds. Doing aquaculture in planned environment would lead to higher level of technical super-efficiency than in unplanned (Table 8). It means that the first hypothesis that planned farm had higher technical efficiency than unplanned farms was true. This result might imply that production environment was really an important factor in doing aquaculture. And in order to improve productivity aquaculture area should be planned to get better water quality.

However, most efficient farms were from unplanned group. More than 70 percent of total efficient farms were unplanned, only less than 30 percent were planned. That might be due to small planned samples collected. If considering the efficient proportion in each type of ecosystem, from 40 to 50 percent of total planned farms were operating efficiently, while only 29-38 percent of total unplanned farms were on the frontier (Table 8).

Furthermore, the individual analysis reveals that except 31.8 percent of CRS farms which were at optimal scales, about 66 percent of IRS farms should expand their operating scale to improve their productivities. Because if any farm in IRS farms increased by one percent of input levels, he/she could expand by more than one percent of outputs produced. Any *k* percent increase in input levels used by those 14 CRS farms would lead to *k* percent increase in outputs produced. Only 2.3 percent of total farms should not increase their scale because their outputs would only be expanded less than 1 percent when they used one more percent of inputs (Table 6).

Being more experienced or attending more aquaculture training courses also enabled prawn poly-culture farms to improve the level of technical efficiency due to the statistically significant positive coefficients. The results show that a 0.51 percent increase in technical super-efficiency associated with a one percent increase in farmers' experience. Moreover, a one percentage increase in attending times to aquaculture training courses would lead to an increase in technical super-efficiency scores of 0.13 percent. Therefore, the extension services should be expanded more in this study area. In addition, although experience could not be increased simply by attempts of human being, sharing experience should be done to improve the knowledge of aquaculture farmers. This should especially be implemented in unplanned group, because a one percentage increase in experience would result in almost 0.54 percentage change in technical super-efficiency of this group (Table 8).

On the contrary, stocking density was found to be a negative important factor influencing technical efficiency of prawn poly-culture. A one percent increase in shrimp stocking density might be the cause of a 0.33 decrease in technical efficiency. In other words, the sign of this coefficient indicates that less stocking density would lead to higher efficiency. This variable had especial effect on technical efficiency score of unplanned farms. A one percent increase in shrimp density would lead to more than 0.35 percent decrease in technical super-efficiency (Table 8). That might be due to the existent impacts of shrimp disease spread in some last crops. Those results also reveal that there might be congestion2 problem in shrimp poly-culture production process of those samples. This means that there might be an optimal shrimp stocking density larger than zero and less than the present level. And from zero to the optimal level, an increase in shrimp stocking density would lead to higher technical super efficiency. However, at the optimal stocking, an increase in shrimp stocking density would result in a decrease in technical super efficiency. These imply that most farms should reduce the prawn stocking density to the optimal level to improve their technical efficiency. Due to the limitation of time and ability, this study could not presently show how much slack of the input congestion is. This might be an interesting topic for further study in the future.

[2] Congestion is said to occur when some of the outputs that are maximally possible are reduced by increasing one or more inputs without improving any other input or output (Cooper 2001; Cooper 2004)

6. Conclusion and recommendation

This study specified a two-stage data envelopment analysis to estimate technical efficiency of prawn (*Peneaus monodon*)-rabbitfish (*Siganus oramin*) poly-culture in Tam Giang – Cau Hai lagoon system, Vietnam. The estimated technical super-efficiency scores were then regressed on operator characteristics, extension services, stocking density and production environment. A comparative technical efficiency of planned and unplanned ponds in this area was also made.

On average, the estimated technical efficiency score was relatively similar to that of aquaculture in some countries, but was much higher than that in some other studies about prawn and freshwater poly-culture ponds in Vietnam. The results of the first step (stage) also reveal that technical inefficiency of prawn poly-culture was mainly due to scale inefficiency. Most of farms should expand their scale to improve their technical efficiency. In which, planned farms seemed to be more efficient with a mean technical efficiency of 95 percent, compared to a mean of 89 percent of unplanned farms.

Using Cobb-Douglas function in OLS regression step, the results show that almost 45 percent of the variance in technical super-efficiency was explained by the variance in operator characteristics, their ability to access to extension services, stocking density, and production environment. Of these, experience of farmers, the attending times to aquaculture training course and ecosystem dummy variable had the anticipated positive sign. Only prawn stocking density, which was expected to have no effect, did impact negatively on technical super-efficiency. This might reveal the problem of congestion in production process of the prawn poly-culture samples in this study, which can be an interesting topic for further study. The results further show that there existed a statistically significant positive relationship between technical super-efficiency and experience in only unplanned farms. Meanwhile prawn stocking density was found to have statistically significant negative effect on technical super-efficiency of unplanned farms only. The elasticity of technical super-efficiency with respect to all variables was especially found to be not statistically significant for planned farms.

