COST-EFFECTIVENESS OF NUTRIENT POLLUTION REDUCTION IN TAAL LAKE, PHILIPPINES

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ABSTRACT

Stakeholders of the Taal Lake fish cage industry face the challenge of producing fish in a situation of frequent fish kill occurrences, which have been attributed to the deteriorating water quality due to nutrient pollution from fish cages. This study estimates the cost-effectiveness of nutrient pollution reduction options. Fifty operators were surveyed and the production data elicited were used in the estimation of a Cobb-Douglas production function. Results show that the types of ownership arrangements and institutional set-up in the municipalities of Agoncillo, Laurel, San Nicholas, and Talisay affect the production efficiency and nutrient loadings in the four cage locations. Marginal analysis reveals that operators are over-utilizing stocking density relative to feeding ration. At different percentage reductions in nutrient loadings, the cost-effectiveness of nutrient pollution reduction options differs among municipalities. With the current fish production technology and institutional set-up, nutrient pollution and decreasing biodiversity are inevitable. Developments in the institutional structures may lead to future technological changes in the fish production system and improvement of water quality in cage areas.

Keywords: Cost-effectiveness, externalities, fish cage, nutrient pollution, Taal Lake

INTRODUCTION

Philippine lakes are threatened by various stressors, such as watershed deterioration, household and agricultural pollution, unregulated open water fishing, and lately, intensive fish cage sprawl [24]. Recent fish kill occurrences in Taal Lake in the province of Batangas suggest a deteriorating water quality in cage areas. An excessive amount of nutrients accumulating from the cages led to nutrient enrichment, endangering the industry itself and the general lake ecosystem. Marte *et al.* [16] pointed out that the more informed local government authorities chose to adopt measures that limit further expansion of cage and pen culture activities beyond the carrying capacity of the freshwater bodies. Considering the inherent characteristics nature of the lake and its interdependence with the current institutional structure, the appropriate environmental policy to address the problem is one that minimizes the environmental costs of the wastes, the cost to producers in reducing those levels, and the administrative costs to the regulator of monitoring and enforcing compliance [25].

The cage and its surrounding environment cater to two incompatible uses. Fish cage operators rely on water both as an input into the production and as a place to put waste. Using the water excessively for the latter decreases the productivity of the former. This situation arises for two reasons. First, the inherent characteristics of the lake make it difficult to assign efficient property rights, to implement laws, and to monitor compliance with regulations. Research results show that local government implementation of the open-access policy in Taal Lake tends to have negative effects on the lake's fisheries [18]. In theory, open-access policy results in ubiquitous externalities and has this problem of "free-ridership," a situation where others pay the cost of goods that will benefit everyone. Externality is defined as "…a by-product of some production process…" (e.g. air pollution) or "…the lost opportunity occasioned by the incompatible use of a good…." [2]. The lake's resource uses are high exclusion cost goods; hence, excluding other users is difficult and very costly. In the same way, the lake quality characterizes a congestible good. Once the good becomes congested, each additional user imposes external costs on all the other users. Since each additional user does not pay the full marginal cost of their activities, the resource becomes overused. Thus, a market situation will fail to produce an efficient quantity of the good. Second, the input-specificity associated with an intensive production system is in itself a polluting technology. The intensive production results in larger volume of wastes generated [9] and greater possibilities for the spread of disease [19]. It can disrupt the balance of plant and animal life [12] resulting in a reduction in the species diversity (e.g. *Harengula tawilis*) and a dominance of the surviving organisms (e.g. *Oreochromis niloticus*) [17]. Other studies conducted indicate that the practice of aquaculture technology in many areas is on a destructive path that poses a threat not only to endemic fish populations but also to the industry's own long-term potential [19]. Many other areas in the Philippines are facing the same problem due to nutrient pollution [6, 23].

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 to describe the limnological, ecological, and biophysical characteristics of the lake and its watershed, and the socio-economic and legal considerations of cage culture [11, 10, 1, 18, 24, 21]. Various researchers have suggested different management techniques [5, 7], yet the majority of the fish cage operators are not very receptive to changing their current practices.

Nutrient pollution is inevitable, and so the current management options for reducing the loss of nutrients into the surface water are largely limited to controlling the intensity of cage production [19]. This paper explores the costs of reducing the nutrient loadings from the fish cage production by reducing the total number of cages, reducing the feeding ration, reducing the stocking density, and reducing the water quality impacts of nutrient loadings by the introduction of single-line positioning of cages and the use of aerator. It also looks into the ownership arrangement, i.e. owner as operator vs. owner hiring caretakers, in minimizing inefficiencies and other wastage, which is suspected to affect net revenue and nutrient enrichment in Taal Lake. Research results is hope to provide information on the possible impacts of implementing nutrient pollution reduction strategies on individual fish cage operators and present a guide to local government units and policy-makers in enhancing existing institutions or create alternative structure(s) geared toward addressing the problem.

