Nutrient Loading and Efficiency of Tilapia Cage Culture in Taal Lake, Philippines

Arvin Vista1*, Patricia Norris2, Frank Lupi2 and Richard Bernsten2

INTRODUCTION

Fish kill occurrences in Taal Lake in the Province of Batangas, Philippines suggest a deteriorating water quality in the cage areas. An excessive amount of nutrients accumulating from the cages leads to nutrient enrichment, endangering the industry itself and the general lake ecosystem. The high nutrient loadings in Taal Lake are due to excessive amounts of nitrogen (N) and phosphorus (P), in which its associated parameters exceeded the acceptable level set in Administrative Order (DAO) No. 34 of the Department of Environment and Natural Resources (DENR). Fish cage culture has been practiced for the past two decades and the present trend is toward increased stocking density and intensive feeding. The current management options for reducing the loss of nutrients into the surface water are largely limited to controlling the intensity of fish cage production (Naylor et al. 2003; Marte et al. 2000).

The rapidly growing fisheries trade has had its impacts, both positive and negative. In the Philippines, Batangas was the top freshwater fish cage producer in 2000, contributing a total of 15,268 mt of fish equivalent to 52% of the country’s total freshwater fish cage production (BAS 2003). While aquaculture accounts for 30% of the world’s food fish (Delgado et al. 2003), it has significant environmental tradeoffs (Naylor et al. 2003). Between 1999 and 2000, six massive fish kill occurrences in Taal Lake were recorded (Mercene 2000 unpublished). Rosana and Salisi (2001 unpublished) recorded at least 38 fish kill incidences in various cage areas from May 1999 to June 2001. In January 2006, another massive fill kill was reported affecting 80% of the cages in the lake (Rulla 2006).

Examining the past and present status of the lake is imperative for finding a sustainable solution to the problem. Many scientific studies have been conducted describing the limnological, ecological and biophysical character-
istics of the lake and its watershed, and the socio-economic and legal considerations of cage culture (Herre 1927; Castillo and Gonzales 1976; Hargrove 1991; Acedera 1993; UPLBFI 1996 unpublished; Bartolome 1999 unpublished; Zafaralla et al. 1999 unpublished; Mercene-Mutia 2001; Guerrero III 2002). Various researchers have suggested different management techniques, yet the majority of the fish cage operators have not been very receptive to changing their current practices.

Each fish cage measures an average of 10 x 10 x 6 m with a stocking of 65 -100 tilapia (*Oreochromis niloticus*) fingerlings per m³. In 2001, Agoncillo had a total number of 2,362 registered cages; Laurel, 2,729, San Nicholas, 481; and Talisay, 1,861. The fish were heavily fed with different types of commercial feeds, which our results indicate are the largest share of production expenses (76%). The culture period spans from four to seven months, which depends on the intensity of feeding and the quality of fingerlings. Many operators reported longer periods of intensive tilapia culture amounting to an additional one to three months of culture period, compared to 1990's situation. At present, the species cultured in cages are tilapia, bangus (*Chanos chanos*), and maliputo (*Caranx ignobilis*). Among the three, tilapia is the most common.

By law, the local residents have the right to own at most five cages. However, due to the lack of financial capital, local residents end up as caretakers for an absentee owner. Financial capital is the limiting input to most of the local residents, who do not have access to or preference for accessing credit facilities. Hence, without the financiers, the majority of the caretakers cannot go into the cage business. The financiers generally own the fish cage units and provide all the production inputs. They also influence most of the decisions about cage culture, specifically those related to financial matters. On the other hand, caretakers provide the labor input in the production process. Overall, fish cage management is laborious. From cage construction, stocking, feeding, until harvesting, caretakers are expected to inspect their cages every day.

Production from the open water fishery declined steadily after fish cage culture expanded in 1994 (Figure 1). The lower productivity of endemic fish species might be attributed to the disturbance and displacement of their spawning ground brought about by tilapia dominance and fish cage wastes. Tilapia is an exotic and prolific breeder, and hence, a competitor of the native fish species. Fish cage production plunged in 1999 due to occurrences of massive fish kills, which were attributed to oxygen depletion during overturn and toxic poisoning from the suspected pollutants (NH₃, NO₂ and H₂S) (Rosana and Salisi 2001 unpublished).

