Small Scale Aquaculture: A Case Study on Giant Gouramy (*Osphronemus gouramy*) Culture in Uthai Thani Province, Thailand

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ABSTRACT

This study examined pond- and cage-based culture systems of the giant gouramy in Uthai Thani Province, Thailand. The economic analysis was based on interview data collected from 8 dealers and 214 farmers. The analysis showed that giant gouramy culture was characterized by a remarkably long culture period resulting in a high average opportunity cost (57.62 and 83.58% of the total cost, for pond-based and cage-based culture, respectively). Culture of giant gouramy was only profitable when the opportunity cost of labor was excluded. An analysis of economic efficiency showed that five input categories determined the yield from pond-based culture, and that the levels of inputs were not optimal. Water exchange needed to be done more frequently, and the quantity of feed and stocking density should be increased. Likewise, expenditure on antibiotics and the quantity of lime applied to the ponds needed to be increased. For cage-based culture, only four input items had significant effects on yield. While the quantity of artificial feed, vegetable and antibiotics expenses should be increased, the stocking density should be decreased. Most of the results were in accordance with scientific data on soil and water quality parameters and farmer practices. However, increased antibiotics use is not recommended due to food safety concerns, even if it is related to enhanced fish yields.

Key Word: giant gouramy, *Osphronemus gouramy*, small scale aquaculture, economic analysis

INTRODUCTION

Fish is an important source of dietary protein, micro-nutrients and essential fatty acids for millions of the world's poor (Kadir *et al*., 2006), contributing to their calorific intake. Despite only very limited information about the contribution of small scale aquaculture to the livelihoods of farmers and economies of developing countries, small scale aquaculture is a considerable source of income which may enable poverty alleviation (e.g. in Sub-Saharan Africa, Kaliba *et al*., 2007). Generally a subsistent

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household's agriculture is not determined by the outcomes of economic analysis (Thapa and Niroula, 2008), which often results in improper planning and eventually economic loss to farmers. The present study aimed to provide an example of a business, which, while minor from an economic viewpoint, is vital to the livelihood of farmers.

Despite low annual production from the aquaculture of giant gouramy (28,644 t world production and 2,149 t from Thailand in 2005; FAO, 2007), it is important to the local economy of certain communities in Thailand where it is intensively produced. The main production region is in Uthai Thani Province located 222 km north of Bangkok, with two rivers, the Chaophraya and the Sakaekrang running across the province. The cage-based culture of giant gouramy, dating back to 1966, has become a provincial highlight. It has been the consumers' perception that the giant gouramy produced here is of the best quality and thus commands a higher price than elsewhere (Suksalee and Tantrapirom, 2009). As such, the culture of giant gouramy has had impacts on enhancing tourism in this province. Despite an attempt by the local authority to promote this activity, there has been no economic analysis of this business. It has always been the case that small-scale farmers, either aquaculturists or agriculturists, run their businesses without knowing the economic cost (Fernandes and Woodhouse, 2008). Therefore, they always have underestimated the cost-return by overlooking the non-cash costs which included the opportunity cost of labor, depreciation cost of equipment and opportunity cost of land-use (Thapa and Niroula, 2008). In general, the amount of the non-cash costs increases with culture duration (Ponce-Marbán *et al*., 2006), rising for example from US$ 4.4/m^3 for 4.5 months of red tilapia cage-based culture (Shovala, 2004) to US$ 24.43/m^3 for 18 months of sea bass cage-based culture (Department of Fisheries, 1978). Therefore, it would be beneficial to farmers to understand the capital structure involved and so be able to improve their farm management accordingly. In addition, the efficient use of economic inputs will facilitate maximizing production through the optimization of each input, providing that this approach is technically reasonable.

In the present study, the economy and the efficiency of the use of inputs of both the pond- and cage-based culture systems of giant gouramy in Thailand were analyzed by considering three questions: 1) Is the giant gouramy culture business feasible in terms of its economic return? 2) Should the activities be expanded? 3) What were the input categories that significantly determined the yield and were they used at an optimal level?

