Technical, economic, and allocative efficiencies of small-scale brackish water pond culture in Mahakam Delta, Indonesia

by Heru Susilo

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[1]Heru Susilo, [2]Oon Darmansyah, [3]Erwiantono, [4]Qoriah Saleha, [2]Bambang I. Gunawan, [2]Gusti Haqiqiansyah, [2]Said Abdusysyahid, [2]Elly Purnamasari, [2]Muhamad Syafril, [2]Eko Sugiharto, [2]Wahyu Fahrizal, [3]Freddy Maryanto

[1] Laboratory of Fisheries Resource Economics, Faculty of Fisheries and Marine Sciences, Mulawarman University, Samarinda, Indonesia; [2] Department of Fisheries Socioeconomics, Faculty of Fisheries and Marine Sciences, Mulawarman University, Samarinda, Indonesia; [3] Laboratory of Coastal Community Development, Faculty of Fisheries and Marine Sciences, Mulawarman University, Samarinda, Indonesia; [4] Laboratory of Fisheries Agribusiness, Faculty of Fisheries and Marine Sciences, Mulawarman University, Samarinda, Indonesia. Corresponding author: H. Susilo, herususilo@fpik.unmul.ac.id

Abstract. This study estimated the technical (TE), economic (EE), and allocative (AE) efficiencies of brackish water pond culture in the Mahakam Delta. The data envelopment analysis (DEA) approach was employed to identify the efficiency, while the Tobit regression model was applied to determine the factors influencing efficiencies. Data were collected from 100 small-scale farmers from five villages in the study area applying a well-structured questionnaire. Results showed that the mean TE, EE, and AE were 88.57%, 46.76%, and 52.97, respectively. In addition, age, education, experience, and pond sizes are crucial determinants of efficiencies. Therefore, creating incentive programs, education facilities, training, and extension services are strongly recommended to improve the performance of brackish water pond culture in the study area.
Key Words: aquaculture, data envelopment analysis, farmers, production, Tobit regression model.

Introduction. Worldwide, fisheries and aquaculture play an essential role in livelihood, poverty alleviation, providing a significant share of animal protein, and food security (Smith et al 2010; Belton & Thilsted 2014; Rahman et al 2019; Susilo et al 2019; FAO 2020; Khan et al 2021). The worlds' fish production in 2018 attained 178.5 million tons, providing a total first sale value at USD 401 billion (FAO 2020). Of overall fish production, 156 million tons were spent on human consumption. Also, about 59.51 million global people work in the fisheries and aquaculture sectors. Since the global capture fisheries production has stagnated and overexploited over the last three decades, aquaculture is the most crucial sector for human consumption. Globally, its production increased rapidly to 82.1 million tons in 2018, up from an average of 14.9 million tons in 1986, contributing about 52% of fish for human consumption (FAO 2020). Asian fish production is one of the world's major fish producers. Fish production in this region has grown from 19.3% in 2000 to 42% in 2018 (excluding China). Moreover, Southeast Asia contributes 13 million tons of world aquaculture fish production (FAO 2020).

Indonesia is a country in Southeast Asia and one of the significant fish producers, contributing 6.61% of the global food from aquaculture and fishing, whose in 2018 Indonesia's aquaculture was documented at 5.43 million tons (FAO 2020; Susilo et al 2021). In Indonesia, aquaculture is the primary source of livelihood for the coastal community, with 2.2 million people living as fish farmers (Erwiantono et al 2020; MMAF Indonesia 2021). Among different aquaculture systems, brackish water pond culture with shrimp farmed species is one of the practical systems developed tremendously in

Indonesia. Moreover, Indonesia is one of the major producers in the global shrimp supply, contributing 239.3 metric tons of global farmed shrimp productions in 2020 (Statista Research Department 2022). Regarding shrimp exports, Indonesia produced 162,580 tons in 2014, providing at USD 1.39 billion, with the export destination countries being The United States and Japan (Susilo et al 2018).