According to DAO 34, Taal Lake has Class C surface water, i.e., fishery water used for the propagation and growth of fish and other aquatic resources. While the dissolved oxygen (DO) level fluctuates monthly and yearly, its level became critical in 1999 and 2000, particularly in the congested cage areas. The concentration of ammonia (NH₃) in 1995 and 2000 exceeded the acceptable level of 0.02 mgL⁻¹. Rosana and Salisi (2001 unpublished) reported high levels of NH₃ (0.15-0.30 mgL⁻¹) and pH (8.5-9.0), indicating heavy feed load and fecal matter accumulated at the bottom of the lake. Nitrate (NO₃) was within the acceptable

![Fig. 1. Estimated fish production in Taal Lake, Philippines, 1993-2002 (Mutia and Magistrado 1999 unpublished; BAS 2003).](image-url)
level, i.e., below 10 mg L\(^{-1}\), while nitrite (NO\(_2\)) reached a toxic level in 2000. Orthophosphate was in abundance in 1973, but has decreased in concentration since the 1977 eruption of Taal Volcano (Table 1).

In Taal Lake watershed, excess nutrients are supplied to the system through point and non-point sources. Table 2 presents the estimated nutrient pollution loading from various sources in 2001. The fish cages mainly contributed to the point source pollution, which were largely supplied by the discharges of N and P derived from uneaten feed, feces and excretion via the gills and urine (Beveridge and Phillips 1993; Kibria et al. 1996; Kibria et al. 1998). Beveridge and Phillips (1993) estimated that about 77% of N put into use is being lost into the cage and its surrounding waters while Phillips et al. (1994) estimated about 85% for P. Consequently, for every 1,000 kg of feed used in 2001, an estimated 47 kg N and 9 kg P were lost (See Appendix I for computation of nutrient loading). In Talisay, we found that the average amount of feed used in 2002 was 5,459 kg per cage per cropping cycle. This situation bears witness to high nutrient loading in the lake. In Taal Lake, N more than P seems to limit primary production (Zafaralla et al. 1999 unpublished). This observation supports the findings in other freshwater lakes, where P has been demonstrated to be more critical in regulating water quality (Howarth et al. 2000).

This paper explored the tilapia cage production efficiency and the effects of ownership arrangements and cage location in minimizing inefficiencies and other wastage, which were suspected to affect net revenue and nutrient loading in Taal Lake. The nutrient loading analyses focuses mainly on point source pollution contributed by the fish cages. The paper then presents the results of the tilapia cage operator survey, income analysis and the optimum input-output analysis on the tilapia cage production.

**METHODS**

A fish cage operator survey was conducted in the municipalities of Agoncillo, Laurel, San Nicholas and Talisay since the cages were limited to the barangays of these municipalities. The survey involved interviews of 50 randomly selected fish cage operators with varying number of fish cages and type of ownership. A total of 316 cages comprised the survey. Aside from the data gathered through the survey questionnaire, secondary data were obtained

<table>
<thead>
<tr>
<th>Parameters (mg L(^{-1}))</th>
<th>Acceptable Level (DAO 34)</th>
<th>1973 (^{a})</th>
<th>1990 (^{b})</th>
<th>1995 (^{c})</th>
<th>1999 (^{d})</th>
<th>2000 (^{d})</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>&gt; 5.00</td>
<td>3.140</td>
<td>4.40-11.60</td>
<td>6.50-9.10</td>
<td>3.4-11</td>
<td>0.3-10.5</td>
</tr>
<tr>
<td>NH(_3)</td>
<td>&lt; 0.02</td>
<td>0.110</td>
<td>0.02-0.90</td>
<td>0.44-0.71</td>
<td>nd</td>
<td>0.15</td>
</tr>
<tr>
<td>NO(_3)</td>
<td>&lt;10.00(^{\text{a}})</td>
<td>0.290</td>
<td>0.37</td>
<td>0.14-0.53</td>
<td>0.14</td>
<td>0.01</td>
</tr>
<tr>
<td>NO(_2)</td>
<td>&lt; 0.10</td>
<td>0.003</td>
<td>nd</td>
<td>0.006</td>
<td>nd</td>
<td>0.25-35</td>
</tr>
<tr>
<td>P</td>
<td>&lt; 0.40</td>
<td>67.000</td>
<td>0.01-0.23</td>
<td>0.04-0.27</td>
<td>0.05</td>
<td>0.08</td>
</tr>
</tbody>
</table>

\(^{a}\)SOGREAH (1973 unpublished), \(^{b}\)Zafaralla (1991 unpublished), \(^{c}\)UPLBFI (1996 unpublished), \(^{d}\)June-July measurement, \(^{e}\)Hilario (2001), and Rosana and Salisi (2001 unpublished), \(^{f}\)applicable only to lakes or reservoir and similarly impounded water , nd – no data.