MATERIALS AND METHODS

Data on giant gouramy culture in ponds and cages were collected using questionnaires which were designed and pre-tested using a sub sample of 15. The survey was conducted by interviewing 99 pond-based and 115 cage-based farmers, and 8 dealers in Amphur Muang, Uthai Thani, the main production area of giant gouramy. The farmers' names were taken from a database of Uthai Thani Provincial Fisheries Office based on a purposive sampling method (Salant and Dillman, 1994). Cost-return analysis was performed following Shang (1990), for opportunity cost labor estimated from wage floor in Uthai Thani Province, and economic efficiency following Coelli *et al*. (1998). A stepwise regression was applied to remove the input items that did not have significant contributions to fish yield. Only six inputs were included in the economic efficiency analysis: stocking density of fingerlings, quantity of artificial feed, vegetable expense, frequency of water exchange, antibiotic expense, and the quantity of lime used. The MPP (Marginal Physical Product) was estimated by dividing the change in total physical product by the change in the variable input. In addition, water quality [dissolved oxygen (DO), pH, temperature, total nitrogen and alkalinity] was measured at three locations for each of the cage-based and pond-based farms and also in the river on a weekly basis.

RESULTS

General information

The total culture area was 7,403 and 276,192 m^2 for cage-based and pond-based systems, respectively. Generally, ponds and cages were stocked with 2-3 cm fingerlings at about 49 and 5 fish/m^2 for cage and pond -culture, respectively. In the ponds, fish were mainly fed commercially-available catfish pellets throughout the culture period which averaged 16 months with occasional supplies of vegetables and/or kitchen leftovers while the latter was the main diet for the cage-cultured fish throughout the 22 months culture period with occasionally supplement of pelleted feed. The market size was 800 to 1000 g and the average sale price was US$ 1.13/kg.

Water quality

Overall water temperature and alkalinity were in the normal ranges for fish culture. DO (measured at 6 am) was extremely low ranging from 0.18 to 0.51 mg/l (mean 0.30 mg/l) in the ponds to moderate (from 0.18 to 7.88 mg/l, mean 4.18 mg/l) in both cages and river (from 2.48 to 6.14 mg/l, mean 4.31 mg/l). The pH was slightly acidic (6.01-6.19 in ponds, 6.69 to 6.98 in cages and 6.56 to 6.90 in river). Moreover, noticeable amounts of ammonia (0.0 to 1.0 mg/l) and nitrite (0.0 to 1.5 mg/l) were observed in the ponds but not in the cages or the river.

Average cost of the giant gouramy culture in ponds and cages

The investment cost in pond-based farming was estimated at US$ 10.50/m^2 (Table 1) composed of 99.43 % variable cost and 0.57% fixed cost. The non-cash costs (US$ 6.08/m^2) contributed 57.90 % to the total cost (US$ 10.50/m^2) due to a noticeably high opportunity cost for labor (US$ 6.05/m^2). The second highest component of the total cost was feed cost (US$ 3.56/m^2 or 33.91% of the total cost). The cost estimated for cage-based culture (US$ 302.91/m^2, Table 1) was much higher than that of pond-based culture. However the capital structure was similar to that observed in pond-based culture, where the highest contribution was from the opportunity cost for labor (US$ 253.18/m^2 or 83.58% of total cost) followed by feed cost (US$ 37.91/m^2 or 12.52% of the total cost).

Table 1. Detailed costs of pond-based and cage-based culture of giant gouramy in Uthai Thani Province, Thailand, crop year 2005/2006

Items	Cash (US$)	Non-cash (US$)	Total (US$)	Percent (%)
Pond-based culture				
Fixed costs				
Pond preparation	0.03	-	0.03	0.29
Pond depreciation	-	0.02	0.02	0.19
Equipment depreciation	-	0.01	0.01	0.09
Total fixed costs	0.03	0.03	0.06	0.57
Variable costs				
Seed	0.32	-	0.32	3.01
Feed	3.56	-	3.56	33.91
Labor	-	6.05	6.05	57.62
Energy	0.46	-	0.46	4.38
Lime	0.01	-	0.01	0.09
Antibiotic	0.04	-	0.04	0.38
Total variable costs	4.39	6.05	10.44	99.43
Total costs	**4.42**	**6.08**	**10.50**	**100.00**
Cage-based culture				
Fixed costs				
Cage repair	3.55	-	3.55	1.17
Equipment depreciation	-	2.80	2.80	0.93
Total fixed costs	3.55	2.80	6.35	2.10
Variable costs				
Seed	3.98	-	3.98	1.31
Feed	37.91	-	37.91	12.52
Labor	-	253.18	253.18	83.58
Energy	0.83	-	0.83	0.27
Antibiotics	0.66	-	0.66	0.22
Total variable costs	43.38	253.18	296.56	97.90
Total costs	**46.93**	**255.98**	**302.91**	**100**