Based on the above conclusions, some policy recommendations can be made. It is expected that the results of this study can contribute to the evaluation of prawn poly-culture in planned area in Tam Giang – Cau Hai lagoon system. The finding that planned farms had a higher level of mean technical efficiency suggests that aquaculture area in Tam Giang – Cau Hai lagoon system should be planned as soon as possible to improve technical efficiency. As for unplanned farms, they should support instead of resisting the governmental offices in planning aquaculture area to improve efficiency in their aquaculture production. Moreover, the determinant analysis reveals that extension services, particularly aquaculture training courses in particular, have a significant positive impact on technical efficiency. Therefore, it is suggested that government authorities may target training of more extension workers or supporting of more NGOs projects that conduct aquaculture training courses in order to have the desired increase in productivity. In addition, the finding of congestion problem through the statistically significant negative relationship between prawn stocking density and technical super-efficiency implies that further studies are needed to work out control methods.

Appendix

Appendix 1: Summary results Technical efficiency and Factors affecting Technical efficiency in Aquaculture

Source and year of study	Production system	Method of estimation	Country	Main results Mean TE	Factors influencing efficiency
Alam and Murshed-e-Jahan (2008)	Prawn-carp poly-culture	DEA	Bangladesh	85	Pond size, feed
Kareem, Dipeolu et al. (2008)	Fish farming	SPF	Nigeria	88-89	Experience
Amos (2007)	Crustacean	SPF	Nigeria	70	Age, family size
Den et al. (2007)	Prawn farms	SPF	Vietnam	46	Experience, age
Cinemre et al. (2006)	Trout farms	DEA (two-stage approach)	Turkey	82	pond tenure, farm ownership, experience, education, extension services, off-farm income, credit availability
Kaliba and Engle (2006)	Catfish farms	DEA (weight-restricted)	Arkansas	57	experience, extension contacts

Mussa (2006)	Integrated aquaculture-agriculture	SPF	Malawi	49 (non-adapter) 63 (adapter)	education, extension services, recycling of materials, number of plots
Dey et al. (2005)	Freshwater pond poly-culture	SPF		(extensive/intensive)	
			- China	77/84	- regional dummy, farm size, distance to seed supplier
			- India	65/86	- education, farm size, pond owner dummy
			- Thailand	72/91	- farm area, pond owner, distance to seed supplier/market
			- Vietnam	42/48	- age, education of operator, farm area, distance to nearest market
Chiang et al. (2004)	Milkfish	SPF	Taiwan	84	Fresh water, location, education, experience labor, monoculture farm, reading ability
Pantzios et al. (2004)	Aquaculture farms	SPF (input-oriented Malmquist)	Greek	70	
Sharma and Leung (2000)	Carp production	DEA	India	80.5 (semi-intensive) 65.8 (extensive)	Fish, water, feed management, primary activity, experience

Iinuma, Sharma and Leung (1999)	Carp pond culture	SPF	Malaysia	42	Age, ownership, intensive culture
Sharma et al. (1999)	Fish poly-culture	DEA	China	83	Farm size,
Jayaraman (1997)	Carp culture	PFPF	India	23/40 farms <50 1 farm = 100	

Appendix 2: Frequency distribution of technical efficiency

Year	Aquaculture area (ha)	Aquaculture Households (household)	Aquaculture Production (ton)	Shrimp production (ton)	Others (ton)
1991	110	-	-	-	-
1996	1103	867	-	-	-
1997	1162	1192	-	-	-
1998	1296	1549	-	-	-
1999	1629	2150	1084	365	719
2000	1850	3162	1467	649	818
2001	2930	4207	2551	1697	854
2002	3122	4691	3242	2130	1112
2003	3694	5093	4192	3149	1043
2004	4021	5734	4783	3443	1340
2005	4050	-	5192	3362	1830
2006	-	-	6387	3861	2526
2007	-		6798.4	3711	3087.4

Source: Fisheries Department and People's Committee of Thua Thien Hue Province

Appendix 3: Descriptive statistics of the sample variables in total

	All farms				Planned ponds		Unplanned ponds	
	Mean	**S.D**	**Min**	**Max**	**Mean**	**S.D**	**Mean**	**S.D**
Outputs/Ha								
Prawn (kg/ha)	209.5	240.5	20.0	1300.0	339.8	206.9	253.9	272.8
Rabbit-fish (kg/ha)	157.8	154.7	0.0	900.0	134.5	53.8	205.1	141.1
Others (kg/ha)	34.9	40.4	0.0	200.0	31.9	38.1	40.7	35.8
Inputs/Ha								
Seed (1000 VND/ha)	5445.4	3566.5	1040.0	15080	4324.1	2546.8	7227.8	2893.2
Feed (kg/ha)	889.7	850.4	138.0	4245.0	638.7	465.7	1239.5	992.5
Labor (man hours/ha)	1073.2	339.6	680.0	2210.0	1521.4	313.1	1534.3	827.9

Source: Field survey

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