**Table 2. Estimated nutrient input loading rates from various sources, Taal Lake, Philippines, 2001.**

<table>
<thead>
<tr>
<th>Source of Nutrients</th>
<th>Total N (mt)</th>
<th>Total P (mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish cages(^{a})</td>
<td>3,758</td>
<td>816</td>
</tr>
<tr>
<td>Household sewage(^{b})</td>
<td>969</td>
<td>146</td>
</tr>
<tr>
<td>Agriculture/ watershed(^{c})</td>
<td>239</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>4,966</td>
<td>997</td>
</tr>
</tbody>
</table>

\(^{a}\)Author’s Fish Cage Operator Survey 2002; \(^{b}\)Adopted from Jacinto et al. (1998), assuming losses of 1.96 kg N per person per yr and 0.29 kg P per person per yr. \(^{c}\)Adopted from Clemente and Wilson (2002), assuming losses of 6.48 kg N per ha per yr and 0.96 kg P per ha per yr and a 10% filtration of nutrients by the watershed vegetation.
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from various sources. The Statistical Package for the Social Sciences software was used in the analysis of the data gathered.

The physical relationship between inputs and output in the fish cage production was estimated with the commonly used Cobb-Douglas (C-D) production function (One limitation of the C-D is that it does not have stage III of the production function), defined as:

\[ Y = f(X_F, X_{SD}, X_{D1}, X_{D2}, X_{D3}, X_{D4}) \]

where \( Y = \) yield, kg per cage per cropping cycle; 
\( X_F = \) total feeding ration, kg per cage per cropping cycle; 
\( X_{SD} = \) stocking density, number of fingerlings per cage per cropping cycle; 
\( X_{D1} = \) dummy variable for ownership arrangement, = 1 if owner as operator or = 0 if owner hiring caretakers; 
\( X_{D2} = \) dummy variable for location, = 1, if cage is located in Talisay or = 0, otherwise; 
\( X_{D3} = \) dummy variable for location, = 1, if cage is located in Agoncillo or = 0, otherwise; and 
\( X_{D4} = \) dummy variable for location, = 1, if cage is located in Laurel or = 0, otherwise.

In the specification of the appropriate functional form for assessing the physical relationship between inputs and output in the fish cage production, the following forms of production function were tested and evaluated: a) linear, b) full quadratic, c) log-linear (C-D) and d) translog form of the quadratic function. Scatter plots of yield against feeding ration and stocking density were made to aid in the choice of the production function models. An F test \( (H_0: \beta_2 = 0) \) was used in the comparison of the different production function forms, except for log-linear vs. linear. The estimation results showed that the full quadratic and the translog form of the quadratic function models have largely non-significant coefficients of the explanatory variables and they did not conform to the expected signs. Hence, these models were rejected. The two remaining models have better fit (in Stata software, the command ‘‘dfit’’ was used to evaluate the effect of the specific observation on the fit) than the full quadratic and translog models.

A Cobb-Douglas model was used rather than the linear model because of the following advantages. First, the elasticities of production are identical to the production coefficients. Second, the sum of the production coefficients \( (\Sigma \beta_i) \), defined below, can be interpreted as a measure of economies of scale, i.e. assuming that the \( \Sigma \beta_i \) is not constrained to unity. Third, input and output data can be used readily without aggregation to estimate the parameters of the model. Finally, a C-D function uses only one degree of freedom per explanatory variable.

Data were transformed into their logarithmic values. The production function was estimated employing the ordinary least square. The C-D log linear model \( (Y=\text{yield}; \ X_i = \text{inputs}; \ \hat{\beta}_1 = \text{factor productivities}; \ \hat{\beta}_0 = \text{constant}. \) Error terms are omitted \( ) \) is written as:

\[ \log Y = \hat{\beta}_0 + \hat{\beta}_1 \log X_1 + \hat{\beta}_2 \log X_2 + \hat{\beta}_3 X_3 + \hat{\beta}_4 X_4 \]

To test whether multicollinearity presented problems, simple correlation among the independent variables was examined. To test homoskedasticity, a plot of the residuals (the difference between the observed \( Y \) and the estimated \( \hat{Y} \) against the independent variables was also made to look for systematic distribution of the deviations around the regression line. The results showed no evidence of multicollinearity and heteroskedasticity. To determine the maximum productive capacity of fish production per cage per cropping cycle, a stochastic frontier estimation of the C-D production function \( (f(X; \hat{\beta})) \) was also evaluated using Stata and LIMDEP softwares. However, the results were not acceptable. The correct convergence was not attained given the data available.

