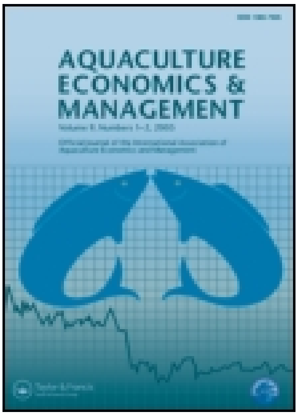

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A PRODUCTION FUNCTION ANALYSIS OF POND AQUACULTURE IN SOUTHERN GHANA

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☐ *Aquaculture is considered an alternative to making up the shortfall in supply of fish in Ghana. The Cobb-Douglas production function, which relates production output to several independent input variables, was used to determine the inputs that affect productivity. A survey was conducted on pond farmers selected from four regions of Ghana. Empirical results show stocking rate as the most significant input that affected production. Aquaculture exhibited increasing returns to scale over the period of the study, meaning an increase in inputs will more than proportionately increase the output. Estimates of the marginal physical productivity of the inputs indicated stocking rate should be increased while decreasing feed and labor use in order to increase productivity.*

Keywords allocative efficiency, aquaculture, Cobb-Douglas Production Function, marginal physical productivity, returns to scale

INTRODUCTION

The contribution of aquaculture production to the Ghanaian economy has grown over the past decade, with an annual average growth rate of 12.4% (FAO, 2006–2011). Aquaculture is seen as an important foreign exchange earner, contributes to food security as well as providing much needed employment to many people. In general, fisheries is estimated to contribute 3% of the total national GDP and 5% of the agriculture GDP of Ghana (FAO, 2006–2011). The first National Aquaculture and Fisheries Policy (NAFP) of Ghana, initiated in 1998, was to develop sustainable

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aquaculture production systems to increase fish production for local consumption and export markets.

The practice of aquaculture was introduced in Ghana in 1953 by the Directorate of Fisheries (FAO, 2006–2011). The first classical earthen ponds are thought to have been constructed at Kalsagri/Touri near Lawra in the Upper West Region of the country. It was initially used to produce fish seed for the numerous dams and reservoirs that had begun to spring up. The first scientifically managed aquaculture facility was put up by the University of Ghana at its Agricultural Research Station situated near Nungua in 1959. By 1969, there were about 220 reservoirs of variable sizes in Northern Ghana (FAO, 2006–2011). In the 1980s, aquaculture received a major boost, especially in the Ashanti, Central, Eastern, Western and Greater Accra regions, this time from government as a way of meeting Ghana's fish deficit (Sualih, 2000; Mensah et al., 2006) and since then, there has been an overall annual increase in aquaculture production. In 2001–2002, production peaked to 6000 tons, valued at US$ 11.4 million (FAO, 2006–2011). It has been estimated that the production from ponds and culture-based fisheries is worth about US$ 1.5 million a year (FAO, 2006–2011).

Most farmers in Ghana use earthen ponds and rely on natural productivity while others supplement with agricultural by-products. Other systems of culture include the pen, cage and raceway systems, which are not commonly practiced (Awity, 2005). Artificial feedstuffs and formulated feed are used mostly in semi-intensive and intensive systems (FAO, 2006–2011) The Nile tilapia (*Oreochromis niloticus*) is the single most predominant tilapia species cultured. Most of the fish produced are either consumed directly by farmers or sold locally. Currently, there is a ban on tilapia import in Ghana (FAO, 2006–2011) and so there is a call for an increase in production.

The aquaculture sector is expected to contribute toward economic growth, food security, and poverty alleviation of present and future generations of Ghanaians. The overall goal of NAFP is to establish the national sector framework outlining the responsibilities, duties, and obligations of regional cooperation, government, local authorities and persons involved in aquaculture. This is to facilitate, promote, regulate, and protect the sustainable development and management of aquaculture and culture-based fisheries in national and shared water bodies and ensuring equitable and sustainable socioeconomic development (Quagrainie et al., 2005).

There is, however, a lack of data and general information relating to aquaculture economics, which are crucial in the selection of appropriate aquaculture production systems and efficient use of inputs. In most African countries, including Ghana, rural aquaculture lacks investment mainly because of the absence of quality economic data and analysis (Quagrainie et al., 2005). According to Pillay (1994), there is a general perception that aquaculture is a high risk activity involving a risk higher than other food production industries such as poultry, pigs and cattle rearing. Most fish farmers in Ghana also see aquaculture as a part-time, limited investment hobby (Aeschliman, 2005).

Production functions are based on the assumption that in a given system or enterprise type, levels of output can be predicted by a given set of inputs, the mix of which basically describes the conversion of inputs into outputs (Asmah, 2008). An understanding of the technology of production is central to the development of realistic theories and to the formulation of a wide range of policies (Bosworth, 1976).