THE TAAL LAKE ENVIRONMENT AND THE FISH CAGE INDUSTRY

Taal Lake is located in the province of Batangas and lies approximately 60 km south of Manila, Philippines (Figure 1). It is a major tourist attraction and is one of the 10 priority freshwater wetlands in the Philippines. Its watershed has 38 tributary rivers draining into the lake. The only outlet, to Balayan Bay, is the Pansipit River. The lake covers an aggregate area of 24,236 ha, excluding the islands, and has an average depth of 60.1 m [8]. It has a circumference of 120 km and is bounded by nine municipalities and two cities. The fish cages are limited to the barangays of four municipalities: Talisay, Laurel, Agoncillo, and San Nicholas. Cages are mostly concentrated in the fish sanctuary area between Barangay Manalao, Agoncillo and Barangay Gulod, Laurel, although regulation restricts construction of cages in this area. Cages located in this area are protected from the destructive effect of strong winds. Other cages are located on the west side of the volcano island and a few cages are near the smaller islands. Cages are absent in the northeast and southwest portions of the lake because of their susceptibility to strong winds and waves during the southwest monsoon season [11]. The municipal regulations for cage culture and lake utilization differ among the four municipalities (e.g. different rate of fees when securing an operator's permit).

Two ownership arrangements exists, namely 'owner as operator' and 'owner hires a caretaker. Cage operators (classified either as owner/financiers or caretakers), open water fishermen, middlemen, and the different feed producers/ suppliers/ retailers are the key actors in the industry. Most of the financiers are non-residents, who hire labor to work as caretakers of their cages and significantly influence decision-making. Due to the lack of financial capital, most local residents end up as caretakers for an absentee owner. The legal right to own at most five cages is vested in the local residents only.

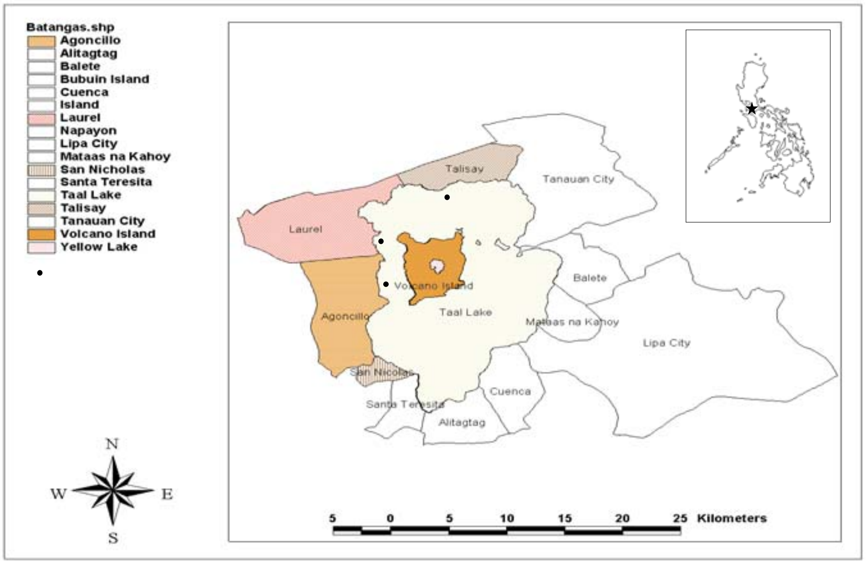

Figure 1. Map of Taal Lake, located in the province of Batangas, Philippines.

Fish cage culture has been practiced for the past two decades, and the present trend is towards increased stocking density and intensive feeding. Each fish cage measures an average of 10 x 10 x 6 m with a stocking of 65 -100 tilapia fingerlings per m^3. In 2001, Agoncillo had a total number of 2,362 registered cages, Laurel had 2,729, San Nicholas had 481, and Talisay had 1,861. The fish are heavily fed with different types of commercial feeds, which comprise the highest proportion of production expenses (76 %). The culture period spans from 4-7 months, which depends on the intensity of feeding and the quality of fingerlings. Many operators observed extended periods of intensive tilapia culture with an additional 1-3 months of culture period compared to 1990s situation. At present, the species cultured in cages are tilapia (*Oreochromis niloticus*), bangus (*Chanos chanos*), and maliputo (*Caranx ignobilis*). Among the three species, tilapia is the most commonly cultured. The estimated total fish production in Taal Lake between 1993 and 2002 is shown in
Figure **2**. Production from the open water fisheries dwindled after fish cage culture flourished in the lake. The lower productivity of endemic fish species may 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 native fish species. Fish cage production plunged to a lower level starting 1998 due to massive fish kill occurrences, which were attributed to oxygen depletion during overturn and toxic poisoning from the suspected pollutants (NH_3, NO_2 and H_2S) [21].