The production relationship is used to assess the profitability of cage production. Variable inputs include feeding ration, stocking density, labor, transportation and cage structure, while capital fixed costs include the license fees, aerator, boat, etc. Both variable and fixed costs were expressed on a per cage (100 m²) per cropping cycle basis. In the short-run period, individual operators are likely to respond to certain changes by changing their variable inputs. Operators will seek to maximize profit \( (\pi) \) above the cost of production per cage per cropping cycle.

Max \( \pi \)

where: \( Y = \) quantity of fish sold + home consumption, kg per cage per cropping cycle; 
\( P_Y = \) price of fish, PhP per kg; 
\( C_F = \) cost of feed, PhP per kg; 
\( C_G = \) cost of fingerlings, PhP per cage per cropping cycle; 
\( C_L = \) cost of labor, PhP per cropping cycle; 
\( C_T = \) cost of transportation (include fuel, maintenance, depreciation and vehicle rental), PhP per cropping cycle; 
\( C_D = \) depreciation cost of cage and raft, PhP per cage per cropping cycle; and 
\( C_O = \) other input costs, PhP per cage per cropping cycle.

Other input costs include fees, medicine, aeration, etc. The fish production cost is defined by:

\[ \sum_{i=2}^{5} \left[ YP_i - \left( C_F \right) \right] \]
The estimated production coefficients and related statistics are shown in Table 6. The net stocking density (SDa), derived as stocking density at stocking (SD) less fingerling mortality at stocking (SDm), was used instead of the actual SD to account for the uncertainty and risk of getting zero output. The net stocking density, ownership arrangement and location with reference to Laurel were found to be statistically significant at 5% level. The production coefficients for feeding ration (B1) and net stocking density (B2) have the expected positive sign, while the ownership arrangement (B3) and location (B6) were negative. The negative coefficient of ownership arrangement (-0.33) and location (-0.29) means an inverse relationship with tilapia yield amounting to, all else equal, about a 7-8% reduction in yield. In the case of ownership arrangement, tilapia yield will decrease in ‘owner-operated’ fish cages. In the case of

### RESULTS AND DISCUSSION

The estimated average feed conversion ratio (FCR) was 2.78 (margin of error = 0.34) and ranged from 2.32-3.37 (Table 3). An FCR of 2.78 suggests a requirement of 2.78 kg of feed to produce a gain of 1 kg fish weight. The recommended feed conversion ratios for tilapia cage culture range from 1.5-1.8 (McGinty and Rakocy 1989). Providing more feed to fish beyond their growth requirements results in a higher FCR, increased costs and nutrient losses. Net revenue of cage operators among the four municipalities and between the two ownership arrangements was not statistically different. However, it should be noted that the feeding ration and practices, and hence feed costs, were statistically different among the operators in the four municipalities and under the two ownership arrangements (Tables 3, 4 and 5).

Notable among the four municipalities was the high cost of feed, specifically for San Nicholas, and the low fish productivity in Laurel (Table 4). The high nutrient loadings in the Laurel area and the low fish productivity are likely related. The ‘owner hiring caretakers’ employed more feed than the ‘owner as operator’ arrangement. Indeed, net income is very sensitive to the amount and cost of feed and the productivity in the cage areas. Some respondents believed that, for 2002, many operators were still recovering financial losses from the effects of massive fish kill occurrences in 2000.

### Cobb-Douglas Production Function Estimate

The estimated production coefficients and related statistics are shown in Table 6. The net stocking density (SDa), derived as stocking density at stocking (SD) less fingerling mortality at stocking (SDm), was used instead of the actual SD to account for the uncertainty and risk of getting zero output. The net stocking density, ownership arrangement and location with reference to Laurel were found to be statistically significant at 5% level. The production coefficients for feeding ration (B1) and net stocking density (B2) have the expected positive sign, while the ownership arrangement (B3) and location (B6) were negative. The negative coefficient of ownership arrangement (-0.33) and location (-0.29) means an inverse relationship with tilapia yield amounting to, all else equal, about a 7-8% reduction in yield. In the case of ownership arrangement, tilapia yield will decrease in ‘owner-operated’ fish cages. In the case of