The most commonly used production function forms are: linear, quadratic, log-linear (Cobb-Douglas, C-D), Constant Elasticity of Substitution (CES) and translog (Felipe and Mehta, 2008). The linear functional form is commonly used in linear programming models; the quadratic describes a parabolic function that is familiar to biologists (Shang, 1990). Economists however prefer using the C-D as well as CES models (Shang, 1990). The C-D model has unity elasticity of substitution whereas the CES permits the empirical data to determine the degree of substitutability among inputs. CES is however difficult to apply when more than two inputs are used; therefore the C-D model is mostly preferred by economists (Smith, 1982),

In this study, the C-D production function was used. It has evolved since its development early in the 1900s and has been widely used in both theoretical and empirical production analyses. There are however some criticisms to the use of this model. These are as follows: it cannot handle a large number of inputs; the function is based on restrictive assumptions of perfect competition in the factor and product markets; it assumes constant returns to scale; serial correlation and heteroscedasticity are common problems that beset this function too; labor and capital, are correlated and the estimates are bound to be biased; unitary elasticity of substitution is unrealistic; it is inflexible in form; single equation estimates are bound to be inconsistent and it cannot measure technical efficiency levels and growth very effectively (Bhanumurthy, 2002).

The translog function which is considered an alternative, especially in addressing the inability of C-D function in handling unitary elasticity of substitution between inputs, was not used in this study. The C-D was chosen for the following advantages (Shang, 1990; Bhanumurthy, 2002; Munzir and Heidhues, 2002):

- The partial elasticities of production, which measures the responsiveness of output to unit increase of input, are identical to the production coefficients (β_i). Therefore, a percentage change in output that results from a given percentage change in output use can be easily identified.

- The sum of partial elasticities of production ($\sum\beta_i$) can be interpreted as a measure of economies of scale, i.e., the percentage change of output relative to the percentage change in all inputs used. If $\sum\beta_i > 1$, for example, positive economies of scale exist. This implies that a doubling of the use of all inputs will result in more than a doubling of output.
- Estimation is simple because input and output data can readily be used without aggregation as they are in the CES function.
- Unlike the linear and quadratic forms that preordain the shapes of production surfaces, the unconstrained C-D function can describe a production surface that demonstrates increasing, unitary or decreasing returns to scale depending upon the data.
- Unlike the quadratic function that requires more degrees of freedom because of interaction terms, the C-D function requires only one degree of freedom per explanatory variable.
- Various econometric estimation problems, such as serial correlation, heteroscedasticity and multicolinearity can be handled adequately and easily.
- It facilitates computations and has the properties of explicit representability, uniformity, parsimony and flexibility.
- Even the problem of simultaneity can be accounted for through the use of stochastic C-D production function.

Previous studies conducted in Ghana focused on aspects of pond culture profitability and production function analysis (Manu, 2004; Asmah, 2008; Onumah and Acquah, 2010). However, only the study by Onumah and Acquah (2010) examined the technical efficiency of input use and not allocative efficiency which is determined by the marginal product value. Therefore, a careful investigation of allocative efficiency in aquaculture production would benefit both producers and policymakers in decision-making, as well as give an indication of the optimal levels of inputs that would increase productivity.

This study is aimed at providing information on efficient use of input factors to existing and potential aquaculture producers and financiers. This information should further result in improved success rates of aquaculture loans acquisition, which in turn could result in growth of the local and regional aquaculture industry. Moreover, this study will serve as relevant literature for tertiary institutions and aquaculture extension for assessing pond aquaculture production systems, among others.

The main objective of the study is to estimate the determinants of fish output in the four Regions selected from Southern Ghana. The specific objectives are to determine which inputs are the most important determinants of total output; the returns to scale and allocative efficiency of inputs used in pond aquaculture production.

METHODOLOGY

Study Area

Ghana has a total of 10 regions divided into three zones namely; the Northern, Middle and Southern zones (Dickson, 1969). The study area covered four regions of the southern part of Ghana, namely, the Western, Central, Greater Accra and Volta Regions. These regions cover an area of approximately 57,562 km^2 or 24% of Ghana's total area and are highly populated regions especially that of the Greater Accra Region (MLGRD, 2006). These regions were selected for the following reasons: pertaining to published literature, there are about 1,000 fish farmers in Ghana and over 2,000 ponds, with a surface area of about 350 hectares (WTO, 2008), and out of these, an estimated 512 (more than 50%) fish farmers are located in these four regions.