However, small-scale brackish water pond culture in Indonesia faces many challenges, including disease outbreaks and a cause of mangrove loss. On the other hand, it also faces the problems of decreasing market prices and increasing input costs. The combined impact of these problems has led to uncertain farmers' income, and some farmers are even driving at a loss. For instance, in the Mahakam Delta, farmers of small-scale brackish water pond culture faced the White Spot Syndrome Virus (WSSV) in the 1990s, causing mass mortality of shrimp and influencing the farmers' incomes (Kusumastanto et al 1998). Some studies also reported that the decline in shrimp productivity in many countries was caused the WSSV attack (Valderrama & Engle 2004; Karim et al 2011; Kalaimani et al 2013). In addition, a study from Susilo et al (2017a) reported that small-scale brackish water pond culture in the Mahakam Delta caused the degradation of mangrove areas, where reductions in mangrove areas lead to a decrease in farmers' income relating to lower productions and unproductive brackish water ponds. Moreover, previous studies revealed that mangrove degradation and water and soil pollution significantly influenced the reduced productivity of aquaculture (Ottinger et al 2006; Primavera 2006; Jayanthi et al 2018). To survive in the long run, farmers of small-scale brackish water pond culture must improve the technical, economic, and allocative efficiency levels by combining inputs and output optimally to reduce costly inputs and environmental degradation and enhance farmers' income (Sarker et al 2016; Khan et al 2021).

With this backdrop, the objectives of this study are: (1) to determine the technical efficiency (TE), economic efficiency (EE), and allocative efficiency (AE) on small-scale brackish water pond culture, applying Data Envelopment Analysis (DEA) model; and (2) to identify the interaction between farmers' demographics and TE; EE; and AE in aquaculture. DEA, a nonparametric technique, is a linear programming model as an analytical technique to establish the efficiency of a set of multiple similar entities or Decision-Making Units (DMU). This model is advantageous because it accomplishes not set a priori functional form and permits multiple-output technologies (Badunenko & Mozharovskyi 2016).

Some studies related to the efficiency of aquaculture using the DEA model have been conducted in many countries, such as Vietnam (Long et al 2020); Indonesia (Hukom et al 2020); Mexico (Cortes et al 2021); Myanmar (Aung et al 2021); and Bangladesh (Alam 2011). However, studies that focus on applying the analysis of TE, EE, and AE on small-scale brackish water pond culture in the Mahakam Delta are limited.

Material and Method

Study area and data. The Mahakam Delta, located in East Kalimantan Province, Indonesia, has 20 villages, with 32% working as fishers and fish farmers (Susilo et al 2017b). This area covers 5200 km^2 divided into pro-delta at 2700 km^2, 1000 km^2 of the delta front, and 1500 km^2 of terrestrial area. In the Mahakam Delta, most small-scale brackish water pond cultures are traditional or extensive systems without feed (Sidik 2009). The samples of farmers were randomly selected by employing a questionnaire and face-to-face interviews. One hundred farmers were chosen and were interviewed from July to September 2021 in five major small-scale brackish water pond culture villages in Mahakam Delta. Three villages are Muara Pantuan, Tani Baru and Sepatin villages under Anggana sub-district; and two villages are Saliki and Salok Palai villages under Muara Badak sub-district (Figure 1).

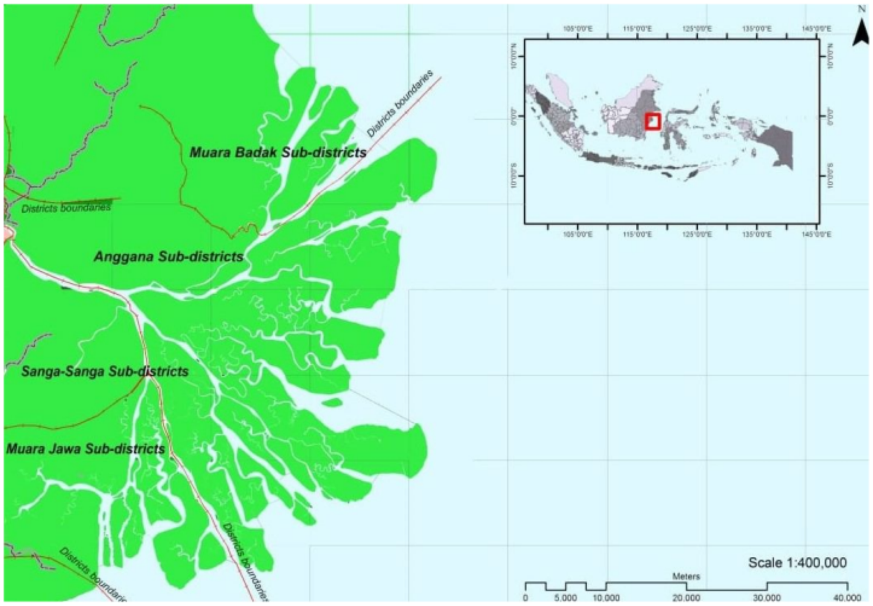

Figure 1. Map displays the location of the study area, Mahakam Delta, Indonesia.