<table>
<thead>
<tr>
<th>Municipality</th>
<th>FCR(^a)</th>
<th>Feeding Ration (kg)</th>
<th>Stocking Density (kg)</th>
<th>Yield(^b) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agoncillo</td>
<td>2.32 (0.54)</td>
<td>8,336 (2,516)</td>
<td>66,222 (20,074)</td>
<td>3,588 (733)</td>
</tr>
<tr>
<td>Laurel</td>
<td>2.55 (0.59)</td>
<td>5,081 (1,255)</td>
<td>40,714 (4,927)</td>
<td>2,058 (189)</td>
</tr>
<tr>
<td>San Nicholas</td>
<td>3.37 (0.59)</td>
<td>9,745 (1,220)</td>
<td>37,500 (3,518)</td>
<td>3,277 (543)</td>
</tr>
<tr>
<td>Talisay</td>
<td>2.69 (0.93)</td>
<td>5,460 (989)</td>
<td>50,140 (14,988)</td>
<td>2,575 (459)</td>
</tr>
<tr>
<td>Average</td>
<td>2.78 (0.34)</td>
<td>7,171 (836)</td>
<td>46,856 (5,886)</td>
<td>2,809 (164)</td>
</tr>
</tbody>
</table>

Notes: Number in parenthesis is the margin of error at 90% confidence interval, defined as; standard error of the mean x 1.64. \(^a\)Feed conversion ratio, calculated as mass of feed given (dry) divided by the increase in mass of fish produced. \(^b\)Fish mortality during harvest were excluded. (Source: Author’s Fish Cage Operator Survey 2002).
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Table 5. Estimated net revenue of 50 cage operators for a 100 m² grow-out cage per cropping cycle under two ownership arrangements in Taal Lake, Philippines, 2002.

<table>
<thead>
<tr>
<th>Item</th>
<th>Owner as Operator (n=13)</th>
<th>Owner Hiring Caretakers (n=37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue a</td>
<td>133,056 (32,821)</td>
<td>166,070 (17,541)</td>
</tr>
<tr>
<td>Operating costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fees</td>
<td>662</td>
<td>538</td>
</tr>
<tr>
<td>Fingerlings b</td>
<td>37,250 (5,952)</td>
<td>28,070 (2,292)</td>
</tr>
<tr>
<td>Feed c</td>
<td>84,369 (11,410)</td>
<td>126,123 (16,609)</td>
</tr>
<tr>
<td>Labor</td>
<td>2,258</td>
<td>3,482</td>
</tr>
<tr>
<td>Transportation d</td>
<td>1,058</td>
<td>2,219</td>
</tr>
<tr>
<td>Depreciation e</td>
<td>5,394</td>
<td>4,753</td>
</tr>
<tr>
<td>Misc. (medicine, etc.)</td>
<td>520</td>
<td>535</td>
</tr>
<tr>
<td>Total</td>
<td>186,401</td>
<td>123,183</td>
</tr>
<tr>
<td>Net revenue (PhP)</td>
<td>15,922</td>
<td>-8,319</td>
</tr>
</tbody>
</table>

Notes: Number in parenthesis is the margin of error at 90% confidence interval, defined as: standard error of the mean x 1.64. aTotal harvest x farm gate price. bStocking density x price of fingerlings. cFeeding ration (kg) x Price feed type (PhP per kg). dInclude feed delivery cost and other transportation expenses. ePhP 4,815 (capital investment for a 100 m² cage frame) divided by 730 days (estimated useful life of cage bamboo frame) x rearing days (e.g. Agoncillo 156 days) + PhP 8,825 (net and other materials, with estimated useful life of seven years) divided by 2,555 days x 156 days + 1,713 (capital investment for bamboo raft divided by 365 days (useful life) x 156.22 = PhP 5,394. (Source: Author's Fish Cage Operator Survey 2002.)

location, Laurel operators are producing significantly less tilapia per cage per cropping cycle than San Nicholas operators.

The coefficients of the explanatory variables XSDa and XD were significantly different from zero at 10% level based on a t-test (H₀: Bᵢ = 0). The coefficient for the explanatory variable (Xf) was only significantly different from zero at 12% level, so care is needed in interpreting this result. With regard to the overall regression, the computed F value (6.60) was greater than the critical value (2.09) at the 10% level of significance. It can be said that the overall regression was statistically significant. The production elasticities were 0.20 and 0.22, respectively. An elasticity of production that is less than one indicates diminishing marginal product. A 1% increase in feeding ration will produce a 0.20% increase in yield (significant only at the 12% level), while a 1% increase in the net stocking density would produce a 0.22% increase in yield. Since the sum of the production elasticities (0.42) was < 1, a decreasing return to scale existed; a doubling of Xf and XSD inputs would less than double yield.