Second, fish consumption is highest in the southernmost zone, with per capita fish consumption of about 30 kg/person/year compared with 20 kg/person/year in the middle zone, roughly the forest belt and 10 kg/person/year in the Northern regions (Wijkstrom and Vincke 1991). Meanwhile, the percentage of catfish and tilapia supply is about 40% in the northernmost zone, 15% in the forest belt and 3% in the southernmost zone (Wijkstrom and Vincke 1991). This implies that knowledge of aquaculture potential can help in supplementing capture fisheries production in meeting the fish consumption needs of southern Ghana. Third, fish marketing is mostly centralized around the southern and middle zones of the country (Wijkstrom and Vincke 1991).

Sampling Procedure and Sampling Size

A structured questionnaire was used to collect data on management practices and input - output data for 74 pond farmers, from October 2007 to June 2008. In all, 84 farmers were approached but only 74 farmers (37%) were able to provide information relevant to this study. These farmers were selected from six districts with the highest numbers of farmers, Wassa West (Western), Upper Denkyira (Central), South Tongu and Jasikan (Volta) and Ashiaman and Dangwe West (Greater Accra). Farmers were selected by proportion, based on numbers obtained from the Fisheries Directorate and sampled using systematic random sampling (Table 1). That is, the more fish farms a region has, the higher the number of respondents selected. Interviews and on-farm observations were used in data collection. The data were collected with assistance from fisheries officers in the four regions and a graduate national service personnel from the Department of Marine and Fisheries Sciences, University of Ghana. For a farmer to be considered in this study, it is assumed that the pond has to be active (operational).

TABLE 1 Sampling Procedure and Sampling Size for Pond Farmers in the Various Regions

Region	No. of Farms	No. of Farms Sampled	% Farms Sampled
Western (Wassa West)	83	38	45.8
Central (Upper Denkyira)	53	19	35.8
Volta (South Tongu and Jasikan)	57	11	19.3
Greater Accra (Ashiaman and Dangwe West)	9	6	66.7
Total	202	74	36.6

Production Function Model

The C-D function is expressed as follows:

$$ln\ (Y) = \beta_0 + \sum \beta_i\ ln(X_i) + \varepsilon_i \tag{1}$$

where Y denotes output; X_{i} denotes inputs; β_0 denotes a constant; β_{i} denotes model coefficients (the elasticities of production) and ε_{i} denotes the random or systematic error.

The empirical C-D production function for this study, one with location and culture system dummies and the other without are expressed as follows:

$$ln\ (Yd) = \beta_0 + B_{Fd}\ ln\ Fd + \beta_{Ft}\ ln\ Ft + \beta_{Fg}\ ln\ Fg + \beta_{Lb}\ ln\ Lb + \beta_{Exp}\ ln\ Exp + \varepsilon_i \tag{2}$$

$$\begin{aligned} ln\ (Yd) = \beta_0 &+ B_{Fd}\ ln\ Fd + \beta_{Ft}\ ln\ Ft + \beta_{Fg}\ ln\ Fg + \beta_{Lb}\ ln\ Lb + \beta_{Exp}\ ln\ Exp \\ &+ d_1D_1 + d_2D_2 + d_3D_3 + d_4Cs + \varepsilon_i \end{aligned} \tag{3}$$

where Yd denotes quantity of fish produced per square meter of pond area (kg/m^2); Fd denotes quantity of feed used per square meter of pond area (kg/m^2); Ft denotes quantity of fertilizer applied per square meter of pond area (kg/m^2), Fg is the stocking rate per square meter of pond area (fingerlings/m^2); Lb is the labor per square meter of pond area (man-days/m^2); Exp denotes experience (years), D_1 (1: if farm is located in Western region; 0: otherwise), D_2 (1: if farm is located in Central region; 0: otherwise) and D_3 (1: if farm is located in Volta region; 0: otherwise), Cs denotes culture system (1: if pond is stocked with mixed-sex tilapia fingerlings with catfish (*Clarias sp.*), African bonytongue (*Heterotis sp.*) and/or snake head (*Parachanna* sp.) predation; 0 if otherwise) and ϵ_{i} denotes the random or systematic error.

The regression coefficients for inputs are all expected to have positive signs *a priori*, except for labor (Inoni, 2007; Asmah 2008; Kurbis, 2000). Coefficients for dummies, D1 and Cs are assumed to have positive signs *a priori* as opposed to those for D2 and D3, which will be negative.