Analytical framework

DEA model. Diverse approaches to measuring efficiency have been designed over the past 40 years, including parametric and non-parametric models. Stochastic frontier analysis (SFA) and DEA are two popular techniques. SFA is a parametric method by approaching econometrics considering both the inefficiencies and white noise, while the DEA is a non-parametric model relating to all deviations from the frontier to inefficiency (Coelli et al 2005). DEA, in particular, was first presented by Charnes et al (1978) and had several advantages: (1) each observation can evaluate the technical inefficiency measure; (2) able to determine sources and amounts of inefficiency in each input and output for DMU; (3) able to manage multiple outputs and inputs; (4) not require a prior detailed functional structure for the production frontier and the distributional assumptions of the inefficiency term (Førsund et al 1980; Coelli et al 2005; Cooper et al 2010). Furthermore, Farrell (1957) explained that economic efficiency (EE) is the combination of two components: (1) technical Efficiency (TE) that refers to the capability of a farm to achieve maximum outputs; (2) allocative efficiency (AE) that refers to the capability of a farm to combine different resource inputs to achieve a mix of different outputs. The efficiency of decision-making units in the DEA model is estimated in an input-oriented model or an output-oriented model. This study applied an input-oriented DEA method due to the increase and limited inputs and the restrictions on land use for brackish water ponds.

This study assumes that brackish water pond culture is denoted by *N*, which each farm produces *M* kinds of output utilizing *K* kinds of inputs. The input and output data of *i*th farm used symbols x_i and y_i, respectively. All data of farms are defined by input matrix *X* (*KxN*) and output matrix *Y* (*MxN*). TE is calculated by applying the input-oriented DEA model determined as follows:

$$\begin{gathered} Min_{\theta,\lambda}\ \theta \\ s.t. \\ -y_i + Y\lambda \geq 0 \\ \theta x_i - X\lambda \geq 0 \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \geq 0 \end{gathered}$$

where: λ = an *Nx1* vector of constant weights, representing the linear combination of the peer of the *i*th farm;

θ = the proportional reduction in input that a farm can produce the given output;

$Y\lambda$ - the output vector of the efficient farm;

$X\lambda$ - the minimum input of the efficient farm utilized.

To estimate EE, cost-minimizing DEA is defined as:

$$Min_{\lambda,x_i^*} W_i X_i^*$$
$$s.t.$$
$$-y_i + Y\lambda \geq 0$$
$$x_i^* - X\lambda \geq 0$$
$$\sum_{j=1}^{n} \lambda_j = 1$$
$$\lambda_j \geq 0$$

where: W_i = a vector of input prices for the *i*th farm;

X_i^* = the cost-minimizing vector of input quantities for the ith farm, by the input price w_i and the output levels y_i.

Therefore, EE of the *i*th farm is estimated by comparing the minimum cost of the farm to its actual cost:

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

Further, AE is the ratio of EE and TE calculated as follows:

$$AE = \frac{EE}{TE}$$

Tobit regression model. The Tobit regression is employed to estimate the factors affecting technical efficiency, allocative efficiency, and economic efficiency. The formula can be defined as follows (Tobin 1958):

$$y_j^* = \beta_0 + \sum \beta_m X_{jm} + \varepsilon_j, \quad \varepsilon_j \sim N(0, \sigma^2)$$

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

where: y_j^* = the latent variable describing the efficiency of farm *j*;

β_m = a vector of coefficients;

X_{jm} = a vector of independent variables;

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

The empirical model is calculated in the form as follows:

$$Efficiency = \beta_0 + \beta_1 Age + \beta_2 Education + \beta_3 Experience + \beta_4 Pond\ age + \beta_5 Pond\ size$$

Efficiency is an independent variable describing the technical efficiency, allocative efficiency, and economic efficiency of small-scale brackish water pond culture calculated by the DEA method.

Results and Discussion

Descriptive statistics. Table 1 reports summary statistics of the variables employed in TE, EE, and AE efficiencies analysis. The outputs of both shrimp and fish were measured in kilograms per hectare. Inputs, such as shrimp seed and fish seed, were measured in fingerlings per hectare, while lime and fertilizer were measured by kilograms per hectare and chemicals in liters per hectare. Also, labor was measured by person-days per hectare. Summary statistics demonstrated that the average outputs were 50.11 kg ha^{-1} (shrimp) and 79.27 kg ha^{-1} (fish), respectively, ranging from 2.45 to 157.50 kg ha^{-1} (shrimp) and from 5.75 to 400 kg ha^{-1} (fish), respectively.