Efficiency of Fish Cage Operators

Testing for efficiency, the marginal rate of technical substitution and the input price ratio were estimated and com-
Table 6. Estimated Cobb-Douglas production function coefficients and related statistics for a sample of 50 operators in Taal Lake, Philippines, 2002. [Dependent variable: Log Y [Yield (kg) per cage per cropping]].

<table>
<thead>
<tr>
<th>Variables</th>
<th>Parameter</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total feeding ration (logX_F)</td>
<td>ß₁</td>
<td>0.20</td>
<td>0.12</td>
<td>0.12 a</td>
</tr>
<tr>
<td>Net stocking density (logX_SD)</td>
<td>ß₂</td>
<td>0.22</td>
<td>0.09</td>
<td>0.03 b</td>
</tr>
<tr>
<td>Ownership arrangement (X_D1)</td>
<td>ß₃</td>
<td>-0.33</td>
<td>0.13</td>
<td>0.01 b</td>
</tr>
<tr>
<td>Location, i.e. Laurel (X_D4)</td>
<td>ß₄</td>
<td>-0.29</td>
<td>0.13</td>
<td>0.04 b</td>
</tr>
<tr>
<td>Intercept</td>
<td>ß₀</td>
<td>3.99</td>
<td>1.33</td>
<td>0.00 b</td>
</tr>
</tbody>
</table>

R²: 0.37
F-statistics: 6.6

a Significant only at 12%; b Significant at 5% level. H₀: Bi = 0.

pared to find out the optimal level of use of inputs. The optimal condition was written as:

\[
\tilde{\psi} = \tilde{\beta}_1 \left( \frac{X_{SDa}}{X_F} \right) - \tilde{\beta}_2 \left( \frac{P_F}{P_{SDa}} \right) = 0
\]

where \( X_{SDa} \) and \( X_F \) values were the geometric mean, \( P_{SDa} \) was the price of fingerlings for net stocking density and \( P_F \) was the price of feed. The price used for the net stocking density was the adjusted price, which was estimated as:

\[
P_{SDa} = \frac{P_G}{\gamma_0 + \gamma_1 SD}
\]

The derivation of this price has two steps. First, fingerling mortality was a function of stocking density, and the interviews with operators suggested that they know the actual yield would depend on the net stocking density. Thus, the coefficient \( \gamma_0 \) was derived from the relationship between fingerlings mortality (SDm) and stocking density (SD), which was defined as:

\[
SD_m = \gamma_0 + \gamma_1 SD
\]

Table 7 shows the estimated stocking density coefficients as linked with fingerling mortality. Both the parameter estimates were statistically significant at the 5% level. The overall regression was also statistically significant at the 5% level.

Second, the relative price of net stocking density was derived by getting the first order condition of the equation below with respect to stocking density (SD):

\[
P_F \left[ F_{SD} \cdot \gamma_0 SD - P_F \right] - P_{SD} - P_F \cdot C = 0
\]

where C represents all costs other than feed and stocking. The first order condition with respect to SD was written as:

\[
P_F \left[ \gamma_0 SD - P_F \right] = 0
\]

which establishes the rationale for using \( X_{SDa} \) and \( P_{SDa} \) in the production function and the computation of optimal conditions.

The resulting value for the optimal condition \( \tilde{\psi} = 1.45 \) is greater than zero, which implies that the marginal productivity of feeding ration over the marginal productivity of net stocking density was greater than the price ratio of feeding ration over net stocking density. This result suggests that fish cage operators in Taal Lake overutilized stocking density relative to the feeding ration. This implied that the marginal productivity of feeding ration over the marginal productivity of net stocking density was greater than the price ratio of feeding ration over net stocking density. It should be noted that Municipal Ordinances 06-96 of Agoncillo and Laurel, and Municipal Ordinance 07-97 of San Nicholas restrict maximum stocking density to

Table 7. Estimated stocking density coefficient and related statistics for a sample of 50 operators in Taal Lake, Philippines, 2002. [Dependent variable: Fingerling mortality (SDm)].