The parameters of investigational significance include:

- Inputs significant to the production process;
- Factor elasticity of each significant input; factor Elasticity (β_i) measures the marginal change in fish yield from a change in a single input while other inputs are held constant. This would be obtained from the regression analysis;
- Significance of qualitative variables captured by dummy variables (e.g., culture system);
- Elasticity of scale (ε): measures the percentage change in output with a simultaneous percentage change of equal magnitude in all inputs. The elasticity of scale is the sum of the factor elasticities in the production function:

$$\varepsilon = \sum \beta_i \quad i = 1, \ldots, n \tag{4}$$

  ε is constant if β_i is constant, i.e., if the elasticity for X_I is independent of the quantities utilized of all X_i (i = 1,. . ..,n) and the production function is a homogeneous function. If the production function is homogeneous and $\varepsilon = 1$, then the function is said to be homogeneous of degree one.If ε depends on the level of inputs, then returns to scale differs from point to point on the production surface and the function is said to be homothetic. The production function is said to exhibit increasing returns to scale if $\varepsilon > 1$ i.e., a simultaneous increase in all inputs by a certain percentage results in greater percentage increase in output. If $\varepsilon = 1$, the production function exhibits constant returns to scale, i.e., a simultaneous increase in all inputs by a certain percentage results in an increase in production by the same percentage. If $\varepsilon < 1$, the production function exhibits decreasing returns to scale i.e., proportional increase in output is less than the proportional increase in all inputs (Kurbis, 2000);
- Allocative efficiency of input use: to estimate the allocative efficiency of input use, the marginal physical productivity (MPP) and the value marginal product (VMP) have to be calculated. MPP is obtained by multiplying the input elasticity by the mean yield and dividing by the mean of the input used. VMP is the price of the output multiplied by the MPP. That is $VMP = P_V MPP = P_i$, where P is the price of output, or $(VMP/P_i) = 1$. If the value of the marginal product of an input is greater than its price, profit could be increased by increasing the use of that input (Wattanutchariya and Panayotou, 1982).

Statistical Analysis

Data collected were coded and incorporated into computerized databases using SPSS (Statistical Package for Social Science), GRETL econometric software and Excel software. The data was then normalized for pond sizes, that is on a per meter square basis. The ordinary least squares method, which fits a line to the data by minimizing the sum of the squares of the distance from the observed data points to the fitted line $\sum (Yi - Ye)^2$, was used to estimate the C-D function. Autocorrelation was not considered because it is usually not a problem for cross-sectional data. Heteroscedasticity, on the other hand, often shows in cross-sectional data and hence the White's test was used to test for its presence. Multi-colinearity was also tested for using the variance inflation factor, VIF (O'Brien, 2007). The *t*-test was used to test the significance of the individual estimated coefficients. The *F*-distribution was employed to test the overall significance of the models.

RESULTS AND DISCUSSION

Socioeconomic Characteristics and Farm Level Information of the Farmers

The socioeconomic characteristics and farm level information provided by the farmers is presented in Table 2. There were 65 males and 9 female pond fish farmers implying that aquaculture is principally a male-oriented activity. Asmah (2008) attributed the low number of female ownership of farms to the fact that traditionally men are deemed to be the heads of the household unit in Ghana and farms owned and operated by a family are likely to be in the name of the head of the family. The average age was 50 years. This is consistent with observations made by Aeschliman (2005) that age of the Ghanaian fish farmers, in keeping with the population itself, shows clearly that fish farming is something older and middle-aged farmers do; very few young people venture into aquaculture.

The average household size was 7 persons and the majority of the farmers were married (Table 2). The large household size could be a source of cheap and affordable labor for the farmers. A total of 32 farmers (43%) had completed middle school education, whereas the others had completed various levels of education. The level of education of the fish farmers is generally thought to have an effect on the knowledge level, skill development, exposure to production technology and marketing practices, and adoption level of improved technology (Singh, 2003). Onumah and Acquah (2010) reported a positive relationship between households with a high level of formal education and technical efficiency of farmers. Therefore, level of education for farmers is very important to the development of the aquaculture industry. Also, the level of education can help in designing appropriate training programs tailored to their levels. In terms of aquaculture farming experience, farmers reported being in the profession for about an average of 8.3 years.

TABLE 2 Socioeconomic and Farm Level Information of 74 Farmers in 4 Regions

Socioeconomic Variables	Greater Accra N = 6	Western N = 38	Central N = 19	Volta N = 11	All Regions N = 74
Gender					
Male	6	32	16	11	65
Female	0	6	3	0	9
Average Age (years)	49.8	49.6	50.4	52.2	50.2
Average Household Size	4.5	7.9	8.3	6	7.5
Average Years in Farming	7.8	5.5	11.7	12.4	8.3
Marital Status					
Married	6	36	18	10	70
Single	0	2	1	1	4
Education					
No education	0	4	1	0	5
Primary	0	3	4	3	10
Middle school	1	14	11	6	32
Tertiary	3	9	2	1	15
Post-secondary	2	8	1	1	12
Occupation					
Fish Farming	1	6	0	0	7
Crop Farming	0	15	14	9	38
Trader	1	0	2	0	3
Other	4	17	3	2	26
Primary Source of Water for pond					
Perennial Stream	5	9	7	8	29
Ground Water and Rain fed	0	29	12	3	44
Reservoir	1	0	0	0	1
Average size of pond (m^2)	1844.3	1025.2	570.1	885.7	954.1
Average size of farm (m^2)	8590.3	2376.8	1010.9	1765.6	2439
Number of ponds					
1–2	1	28	11	10	50
3–4	1	7	8	1	17
5–6	2	2	0	0	4
>7	2	1	0	0	3

On the average, only 7 farmers (9%) claimed that aquaculture was their major occupation while the majority (51%) was engaged in crop production. Aeschliman (2005) stated that farmers use occupational diversification as a survival strategy as well as a means of spreading risk in case of failure. A study conducted by Sualih (2000) on fish farmers in Ashanti and Brong Ahafo Regions also found that farming was undertaken to supplement family income, which is consistent with results from this study.