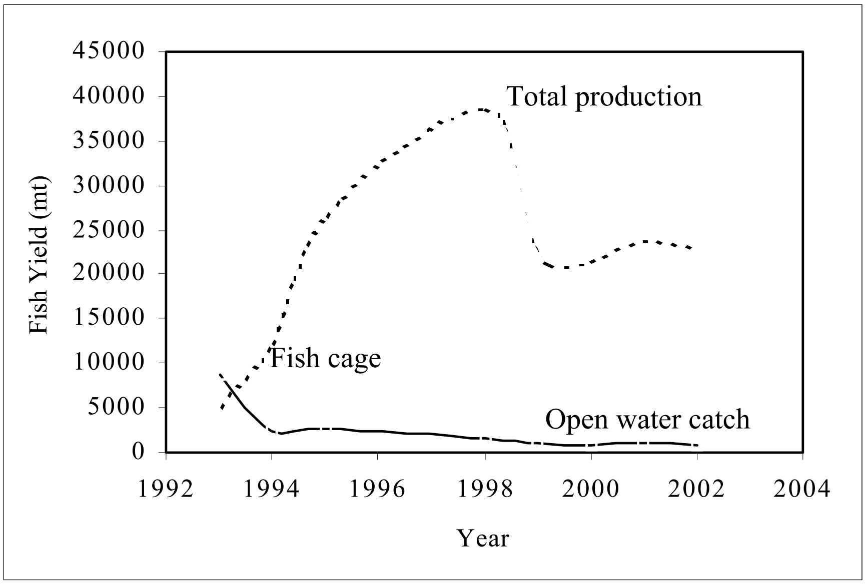

Figure 2. Estimated fish production in Taal Lake, 1993-2002 [18, 2]

In Taal Lake watershed, excess nutrients are supplied to the system through point and non-point sources. Table I presents the estimated nutrient pollution loading from various sources in 2001. The fish cages mainly contribute to the point source pollution, which are largely supplied by the discharges of nitrogen (N) and phosphorus (P) derived from uneaten feed, feces, and excretion via the gills and urine [3, 14, 15]. Beveridge [3] estimated about 76.56 % of N put into use is being lost into the cage and its surrounding waters, while Phillips *et al.* [20] estimated about 85 % for P. Consequently, for every 1000 kg tilapia harvested in 2001, an estimated 83 kg N and 18 kg P are being lost. This situation bears witness to high nutrient loading in the lake. In Taal Lake, *N* more than *P* seems to limit primary production [24]. This observation supports the findings in other freshwater lakes, where *P* has been demonstrated to be more critical in regulating water quality [12, 24].

Table I. Estimated nutrient input loading rates from various sources, 2001.

Source of Nutrients	**Total N**		**Total P**	
	(mt)	%	(mt)	%
Fish cages	3,758	76	816	82
Household sewage [(a)]	969	20	146	15
Agriculture/watershed [(b)]	239	5	35	4
Total	4,966		997	

RESEARCH METHODS

A fish cage operator survey was conducted in the four municipalities. The survey process involved two stages. The first stage, community familiarization and field reconnaissance, acquainted the researcher with the current practices of fish cage farming in the area. The second stage, the actual survey, involved interviews of 50 randomly selected fish cage operators with a varying number of fish cages and types of ownership. A total of 316 cages comprised the survey. Aside from the data gathered through the survey questionnaire, auxiliary information was obtained from various sources. The Statistical Package for the Social Sciences software was used in the analysis of the data gathered.

A cost-effective solution to nutrient enrichment in Taal Lake was based on the comparison of the baseline cost with pollution reduction costs associated with the option(s) selected. The decision variables include *N* and *P* level or loading, and the rule used was to choose the option with the lowest cost of attaining the objective. First, baseline waste generation was measured. Survey data served as input into the estimation of a production function and the optimal values of inputs and output. Second, pollution reduction options were identified and the costs and benefits of each option were estimated. Third, costs of each option were compared with the baseline data. Finally, sensitivity analyses were conducted, which indicates how measures of each option's worth might change under different assumptions about values, input-output relationships, and other changes.