<table>
<thead>
<tr>
<th>Variables</th>
<th>Parameter</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>( \gamma_0 )</td>
<td>-20,337.41</td>
<td>4,009.37</td>
<td>0.00 a</td>
</tr>
<tr>
<td>Stocking density (SD)</td>
<td>( \gamma_1 )</td>
<td>0.64</td>
<td>0.07</td>
<td>0.00 a</td>
</tr>
</tbody>
</table>

R²: 0.60
F-statistics: 72.71

a Significant at 5% level. H₀: Bi = 0.
On average, the tilapia fish cage operators interviewed were not economically efficient. Increasing physical efficiency and the optimal use of inputs would maximize profits. In this regard, the marginal product of each of the variable inputs was calculated and compared with the input-output price ratio. The MP of stocking density and feeding ration were less than the price ratios (0.08 < 0.30; 0.01 < 0.13); hence, increasing these inputs is discouraged. To be efficient, the MP of stocking density and feeding ration should be equal to the price ratios of fingerlings stocked and feeds used. This can also be illustrated by the fact that the value of the MP of feed (VMPF = MPF*PY = PhP 4.54) is less than the marginal cost (MC) of feed (PF = PhP 17.23). Similarly, the value of the MP of net stocking density (VMPG = MPSDa*PY = PhP 0.92) is less than the MC of net stocking density (PhP 7.84).

In the estimation of optimal inputs and output, the data from the 2002 fish cage operator survey served as the baseline level. The estimated optimal net stocking density was 5,495 fingerlings per cage per cropping cycle (10 fish per m³) (Table 8). In a study on the influence of tilapia stocking density in cages on their growth, Yang et al. (1996) recommends 50 fish per m³. Moreover, the estimated optimal feeding ration was 2,606, yielding an estimated value of 1,689 kg per cage per cropping cycle. This yield translates into an FCR of 1.54, which is within the FCR range recommended by McGinty and Rakocy (1989). It should be noted that even at the optimal level, nutrient loss is inevitable given the current production technology. These results relied on the use of the estimated coefficient for XFe, which was only significant at the 12% level (Table 6).

### CONCLUSION

The inherent nature of the fish cage production technology influences water quality in Taal Lake. There is incompatibility in the lake’s resource uses since operators rely on water both as an input into fish production and as a place to put waste production. The current intensity and nature of cage production are not consistent with the standard set for the allowable cage areas. While output is influenced partly by the feeding ration employed, increasing this input does not necessarily mean a corresponding increase in profits. In areas of low water quality, operators' need to recoup losses due to fish kills often leads them to stock fingerlings beyond the recommended level. It seems an irrational decision, but some operators must generate some revenues to repay borrowed money. There may be other pressing reasons why operators continue to practice high stocking density and feeding ration. Operators may not be fully aware of applying the marginal principle in their production. Alternatively, there may be other significant production factors that would become apparent in a larger study.

The low tilapia productivity in Laurel is consistent with the regression results that this cage location is inversely related to yield. With the congestion of cages in San Nicholas, Laurel and Agoncillo areas, it may be possible that more owners will exit or transfer production to the Talisay area. Moving away from the highly concentrated cage areas is promising for expanding cage production. Moreover, the ownership arrangement 'owner hiring caretaker' is more likely to reduce inefficiency.

The inherent characteristics of the Taal Lake ecosystem mean that externalities, such as nutrient pollution, are inevitable with the current fish production technology. Even at the optimal level of inputs and output, nutrient losses are certain. In addition, the open-access nature of the cage production means that there is steady pressure for the number of cages to exceed an economically optimal level.

### Table 8. Estimated baseline levels, prices, price ratio and optimal levels of feeding ration (XFe), net stocking density (XSDa), yield (Y) and nutrient loss per cage per cropping cycle of the 50 sampled operators in Taal Lake, Philippines, 2002.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Baseline Levels</th>
<th>Prices per kg (PhP)</th>
<th>P_X/P_Y</th>
<th>Optimal Levels b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean a Low High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeding ration (kg)</td>
<td>6,188 2,800 18,200</td>
<td>17.23 0.31 2,606</td>
<td>94 20</td>
<td></td>
</tr>
<tr>
<td>Net stocking density (No.)</td>
<td>33 126 90 81,000</td>
<td>7.84 0.14 5,495</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield (kg)</td>
<td>2,495 612 6,602</td>
<td>56.19 1.889 d</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aGeometric mean: \[ \bar{x} = \left( \frac{1}{n} \right)^n \sum x_i \]

The baseline geometric N loss is estimated at 224 kg per cage per cropping cycle while P loss is estimated at 47 kg per cage per cropping cycle. b Derived by equating the MPX to the X-input and output price ratio. cBased on the average of four pieces per kg of market size tilapia at PhP 1.96 per fingerling (adjusted price from the net SD). dThe optimal yield was obtained using the optimal feeding ration (2,606) and net stocking density (5,495). (Source: Author’s Fish Cage Operator Survey 2002).
Since the amount of nutrient pollution is directly related to the cage culture itself, the authors support recommendations limiting the intensity of cage production and increasing monitoring in the lake. Exclusion through prices and transactions costs (i.e. fee increase) may be advisable.