A total of 44 farmers (59.5%) depended on underground water and rainfall as their major water source. There are, however, some disadvantages and advantages on relying solely on rain or ground water sources, even though they make up a higher percentage of water sources for pond culture (Kelly & Kohler, 1997). Rainwater is not considered an ideal sole source as during dry or drought periods, water losses from the pond may result in higher densities of fish in the pond, which can lead to various water quality problems, resulting in the loss of all the fish. On the other hand, water from streams and rivers usually has high oxygen concentrations and, if the topography is right, pumping into the ponds may be unnecessary. Groundwater on the other hand is most preferred for aquaculture, particularly if an abundant supply of good-quality water could be obtained without having to drill a deep well (Stickney, 2005). Problems however arise when it renders the pond un-drainable, and where water exchange depends primarily on infiltration.

The average pond size was 954 m^2 with the farm size averaging 2439 m^2. Farmers owned between 1–18 ponds, with an average of 2.6 ponds. A majority of pond (55.4%) and pen (92.3%) farmers practiced polyculture or mixed sex culture with predation. The species mostly used in polyculture included tilapia (*O. niloticus*) and the predators, catfish (*Clarias sp.*), African bonytongue (*Heterotis sp.*) and snakehead (*Parachanna* sp.). Rakocy and McGinty (1989) reported that tilapia are frequently cultured with other species to take advantage of many natural foods available in ponds and to produce a secondary crop, or to control tilapia recruitment and allows the original stock to attain a larger market size. Monoculture practices involved stocking with all male, sex-reversed, hand sexed or both sexes of tilapia. The sources of fingerlings were from the Aquaculture Research and Development Center (Akosombo), other farmers, commercial fingerling producers (for example Tropo Farms) and from the wild. Some farmers cited that catfish from adjacent water bodies get into their facilities.

Determinants of Fish Yield

Summary statistics of the variables used in the production function has been presented in Table 3. Testing the hypotheses that the coefficients are equal to zero for Model 1 (Table 4), suggested that output was significantly

TABLE 3 Summary Statistics of Variables

Variable	Minimum	Maximum	Mean	Standard Deviation
Age (years)	30.00	78.00	50.22	1.40
Household size	0.00	23.00	7.46	0.45
Farm size (m^2)	26.80	15416.00	2439.02	363.77
Pond size (m^2)	10.00	4687.50	954.06	116.49
Pond number	1.00	18.00	2.62	0.28
Yield (kg/m^2)	0.12	30.07	2.29	4.16
Feed (kg/m^2)	0.43	73.00	8.56	12.26
Fingerlings ($number/m^2$)	0.50	16.48	4.46	3.49
Labor ($man\text{-}days/m^2$)	0.08	54.48	2.85	7.41
Fertilizer (kg/m^2)	0.01	67.16	2.26	8.21
Experience (years)	1.00	28.00	8.31	6.42

TABLE 4 Cobb–Douglas Production Function Estimation for 74 Pond Farmers

	MODEL 1		MODEL 2	
	Coefficient	Std. error	Coefficient	Std. Error
Const	-1.143^{***}	0.237	-1.590^{***}	0.324
Fd	0.126	0.076	0.085	0.074
Fg	1.098^{***}	0.085	1.141^{***}	0.086
Lb	−0.109	0.074	-0.1341^{*}	0.077
Ft	0.058	0.043	0.09307^{*}	0.050
Exp	−0.064	0.080	0.004	0.087
D_1			0.4715^{*}	0.261
D_2			0.449	0.289
D_3			−0.065	0.296
Cs			0.02	0.143
Mean dependent var	0.22		0.22	
S.D. dependent var	0.983		0.983	
Sum squared resid	19.525		16.665	
S.E. of regression	0.536		0.51	
R-squared	0.723		0.764	
Adjusted R-squared	0.703		0.731	
F(9, 64)	35.571		23.013	
P-value(*F*)	1.04E-17		7.03E-17	

*Indicates significance at the 10% level: **Indicates significance at the 5% level: ***Indicates significance at the 1% level.