Cost-revenue analysis

The yield of giant gouramy culture in ponds was 3.43 kg/m^2 with a selling price of US$ 1.46/kg, resulting in a total revenue of US$ 4.99/m^2, but also having a net return and loss of US$ -5.45/m^2 and US$ 5.52/m^2, respectively. The yield of giant gouramy culture in cages (32.06 kg/m^2) was much higher than that of ponds. It commanded a selling price of US$ 1.68/kg and total revenue of US$ 53.94/m^2. The net return and loss were US$ -242.63/m^2 and 249.10/m^2, respectively (Table 2).

Table 2. Costs and revenues of pond-based and cage-based culture of giant gouramy in Uthai Thani Province, Thailand, crop year 2005/2006

Items	Pond-based culture	Cage-based culture
Cash cost (US$/m^2)	4.42	46.93
Non-cash cost (US$/m^2)	6.08	255.98
Total cost (US$/m^2)	10.50	302.91
Cost per kg (US$/kg)	3.06	9.45
Farm-gate price (US$/kg)	1.46	1.68
Yield (kg/m^2)	3.43	32.06
Total revenue (US$/m^2)	4.99	53.94
Net return (US$/m^2)	-5.45	-242.63
Loss (US$/m^2)	5.52	249.10
Loss (US$/kg)	1.61	7.77
Net cash return (US$/m^2)	0.57	7

Technical efficiency of production factor

In order to evaluate the technical efficiency of a production factor, the marginal physical product (MPP) was estimated (Table 3). Results showed that increasing the stocking density by 1 fish/m^2 in the ponds would reduce the production by 0.64 kg/m^2. On the other hand, if the amount of feed input was increased by 1 kg/m^2, the yield would increase by 0.99 kg/m^2. The frequency of water exchange positively influenced production and an increment in water exchange interval of one day (decreasing the frequency) resulted in a reduction in yield by 0.29 kg/m^2. Antibiotic expense was another factor positively correlated with the yield. Increasing antibiotic expense by US$ 1/m^2 increased the yield of giant gouramy by 3.35 kg/m^2. Similarly, when the amount of lime applied was increased by 1 kg/m^2, the yield increased by 9.53 kg/m^2.

The factors that significantly affected the yield of the giant gouramy culture in cages (Table 3) were slightly different from those of the pond-based culture. An increment in cage stocking density of 1 fish/m^2 decreased the yield by 1.30 kg/m^2. On the contrary, an increment of 1 kg/m^2 artificial feed or US$ 1/m^2 in antibiotic expense resulted in enhancement of yield by 5.99 and 28.96 kg /m^2, respectively. In addition, an increase of US$ 1/ kg/m^2 in vegetable expense increased the yield by 3.92 kg/m^2.

Table 3. Geometric mean and marginal physical product (MPP) of inputs for pond-based and cage -based culture of giant gouramy in Uthai Thani Province, Thailand, crop year 2005/2006

Items	**Pond culture**		**Cage culture**	
	Geometric mean	**MPP**	**Geometric mean**	**MPP**
Stocking density (fish/m^2)	4.74	-0.64	48.57	-1.30
Artificial feed (kg/m^2)	5.18	0.99	48.65	5.99
Frequency of water exchange (times/day)	26.00	-0.29	-	-
Antibiotics (US$/$m^2$)	0.06	3.35	0.12	28.96
Lime (kg/m^2)	0.20	9.53	-	-
Vegetables (US$/$m^3$)	-	-	2.49	3.92

Market tendency and distribution channel

The estimated 2006 annual production of giant gouramy in Uthai Thani Province (calculated from the number of farmers and average production/farm) was 809,376.19 kg (37.66% of Thailand's production). The annual market demand for giant gouramy in Uthai Thani was 807,344.95 kg, of which 25.40% (205,094.95 kg/year) was for the local market and 74.60% (602,250 kg/year) for markets outside the province. Within the local market, 20.34% of the demand (164,250 kg/year) was met through middlemen/dealers who distributed the products to consumers either directly (18.24%) or through restaurants (2.10%). A small portion of the local demand (40,844.95 kg/year; 5.06%) was delivered directly to the consumers. The consumer demand from markets outside the province was processed completely through middlemen/dealers. The marketing channels for giant gouramy existing in Uthai Thani province are shown in Figure 1. There were only 8 dealers servicing 440 pond-based and 339 cage-based culture farms. Dealers bought fish at an average price of US$ 1.46/kg and sold them at an average price of US$ 1.82/kg, which generated a margin of US$ 0.36/kg.