Amendments in the municipal regulations may change the unreceptive behavior of many operators toward sustainable production practices. The establishment of 'entry and exit procedures' in the four municipalities may be necessary. Full enforcement of fishery regulations through sharing of resources from the four municipalities may also be effective. Managing the lake holistically calls for a unified institutional structure. Closer working links among cage operators, the Bureau of Fisheries and Aquatic Resources and the local government units in Taal Lake are essential. Developments in the institutional structures warrant future technological changes in the fish cage production system.

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This section presents an indirect estimate of organic and inorganic N and P loading associated with wastes from the fish cages, watershed/agriculture and the household sewage.

<table>
<thead>
<tr>
<th>Fish Cages Unit</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage nutrient loss into the surface water</td>
<td>% 76.56a</td>
<td>85.00c</td>
</tr>
<tr>
<td>Amount of nutrient per metric ton of feed used</td>
<td>kg 47.33</td>
<td>9.00</td>
</tr>
</tbody>
</table>

\[ \text{Amount of N present per ton of feed} = 1000 \text{ kg} \times 0.04733 \text{ kg} = 47.33 \text{ kg} \]

\[ \text{The amount of N present per ton of feed} = 1000 \text{ kg} \times 0.04733 \text{ kg} = 47.33 \text{ kg} \]

\[ \text{The amount of N present per ton of feed} = 1000 \text{ kg} \times 0.009 \text{ kg} = 9.00 \text{ kg} \]

\[ \text{The amount of P present per ton of feed} = 1000 \text{ kg} \times 0.009 \text{ kg} = 9.00 \text{ kg} \]

The amount of N present per ton of feed = 1000 kg * 0.04733 kg = 47.33 kg

\[ \text{N loss}_{2001} = \sum_{i=1}^{4} \left( \frac{(1002 \times 2.362^2 + (84 \times 2.729^2 + 2.71) + (353 \times 481^2)^2)}{1000kg} \right) = 3,758 \text{ mt N} \]

The amount of P present per ton of feed = 1000 kg * 0.009 kg = 9.00 kg

\[ \text{P loss}_{2001} = \sum_{i=1}^{4} \left( \frac{(64 \times 2.362^2 + 39 \times 2.729^2 + 75 \times 481^2)^2}{1000kg} \right) = 816 \text{ mt P} \]

**Agriculture/watershed** (Clemente and Wilson 2000)
Assuming an average nutrient loss of 6.48 kg N per hectare per year, 0.96 kg P per hectare per year and a 10% filtration of nutrients by the watershed vegetation, the estimated total nutrient loading rates in 2001 are shown below.

\[ \text{N loss}_{2001} = \frac{6.48 \text{ kg N} \times 0.9 \times 41006ha}{1000kg} = 239.15 \text{ mt N} \]

\[ \text{P loss}_{2001} = \frac{0.96 \text{ kg P} \times 0.9 \times 41006ha}{1000kg} = 35.43 \text{ mt P} \]

**Household Sewage** (Jacinto et al. 1998)
A 90% approximation of the total catchment population in 2001 (equal to 494,221) directly discharge into the system. Assuming an effluent load factor of 20 kg per person per year of BOD to estimate the household sewage input and taking the CNP ratio of the organic matter to be 190:15:1 of carbon, nitrogen and phosphate, the per capita organic carbon loading is about 21 kg per year or 1800 moles C per person per year, while the inorganic discharge associated with this load is about 9.5 moles P per person per year and 140 moles N per person per year. BOD measures the ability of naturally occurring microorganisms to digest organic matter. Using N and P estimate discharge per person per year and multiplying it with the population directly discharging into the lake, which is 494,221, we then get the following results.

\[ \text{N loss}_{2001} = \frac{140 \text{ moles person/year} \times 0.9 \times [535,323 + 535,323(0.0258)] \times \text{person/year} \times 14 \text{ mole gN}}{1000 \text{ kg} \times 1000 \text{ kg} \times 1 \text{ year}} = 968.67 \text{ mt N} \]

\[ \text{P loss}_{2001} = \frac{9.5 \text{ moles person/year} \times 0.9 \times [535,323 + 535,323(0.0258)] \times \text{person/year} \times 31 \text{ mole gP}}{1000 \text{ kg} \times 1000 \text{ kg} \times 1 \text{ year}} = 145.45 \text{ mt P} \]

Annual population growth rate