– *Fd* denotes quantity of feed used (kg/m^2).
– *Ft* denotes quantity of fertilizer applied (kg/m^2).
– *Fg* is the stocking rate (fingerlings/m^2).
– *Lb* is the labor (man-days/m^2).
– *Exp* denotes experience (years).
– D_1, D_2 and D_3 denote region.
– *Cs* (1: if pond is stocked with mixed-sex tilapia fingerlings with predation; 0 if otherwise).
OLS estimates: Dependent variable: ln Yd (Yield).

influenced by stocking rate (*Fg*) at the 1% level of significance. This implies that as the stocking increases by 1%, fish yield will increase by 1.1%, *ceteris paribus*. The model was highly significant (ANOVA gave highly significant F-statistic, with a P-value significant at the 1% level of significance). The adjusted R^2 was 0.70, implying that 70% of the variation in fish yield is explained by the explanatory variables in the model.

Including the four dummy variables for location and culture system (Model 2), the constant and coefficient of stocking rate (*Fg*) were statistically significant at the 1% level of significance whereas both labor (*Lb*) and fertilizer (*Ft*) were statistically significant at the 10% levels of significance (Table 4). The dummy variable for Western Region was significant at the 10% level of significance. The adjusted R^2 increased to 0.73, implying that 73% of the variation in fish yield is explained by the explanatory variables in the model. The model was also highly significant ($p < 0.01$).

The signs of the regression coefficients were also in consonance with *a priori* expectations, except for the coefficient of the dummy variable for the Central region, which was positive. The results compare with those of Inoni (2007), Asmah (2008) and Kurbis (2000) who found that stocking density, feed, fertilizer, labor were significant factors that affected fish yield. Aeschliman (2005) gave negative returns for the Central Region; however, this study gives a positive coefficient, which would imply that aquaculture production in the region since 2005 has increased.

Model 2 can be expressed as follows:

$$\begin{aligned} ln\ (Yd) = -1.59 + 0.08\ ln\ Fd + 1.14\ ln\ Fg - 0.13\ ln\ Lb + 0.10\ ln\ Ft \\ + 0.004\ ln\ Exp + 0.47\ D_1 + 0.45\ D_2 - 0.06\ D_3 + 0.02\ Cs. \end{aligned} \quad (5)$$

Equation 5 can be used to predict the fish yield for farmers, given their production inputs, geographic location, their years of experience and the culture system being practiced. Stocking rate was the most powerful explanatory variable with the highest partial output elasticity of 1.14, which means that a 10% increase in stocking density, holding other inputs constant, will increase fish yield by 11.4%. In general, the levels of statistical significance of the estimated production coefficients in Model 2 are encouraging. Last, there appears to be no problems with multi-colinearity (VIF gave values lower than 10, Table 5) and results from White's Test implies no heteroscedasticity (LM = 56.3, p (Chi-square) = 0.14).

Based on the wide spread of farm sizes, three separate Cobb-Douglas models were run for small ($\leq 500\,m^2$), medium ($501–2000\,m^2$) and large (>20,001) scale farms. The sample sizes were however small and so the dummy variables were dropped to gain some degrees of freedom. Results

TABLE 5 Variance Inflation Factors Analysis for Multicolinearity

Variable	VIF
ln Fd	2.14
ln Fg	1.15
ln Lb	2.95
ln Ft	1.97
ln Exp	1.38
D_1	4.85
D_2	4.53
D_3	3.15
Cs	1.22

Variance Inflation Factors for multicolinearity. Minimum possible value = 1.0.

Values >10.0 may indicate a colinearity problem.

showed stocking rate, labor and fertilizer significantly influenced output from small scale farms (Table 6). Feed, stocking rate and experience significantly influenced medium scale farm output whereas only stocking rate had a significant influence on large-scale farm output. The sign for the coefficients of feed (small scale) and labor (medium- and large-scale) were not in consonance with *a priori* expectations, probably because if the small sample size in each category. All three models were highly significant as shown by their P-values. Also, the adjusted R^2 values 0.76, 0.65 and 0.66 for small, medium and large scale production, implying that 76%, 65% and 66% of variations in the three models were explained.

Factor Elasticities

It is of interest to Extensionists which inputs are significant to the production process, and, of those inputs, which have a greater per-unit effect on total production relative to the other inputs (Kurbis, 2000). One can interpret the positive production coefficients of the respective inputs as implying that an increase in output can be accomplished by increasing the intensity of input use (Kurbis, 2000). On the other hand,

TABLE 6 Cobb–Douglas Production Function Estimation for Small-, Medium- and Large-Scale Pond Farmers