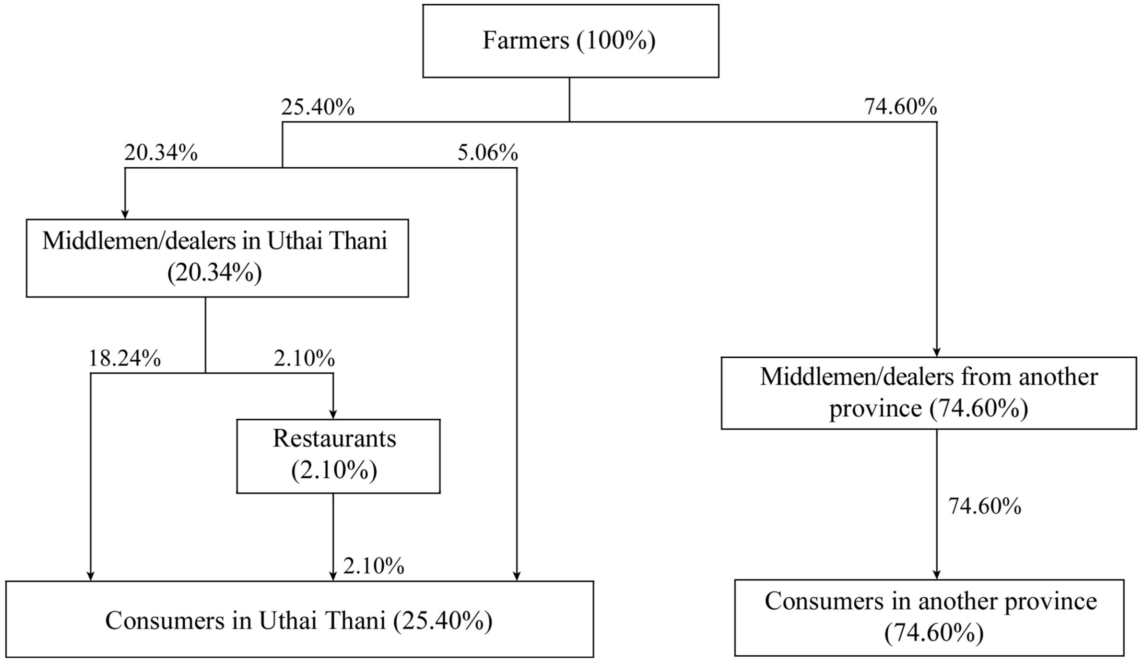

Figure 1. Marketing channels for giant gouramy in Uthai Thani Province, Thailand, crop year 2005/2006

DISCUSSION

The aquaculture of giant gouramy in Thailand is characterized by a noticeably long culture period (e.g. 16 months for pond -based and 22 months for cage-based culture) compared to 4.5 months for red tilapia cage -based culture (Shovala, 2004), 5 months for Nile tilapia cage-based culture (Diana *et al*., 1996) and 6 months for sea bass cage -based culture (Tookwinas and Charearnrid, 1988). Thus, it resulted in a high opportunity cost for labor (Griffiths and Wall, 1999) which was responsible for the higher total cost of giant gouramy production compared to other economically-important species, e.g. US\$ 2.65/m^2 for walking catfish pond-based culture (Division of Agriculture Economic, 1977) and US\$ 4.42/m^3 for red tilapia cage -based culture (Shovala, 2004). However, the management of both the cage-based and pond-based farms was not labor intensive. For example, the cages did not require water exchange, while water was changed once every five days in ponds. As such, the opportunity cost may be ignored if the farms were operated as a side occupation, resulting in a profit of US\$ 0.31/kg and US\$ 0.13/kg for pond-based and cage-based culture, respectively. This consideration agreed well with the current situation wherein most farmers (84.5%) had other occupations, e.g. rice grower, horticulturist and grocer. More importantly, it suggested that the returns may not be the main motivation for farmers to culture giant gouramy, rather they continued with this activity as part of their livelihood. It was noticeable that most of the farmers were older (average 50 years old) and that they had inherited this occupation from the previous generation. Consequently, giant gouramy culture in Uthai Thani Province should be managed with consideration to its importance in the livelihood of the people, rather than solely for its economic aspects. However, there are some technical issues that could be improved and could consequently enhance yield and profit.