The physical relationship between inputs and output in the fish cage production was estimated following the Cobb-Douglas (C-D) production function [c], defined as:

$$Y = f(X_{SD}, X_F, X_L, X_D) \qquad \text{(Eq. 1)}$$

where Y = yield, kg per cage per cropping cycle;
X_{SD} = stocking density, number of fingerlings per cage per cropping cycle;
X_F = total feeding ration, kg per cage per cropping cycle;
X_L = total labor in tending the cages, man-hours per cage per cropping cycle; and
X_D = dummy variable for ownership arrangement,
= 1 if owner is the operator or = 0 if owner hire caretaker (s).

Data were transformed into their logarithmic value. The production function was estimated employing the ordinary least square (*OLS*) method using *Stata* version 8 software. The *C-D* log linear model [d] is written as:

$$Y = AX_1^{\beta_1} X_2^{\beta_2} \ldots X_n^{\beta_n} \qquad \text{or} \qquad \text{(Eq. 2)}$$

$$\log Y = \log A + \beta_1 \log X_1 + \beta_2 \log X_2 \ldots + \beta_n \log X_n \qquad \text{(Eq. 3)}$$

To test whether multicollinearity presented problems, simple correlation among the independent variables was examined. To test homoskedascity, a plot of the residuals (the difference between the observed Y and the estimated Y) against the independent variables was also made to look for systematic distribution of the deviations around the regression line. The results show no evidence of multicollinearity and homoskedasticity.

To determine profit maximizing level of production, the marginal product of X_i was calculated:

$$\left[MP_{X_i} = \frac{\partial Y}{\partial X_i} = \frac{\beta_i}{X_i}(Y) \right] \qquad \text{(Eq. 4)}$$

The optimum value of X_i was derived by equating MP_{Xi} to the X_i input and output price ratio. The optimal yield was derived from the optimal input levels obtained. Numerical solutions were derived through optimization of the variables *F* and *SD* using Microsoft Excel Solver.

ESTIMATES OF THE COST-EFFECTIVENESS OF NUTRIENT POLLUTION REDUCTION OPTIONS

Figure 3 presents the comparative amount and type of feed given to fish among the four municipalities. The average feed conversion ratio (FCR) was 2.78 +/- 0.34 and ranges from 2.32–3.37. An FCR of 2.78 suggests a requirement of 2.78 kg of feed to produce a gain of 1 kg fish weight. 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 from each other. However, it should be noted that the feeding ration and practices, and so feed costs, was statistically different among the operators in the four municipalities and under the two ownership arrangements. This observation has significant implications to the amount of nutrient loadings, and so, with the existence of negative existence loop in the fish cage production.

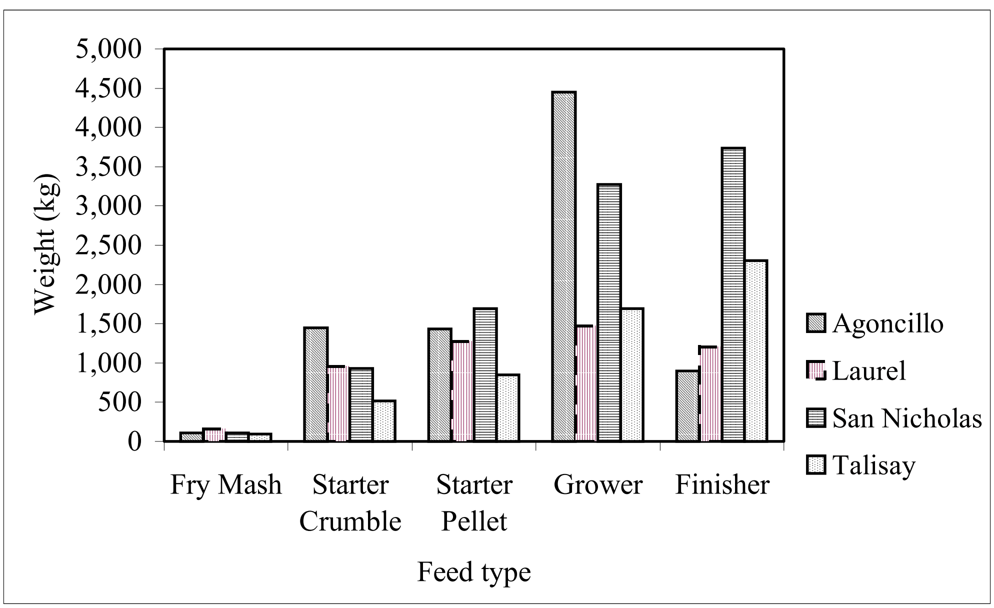

Figure 3. Feed usage per cage per cropping cycle in Agoncillo, Laurel, San Nicholas, and Talisay, Philippines, 2002 (Source: Fish cage operator survey, 2002).