	SMALL (n = 23)		MEDIUM (n = 27)		LARGE (n = 24)	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Const	−0.664	0.451	−0.802**	0.349	−1.140**	0.541
Fd	−0.070	0.134	0.184*	0.105	0.146	0.186
Fg	1.231***	0.163	0.859***	0.145	1.095***	0.166
Lb	−0.305**	0.142	0.097	0.137	0.024	0.193
Ft	0.186*	0.093	0.075	0.058	−0.025	0.103
Exp	−0.036	0.163	−0.221*	0.123	−0.023	0.150
Mean dependent var	0.514		−0.108		0.309	
S.D. dependent var	1.031		0.772		1.075	
Sum squared resid	4.214		4.365		7.073	
S.E. of regression	0.498		0.456		0.627	
R-squared	0.820		0.719		0.734	
Adjusted R-squared	0.767		0.652		0.660	
F Value	15.476		10.722		9.940	
P-value(F)	8.27E-06		0.000		0.000	

*Indicates significance at the 10% level: **indicates significance at the 5% level: ***indicates significance at the 1% level.

– *Fd* denotes quantity of feed used (kg/m^2).

– *Ft* denotes quantity of fertilizer applied (kg/m^2).

– *Fg* is the stocking rate (fingerlings/m^2).

– *Lb* is the labor (man-days/m^2).

– *Exp* denotes experience (years).

negative coefficients suggest that use of that particular input should be reduced.

The inputs specified in Model 1 were feed, fertilizer, stocking rate, labor and experience of farmers. Econometric estimation indicated stocking rate was statistically significant at 5% level of significance. This implies that more attention should be given to this input. The factor elasticity for stocking rate was 1.10. This is a unit-free estimate that does not change when input levels are varied and indicates that a 10% increase in stocking rate will increase fish yield by 11.0%.

From Model 2, factor elasticities for stocking rate, fertilizer and labor were 1.14, 0.10 and −0.13 respectively, implying a 10% increase in stocking rate or fertilizer will increase production by 11.4% and 1.0%, respectively. On the other hand a 10% increase in labor will decrease production by 1.3. The implication of this result is that optimum levels of labor utilization under the current scale of pond fish production in these regions have been reached. Therefore a further addition to labor is likely to exert a depressing effect on fish yield, and thus the observed inverse relationship between labor and fish yield. Similar findings were reported by Inoni (2007), Goswami et al. (2004) and Inoni and Chukwuji (2000). Extensionists may wish to use this information to assist in improving yields where inefficient production is suspected (Kurbis, 2000).

The significance and factor elasticity of the stocking rate has considerable policy implications given that most farmers consider fingerling production as very lucrative. The coefficients of experience and feed were not significant in both models. This implies there was no difference in production between experience and inexperienced farmers. Asmah (2008) however found feed application, per hectare, to be highly significantly related to production in four regions in Ghana (Greater Accra, Eastern, Ashanti and Volta Regions).

Dummy variables were added to the production function in order to determine the sensitivity, if any, of fish production to qualitative factors (Kurbis, 2000). Dummy variables consisted of location and culture type. The dummy variable for Western Region (D_1) was found to be statistically significant ($p = 0.08$) from Greater Accra Region at 10% level of significance. Those for the Central (D_2) and Volta Regions (D_3) were, however, not statistically different from production in the Greater Accra Region. There was a positive relationship between fish yield and the dummies for Western and Central regions; with the Volta region having a negative coefficient. These results have significant policy implications and it is recommended that government interventions and support, as well as extension services should focus more on the Western, Central and Greater regions to improve aquaculture yields.

The dummy representing culture systems (Cs) was also not statistically significant, implying that there were no differences between farmers stocking with mixed-sex tilapia fingerlings with predation (either catfish (*Clarias* sp.), African bonytongue (*Heterotis sp.)* and/or snakehead (*Parachana* sp.) or monoculture (which usually involved using sex-reversed tilapia males alone). Mixed-sex tilapia fingerlings, which were mostly obtained from natural pond reproduction and the wild, are relatively cheaper or free as compared to sex-reversed male fingerlings, which must be purchased from a hatchery and most often transported to the farm. Mixed sex culture should therefore have a higher return on investment for farmers, *ceteris paribus*. This implies that extension efforts should focus on disseminating mixed-sex tilapia production methods (Kurbis, 2000).

The factor elasticities for stocking rate, labor and fertilizer for small scale farms were 1.23, −0.30 and 0.19, meaning a 10% increase in stocking rate or fertilizer, holding all other variables constant, will increase production by 12.3% or 1.9%, respectively, whereas a 10% increase in labor will decrease output by 3.0%. For medium scale farms, a 10% increase in either feed or stocking rate will increase output by 1.8% or 8.6% respectively. However, there was a significant difference between experienced and inexperienced medium scale farmers. A 10% increase in a medium scale farmer's experience, holding all other variables constant, will therefore decrease output by 2.2%. Lastly, a 10% increase in stocking rate for large scale farms will increase output by 1.1%.