Market factors

The giant gouramy market in Uthai Thani Province was characterized by a noticeably small number of dealers relative to the large number of farmers, which is a characteristic of an oligopsony (Lloyd, 1967). Consequently, the selling price was solely determined by the dealers, as what generally occurs with agricultural products (Richard *et al*., 1982). A characteristic of an oligopsony that was observed was the relatively high margin price received by the dealers, which was also reported for other fish species (e.g. US$ 0.22/kg for red tilapia, Shovala, 2004; US$ 0.22/kg for sea bass, Saereerut, 2000).

The almost equal balance between supply and demand implied that the production of giant gouramy should not be increased, which is in accord with the resultsof the cost-revenue analysis.

The efficiency of production factors

The MPP value which is an indicator of the technical efficiency of production showed that the stocking density (MPP = -0.64 and -1.30 for pond-based and cage based culture, respectively) was already too high (~5 fish/m^2 in ponds and 49 fish/m^2 in cages). The stocking densities used in this study were higher than the density recommended for giant gouramy culture (1 fish/m^2 in ponds and 23.14 fish/m^3 in cages, Viwatchaiset, n.d.). Although high stocking density is of importance to commercial aquaculture because it enhances maximum use of infrastructure (Merino *et al*., 2007), this can result in adverse effects (such as increased stress) when it exceeds the optimal level (Grant, 1997; Pickering and Stewart 1984). The adverse effects could lead to reduced in food utilization, enhanced energy requirements and subsequently reduced growth and yield (Grant, 1997). More importantly, crowding compromises the functions of the immune system in many fish species (e.g. Atlantic salmon, Mazur and Iwama, 1993; common carp, Yin *et al*., 1995; gilthead seabream, Tort *et al*., 1996) which leads to disease outbreak and death (Maule *et al*., 1989).

The results indicated that the amount of feed used in the pond-based culture was too high (MPP = 0.99) with regard to the yield. Generally, overfeeding resulted in poor water quality (as indicated by low DO, high total ammonia) which in turn is a limiting factor in fish production (Rahman *et al*., 2008). Such a detrimental effect may be alleviated by enhancing water exchange. However, the results also indicated that there was insufficient water exchange in the pond-based culture (MPP = -0.29) which was consistent with the extremely low DO and high ammonia and nitrite levels. Although giant gouramy could tolerate short periods of low DO due to its air breathing capability (Viwatchaiset, n.d.), such extreme conditions could have compromised the growth rate as was reported for African catfish (Kaiser *et al*., 1995) and may also have enhanced the susceptibility to diseases (Bolasina *et al*., 2006).