Table 1

Summary statistics of the inputs and outputs of small-scale brackish water pond culture

Variables	*Unit*	*Mean*	*SD*	*Min*	*Max*
		Input			
Shrimp seed	Fingerlings ha^{-1}	31331.43	14487.96	1363.64	90000
Fish seed	Fingerlings ha^{-1}	1200.93	1150.49	50	6666.67
Lime	Kg ha^{-1}	6.83	0.75	6.00	8.00
Fertilizer	Kg ha^{-1}	7.45	1.20	6.00	9.00
Chemicals	Liters ha^{-1}	0.69	0.19	0.50	1.00
Labor	Person-days ha^{-1}	91.72	82.35	9.13	486.67
		Output			
Shrimp	Kg ha^{-1}	50.11	26.59	2.45	157.50
Fish	Kg ha^{-1}	79.27	71.63	5.75	400

In terms of inputs, shrimp seed was 31,331.43 fingerlings ha^{-1} with the distribution ranging from 1,363.64 to 90,000 fingerlings ha^{-1}, while fish seed was 1,200.93 fingerlings ha^{-1} ranged between 50 and 6,666.67 fingerlings ha^{-1}. The mean actual lime was 6.83 kg ha^{-1} ranging from 6 to 8 kg ha^{-1}. On average, fertilizer was 7.45 kg ha^{-1} ranged between 6 and 9 kg ha^{-1}. Further, the average chemicals were 0.69 liters ha^{-1}, while the mean labor ranged between 9.13 and 486.67 person-days ha^{-1}.

Table 2 shows the socio-economic characteristics applied in the Tobit regression model. Farmers were productive age, i.e., 44.13 years old, with about 8.34 years of education (the primary school), expressing that working as a farmer of small-scale brackish water pond culture does not require any educational background. Most farmers were relatively experienced, reflected by the average experience of 15.57 years. In addition, the average pond age for the total respondents was 21.13 years, with the pond sizes being adequate large, as indicated by an average surface of 9.39 ha.

Table 2

Summary statistics of socio-economic characteristics

Variables	*Description*	*Mean*	*SD*	*Min*	*Max*
Age (years)	The actual age of small-scale farmers in years	44.13	9.63	20	80
Education (years)	Formal education level of small-scale farmers in years	8.34	2.07	6	12
Experience (years)	Number of years in small-scale farmers' experience	15.57	4.52	5	28
Pond age (years)	Age of small-scale brackish water pond in years	21.13	7.94	1	42
Pond sizes (ha)	Small-scale brackish water pond area in hectares	9.39	6.36	2	40

Technical, economic, and allocative efficiencies results. Results of TE, EE, and AE efficiencies analysis are presented in Table 3. The mean actual TE value was 88.57%, implying that small-scale brackish water pond farmers could reduce the physical input by 11.43% to maintain their production levels. On the other hand, the mean actual EE value was 46.76 ranging from less than 20 to 100%. It indicates that small-scale farmers could save an average of 53.24% of production costs without influencing the current output levels. Also, AE value ranged between less than 20 and 100%, with the mean actual at

52.97%, suggesting that production cost reduction could be made approximately 47.03% when small-scale farmers used the appropriate inputs and outputs combination relative to input costs and output prices. All results above prove that there is still room for improving the efficiency of small-scale brackish water pond culture production in the study area, where farmers can reduce inefficient input and production costs. Table 3 also reveals that small-scale farmers are fully technically, economically, and allocative efficient at 39%, 2%, and 2%, respectively.

Table 3

Frequency and percentage distribution of TE, EE and AE

Efficiency level (%)	*TE*	*EE*	*AE*
< 20	0	8	4
20-39.9	0	34	28
40-59.9	7	34	34
60-79.9	18	17	19
80-99.9	36	5	13
100	39	2	2
Mean	88.57	46.76	52.97
Minimum	52.30	9.60	9.60
Maximum	100	100	100

Determinants of TE, EE, and AE. Table 4 presents the estimated parameters of the Tobit regression model. The value of the Likelihood Ratio-Chi-Square test at 172.620 is statistically significant at 1% level of significance, implying that the Tobit regression model produces a good fit for the data. In terms of socio-economic characteristics, the age coefficient has a positive sign and is statistically significant ($p < 0.10$). It expresses that older farmers are more technical than those with a lower age. Iliyasu et al (2016) also reported that the age of fish farmers was statistically significant and had a positive sign with technical inefficiency in freshwater aquaculture. Moreover, education has a significantly positive relationship with TE ($p < 0.05$), indicating that well-educated farmers were more likely to be more technical than those with a lower education level. This finding is in line with Nguyen & Yabe (2014), who reported that shrimp poly-culture was affected by the education of shrimp farmers. Experience has a significantly positive impact associated with TE and EE, implying that farmers with more experience are more technical and economical than those with a lower experience.