Returns to Scale

The returns to scale of the production technology is of essential interest given its implications for potential changes to the targeted size of future production units (Kurbis, 2000). This analysis indicates that the fish production function representing aquaculture in the Western, Central, Volta and Greater Accra Regions of Ghana has elasticity return to scale of 1.19 ($\varepsilon = \Sigma\beta_i$). Since data were normalized for pond size (by dividing all the factors of production by the pond size of each individual pond), this value must be interpreted as a point estimate for returns to scale while holding pond size constant.

Because the estimate is greater than 1, aquaculture production in these regions exhibit increasing returns to scale. On the other hand, both small and medium scale farmers exhibited constant returns to scale ($\varepsilon = 1.0$), whereas large scale farmers exhibited increasing returns to scale ($\varepsilon = 1.2$). This implies that a proportionate increase in inputs will lead to the same proportionate increase in output for small- and medium-scale farmers. On the other hand proportionate increases in inputs will more than increase output for large-scale farmers. Aquaculture therefore has a high potential in these regions. A study of small scale farmers in Honduras in 2000 gave decreasing returns to scale (Kurbis, 2000), but constructing the confidence interval showed that both increasing and decreasing returns were possible. Asmah (2008), on the other hand, reported increasing returns to scale for fish farming in four regions in Ghana, which is consistent with results obtained in this study.

Allocative Efficiency of Input Use

To achieve the most efficient use of an input, the value of its marginal product (VMP) should be equal to its price (Wattanutchariya and Panayotou, 1982). If the VMP of an input is greater than its price then profit can be increased by increasing the level of that input. On the other hand, if the VMP of an input is less than its price, then profit can be increased by reducing the level of that input. From the regression models, stocking rate (Fg), fertilizer (Ft) and labor (Lb) were statistically significant. However, all these inputs were used at inefficient levels (Table 7). Stocking rate should be increased, since its VMP is greater than its price, whereas fertilizer and labor levels should be decreased to improve farm profitability. The result for labor further explains the negative coefficient obtained in the production function estimation. However, the size of the facility should be taken into account when increasing stocking rate, since these could be correlated.

Allocative efficiencies for inputs used in small, medium and large scale farms are presented in Table 8. All inputs were used at inefficient levels. Stocking rate should be increased in small, medium and large scale farms, whereas labor, fertilizer and feed should be decreased.

TABLE 7 Marginal Physical Product, Value Marginal Product, and Input Price of Pond Culture

Regression	Stocking Rate (Fg)	Labor (Lb)	Fertilizer (Ft)
Model 1			
MPP	0.47	–	–
VMP	0.34	–	–
Px	0.10	–	–
Input Use	Increase	–	–
Model 2			
MPP	0.49	−0.08	0.07
VMP	0.35	−0.06	0.05
Px	0.10	0.93	0.52
Input Use	Increase	Decrease	Decrease

MPP = (input elasticity × mean yield)/mean of input used.

VMP = P_yMPP; P_y is the price of the output.

P_x = input price.

TABLE 8 Marginal Physical Product, Value Marginal Product, and Input Price of Small-, Medium- and Large-Scale Farms

	(Fg)	(Fd)	(Lb)	(Ft)
SMALL-SCALE				
MPP	0.77	–	−0.15	0.13
VMP	0.56	–	−0.11	0.09
Px	0.10	–	0.93	0.52
Input Use	Increase	–	Decrease	Decrease
MEDIUM-SCALE				
MPP	0.28	0.03	–	–
VMP	0.20	0.02	–	–
Px	0.10	0.95	–	–
Input Use	Increase	Decrease	–	–
LARGE-SCALE				
MPP	0.60	–	–	–
VMP	0.44	–	–	–
Px	0.10	–	–	–
Input Use	Increase	–	–	–

MPP = (input elasticity × mean yield)/mean of input used.

VMP = P_yMPP; P_y is the price of the output.

P_x = input price.

CONCLUSIONS AND RECOMMENDATIONS

Aquaculture presents an alternative to meeting the global demand for high quality protein. From the analysis, the main factors influencing yield were stocking rate, fertilizer, feed and labor. From the input elasticities, however, fingerling stocking rate was the most significant input. However, the use of these inputs was found to be inefficient. Increasing stocking rate and decreasing the quantities of fertilizer, feed and labor would increase farm profitability. The significance of stocking rate has considerable policy implications given that fingerling production is considered by some farmers as highly lucrative.

Pond aquaculture exhibited increasing returns to scale. Proportionately higher fish yield can be obtained through the use of more inputs, that is, intensifying production methods. It is therefore recommended that government, through the Extension Officers in the four regions, should train more farmers in fingerling production. Because of the viable nature of aquaculture in these regions, government should assist farmers to overcome the problems of high operating capital. Appropriate short-term credit schemes and practical research and effective extension should be made available.

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