In this study, liming was carried out only in ponds, where the MPP of 9.53 indicated that increasing application rates might enhance yield. Generally, liming is required in acidic ponds in order to increase the pH of the bottom mud (Boyd and Tucker, 1998), enhance microbial activity associated with organic matter decomposition (Boyd, 1990) and provide HCO^{3-} to buffer daily pH changes (Boyd and Tucker, 1998). The result of this study was supported by the fact that the soil in Uthai Thani Province was slightly acidic (pH average 5.9 and range 4.7 - 7.8), (Office of Science for Land Development, 2007) as was the water in the giant gouramy ponds measured in this study (pH range 6.01-6.19). Therefore, increasing the application of lime may eventually increase the yield of the giant gouramy in earthen ponds. Despite the low MPP (5.99 and 3.92 for artificial feed and vegetable expenses, respectively) which indicated that the fish in cages were underfed, the amount of feed should not be increased because of the marginal level of DO in the cages (0.18 to 0.51 mg/l). Stocking density should be reduced for the reason discussed in the previous analysis. MPP values for both pond-based and cage-based cultures also indicated that the yield of the giant gouramy could be increase if more antibiotics were applied. However, this suggestion is technically unsound, because if other factors such as stocking density, feed quantity, frequency of water exchange and liming quantity were optimized, then fish health will be improved and hence the application of antibiotics will be unnecessary. Furthermore, due to the growing public concern about food safety (Kerselaers *et al*., 2007), increasing the amount of antibiotics is not recommended.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that giant gouramy culture in Uthai Thani Province was not feasible in terms of its economic return. However, due to its importance in people's lives, giant gouramy culture should receive increased attention to promote sustainability. Related activities, such as agro-tourism, should be promoted so that farmers could earn additional income. The study revealed that the balance between supply and demand suggested that neither the number of farms nor their levels of production should be increased. Rather, the provincial authority should emphasize improving farm practices to help reduce any adverse impacts on the environment. The quality of water resources for giant gouramy culture which is also exploited by the community should be maintained. The yield of giant gouramy from ponds was determined by the frequency of water exchange, quantity of feed, stocking density, expenses for antibiotics and the quantity of lime used. Likewise, the quantity of artificial feed, vegetable and antibiotics expenses, and stocking density determined the yield from cages. Results suggested that an improvement in yield may be possible by adjusting the levels of inputs. A notable exception to this is an increase in expenditure on antibiotics, which, although related to enhanced fish yield, is not recommended due to biosafety concerns.

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LITERATURE CITED

Bolasina, S., Tagawa, M., Yamashita, Y. and Tanaka, M. (2006). Effect of stocking density on growth, digestive enzyme activity and cortisol level in larvae and juveniles of Japanese flounder, *Paralichthys olivaceus*. **Aquaculture** 259, 432– 443.

Boyd, C.E. (1990). **Water Quality in Ponds for Aquaculture,** Alabama Agricultural Experiment Station, Auburn University, USA.

Boyd, C.E. and Tucker, C.S. (1998). **Pond Aquaculture Water Quality Management.** Kluwer Academic Publishers, Boston, USA.

Coelli, T., Rao, D.S. and Battese, G.E. (1998). **An Introduction to Efficiency and Productivity Analysis.** Kluwer. Academic Publishers.

Coulibaly, A., Ouattara, I.N., Koné, T., N'Douba, V., Snoeks, J., Gooré, B.G. and Kouamélan, E.P. (2007). First results of floating cage culture of the African catfish *Heterobranchus longifilis Valenciennes*, 1840: Effect of stocking density on survival and growth rates. **Aquaculture** 263, 61–67.

Department of Fisheries (1978). **Sea Bass Culture.** Ministry of Agriculture and Cooperatives, Thailand.

Diana, J.S., Lin, C.K. and Yi, Y. (1996). Timing of supplemental feeding for tilapia production. **Journal of the World Aquaculture Society** 27, 410-419.

Division of Agriculture Economic (1977). **Cost-Returns of walking catfish at Supanburi Province.** Ministry of Agricultural and Co-operatives, Bangkok, Thailand.

FAO (2007). **Aquaculture Production Statistics.** Available at: http://faostat.fao.org.

Fernandes, L.A.O. and Woodhouse, P.J. (2008). Family farm sustainability in southern Brazil: An application of agri -environmental indicators.**Ecological Economics.** doi:10.1016/j. ecolecon. 2008.01.027

Grant, J.W.A. (1997). **Behavioural Ecology of Teleost Fishes** (Edit by Godin J.G.J.) Oxford Univ. Press, Oxford.

Griffiths, A. and Wall, S. (1999). **Applied Economics. Eighth Edition.** Peason Education Ins. USA. Available at: http://www.fao.org/docrep/field/003/AB707E 295/AB707E08.htm#ch8

Kadir, A., Kundu, R.S., Milstein, A. and Wahab, M.A. (2006). Effects of silver carp and small indigenous species on pond ecology and polycultures in Bangladesh. **Aquaculture** 261, 1065–1076.

Kaiser, H., Weyl, O. and Hecht, T., (1995). The effect of stocking density on growth, survival and agonistic behaviour of African catfish. **Aquaculture International** 3, 217-225.

Kaliba, A.R., Ngugi, C.C., Mackambo, J.M., Osewe, K.O., Senkondo, E. and Mnembuka B.V. (2007). Potential effect of aquaculture promotion on poverty reduction in Sub-Saharan Africa. **Aquaculture International** 15, 445 -459.