In farm characteristics, pond sizes do not appear to influence TE significantly. However, it is a significant negative influence on the EE and AE, suggesting that as the pond sizes increase, EE and AE decrease. Contrary to Alam (2011), who reported that pond sizes have a significant correlation and positively influence the EE and AE.

Table 4

Tobit regression model estimates of TE, EE, and AE analysis

Variables	*TE*		*EE*		*AE*	
	Coef.	*Std. error*	*Coef.*	*Std. error*	*Coef.*	*Std. error*
Age	0.002*	0.001	-0.0007	0.003	-0.003	0.003
Education	0.014**	0.004	0.001	0.010	-0.005	0.011
Experience	0.032***	0.003	0.016**	0.006	0.005	0.007
Pond age	-0.0008	0.001	-0.001	0.002	0.001	0.003
Pond sizes	0.001	0.002	-0.011***	0.003	-0.012**	0.003
Constant	0.233***	0.058	0.376**	0.121	0.721***	0.132
Log-likelihood	64.306		20.780		11.593	
LR χ^2	172.620***		24.580		15.060	
Sig	0.000		0.000		0.000	
Observations	100		100		100	

***, **, and * indicate significance level at 1%, 5%, and 10% respectively.

Conclusions. This study evaluates the technical, economic, and allocative efficiencies of brackish water pond culture in the Mahakam Delta and identifies the effect of socio-economic and farm characteristics on these efficiencies using data envelopment analysis. Results reveal that the mean TE, EE, and AE of brackish water pond culture are 88.57%, 46.76%, and 52.97, respectively, implying that small-scale farmers can still increase physical production and reduce production cost without influencing the current output.

Other findings are relevant for policymakers to identify the factors that can improve the performance of brackish water pond culture. For instance, small-scale farmers' age, education, and experience have a significant influence with a positive sign on brackish water pond efficiency; on the other hand, pond size has a negative correlation. Therefore, policymakers can help small-scale farmers to improve their brackish water pond culture management by focusing on small-scale farmers with lower education levels, fewer years of experience, and unproductive ponds. Creating incentive programs in collaboration among government, NGOs, and private sectors to reduce the farmers' constraints relating to efficiencies is strongly recommended in the study area. In addition, education facilities, training, and extension services provided by policymakers can increase small-scale farmers' skills and knowledge in improving the management efficiency of brackish water pond culture.

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Conflict of interest. The authors declare that there is no conflict of interest.

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Authors:
Heru Susilo, Mulawarman University, Faculty of Fisheries and Marine Sciences, Laboratory of Fisheries Resource Economics, 75119 Samarinda, Indonesia, e-mail: herususilo@fpik.unmul.ac.id
Oon Darmansyah, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: oon.darmansyah@fpik.unmul.ac.id
Erwiantono, Mulawarman University, Faculty of Fisheries and Marine Sciences, Laboratory of Coastal Community Development, 75119 Samarinda, Indonesia, e-mail: erwiantono@fpik.unmul.ac.id
Qoriah Saleha, Mulawarman University, Faculty of Fisheries and Marine Sciences, Laboratory of Fisheries Agribusiness, 75119 Samarinda, Indonesia, e-mail: qoriah.saleha@fpik.unmul.ac.id
Bambang Indratno Gunawan, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: bambang.indratno@fpik.unmul.ac.id
Gusti Haqiqiansyah, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: gusti.haqiqiansyah@fpik.unmul.ac.id
Said Abdusysyahid, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: said.abdusysyahid@fpik.unmul.ac.id
Elly Purnamasari, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: elly.purnamasari@fpik.unmul.ac.id
Muhamad Syafril, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: syafril@fpik.unmul.ac.id
Eko Sugiharto, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: eko.sugiharto@fpik.unmul.ac.id
Wahyu Fahrizal, Mulawarman University, Faculty of Fisheries and Marine Sciences, Department of Fisheries Socioeconomics, 75119 Samarinda, Indonesia, e-mail: wahyu.fahrizal@fpik.unmul.ac.id
Freddy Maryanto, Mulawarman University, Faculty of Fisheries and Marine Sciences, Laboratory of Coastal Community Development, 75119 Samarinda, Indonesia, e-mail: freddymaryanto19@gmail.com

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