Kerselaers, E., Cock, L.D., Ludwig, L. and Huylenbroeck, G.V. (2007). Modelling farm-level economic potential for conversion to organic farming. **Agricultural Systems** 94, 671–682.

Lloyd, C. (1967). **Microeconomic Analysis.** Department of Economics, Purdue University. USA

Maule, A.G., Tripp, R.A., Kaatari, S.L. and Schreck, C.B. (1989). Stress alters immune function and disease resistance in chinook salmon (*Oncorhynchus tsawytscha*). **Journal of Endocrinology** 120, 135–142.

Mazur, C.F. and Iwama, G.K. (1993). Handling and crowding stress reduces thenumber of plaque-forming cells in Atlantic salmon. **Journal of Aquatic Animal Health** 5, 98–101.

Merino, G.E., Piedrahita, R.H. and Conklin, D.E. (2007). The effect of fish stocking density on the growth of California halibut (*Paralichthys californicus*) juveniles. **Aquaculture** 265, 176–186.

Office of Science for Land Development (2007). **Survey of soil nutrient after flooding at central and north of Thailand.** Land Development Department. Ministry of Agriculture and Cooperative. Thailand.

Pickering, A.D. and Stewart, A. (1984). Acclimation of the interregnal tissue of the brow trout, *Salmo trutta* L., to chronic crowding stress. **Journal of Fish Biology** 24, 731-740.

Ponce-Marbán, D., Hernández, J.M. and Gasca-Leyva, E. (2006). Simulating the economic viability of Nile tilapia and Australian redclaw crayfish polyculture in Yucatan, Mexico. **Aquaculture** 261, 151-159.

Rahman, M.M., Nagelkerke, L.A.J., Verdegem, M.C.J., Wahab, M.A. and Verreth J.A.J. (2008). Relationships among water quality, food resources, fish diet and fish growth in polyculture ponds: A multivariate approach. **Aquaculture** 275, 108–115.

Richard, E.J., Darrell, L.H. and Schmitz, A. (1982). **Applied Welfare Economics and Public Policy.** Prentice-Hall, Inc. New Jersey. USA.

Saereerut, K. (2000). **An Economic Analysis of Sea Bass (*Lates calcarifer*) Cage Culture Production in Songkhla Crop Year 2000.** Department of Agricultural and Resource Economics, Faculty of Economic, Kasetsart University.Thailand.

Salant, P. and Dillman, D.A. (1994). **How to conduct your survey.** Wiley & Sons, Inc. New York, USA.

Shang, Y.C. (1990). **Aquaculture economic analysis: an introduction.** Advances in World Aquaculture. The World Aquacult. Soc., Baton Rouge, Louisiana, USA.

Shovala, V. (2004). **Economic Analysis of Tabtim Fish Production in Changwat Chai Nat, Crop Year 2003.** Department of Agricultural and Resource Economics, Faculty of Economic, Kasetsart University.

Suksalee, T. and Tantrapirom, S. (2009). **Giant gouramy, Houseboat and Sakaekrang river.** Available at: http ://www.nairobroo.com/76/modules. php?name=News&file=print&sid= 607, October 7, 2009.

Thapa, G.B. and Niroula, G.S. (2008). Alternative options of land consolidation in the mountains of Nepal: An analysis based on stakeholders' opinions. **Land Use Policy** 25, 338–350.

Tookwinas, S. and Charearnrid, B. (1988). **Cage culture of seabass (*lates calcarifer*) in Thailand. Seabass (*Lates calcarifer*) culture in Thailand.** Available at: http://www.fao.org/docrep/field/003 /ab707e/AB707E08.htm

Tort, L., Sunyer, J.O., Gomez, E. and Molinero, A. (1996). Crowding stress induces changes in serum haemolytic and agglutinating activity in the gilthead sea bream (*Sparus aurata*). **Veterinary Immunology and Immunopathology** 51, 179–188.

Vivatchaiset, Y. (no date). ***Giant Gouramy Culture.*** Department of Fisheries, Ministry of Agriculture and Cooperatives, Bangkok.

Yin, Z., Lam, T.J. and Sin, Y.M. (1995). The effects of crowding stress on the non-specific immune response in fancy carp (*Cyprinus carpio L.*). **Fish & Shellfish Immunology** 5, 519–529.