The estimated production coefficients and related statistics are shown in Table II. The net stocking density and ownership arrangement were found to be statistically significant at 5 % level. The production coefficients for feeding ration (B_1) and net stocking density (B_2) have the expected positive sign while the ownership arrangement (B_3) is negative. All the coefficients of the explanatory variables X_{SDa} and X_D are significantly different from zero at 10 % level according to the t-test [(e)]. The explanatory variable (X_F) is only significantly different from zero at 12 % level. Care need to be taken in interpreting this result. With regard to the overall regression, the computed F value (6.60) is greater than the critical value (2.09) at 10 % level of significance. It can be said that the overall regression is statistically significant. The production elasticities are 0.20, 0.22, and -0.33, respectively. A 10 % increase in feeding ration will produce a 0.20 % increase in yield (not significant) while a 10 % increase in the net stocking density will produce a 0.22 % increase in yield. Since the sum of the production coefficients is < 1, a decreasing return to scale exists; a doubling of X_F and X_{SD} inputs will less than double yield.

Table II. 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]

Variables (Log)	**Parameter**	**Coefficient**	**Standard Error**	**P value**
Total feeding ration *(X_F)*	β_1	0.20	0.12	0.12 [(f)]
Net stocking density *(X_{SDa})* [(g)]	β_2	0.22	0.09	0.03 [(h)]
Ownership arrangement *(X_D)*	β_3	-0.33	0.13	0.01 [(h)]
Intercept	β_0	3.99	1.33	0.00 [(h)]
Observations: 50				
R^2: 0.37				
F statistics: 6.6				

Source: Fish Cage Operator Survey 2002

The *MP* of feeding ration and stocking density were less than the price ratios (0.08 < 0.30; 0.01 < 0.13); hence, increasing these inputs are discouraged (Table III). The estimated optimum-net stocking density was 5,495 fingerlings per cage per cropping cycle while the estimated optimum-feeding ration was 2,606 kg per cage per cropping cycle. The estimated optimal yield was 1,689 kg per cage per cropping cycle. It should be noted that even at the optimal level, nutrient loss is inevitable given the current production technology.

Table III. Baseline levels, prices, price ratio, and optimal levels of feeding ration, net stocking density, yield, and nutrient loss per cage per cropping cycle of the 50 sampled operators in Taal Lake, Philippines, 2002.

Variables	**Baseline levels**			**Prices per kg (PhP)**	**P_X/P_Y**	**Optimal levels [(j)]**		
						Yield	**Nutrient Loss (kg)**	
	Mean [(i)]	**Low**	**High**				**N**	**P**
Feeding ration (kg)	6,188	2,800	18,200	17.23	0.31	2,606	94	20
Net stocking density (No.)	33,126	2,900	81,000	7.84	0.14	5,495		
Yield (kg)	2,495	612	6,002	56.19		1,689		

Waste reduction or minimization reduces the release of nutrients into the surface water. For operators and LGU officials interviewed, the reduction in the total number of cages (Option Z_1) is only a short-term solution; hence, this option may not be fully supported by the operators in the long run. Many local residents are dependent upon the cage culture business as their primary source of family income. This strategy has more appeal with the more informed local government officials rather than the operators. The reduction in feeding ration and stocking density (Options Z_2 and Z_3) are cost-saving strategies, which are assumed to improve yield and increase net revenue. Reducing the amount of feed employed results in less nutrient loss, better water quality, and a possible increase in output. Based on ranking of net revenue per cage per year, the reduction in feeding ration (Option Z_2) is suggested for the municipalities of Laurel, San Nicholas, and Talisay (except at 15 % reduction in nutrient loading) (Table IV). For the municipality of Agoncillo, reduction in stocking density (i.e. with proportional reduction in feeding ration, Option Z_3) is recommended. Option Z_2 is advised for Talisay at 5 % and 10 % reduction in nutrient loading and Option $Z_{3\ at}$ 15 % reduction in nutrient loading. Based on cost or incentive per year, Option Z_2 is recommended in all municipalities, expect for Agoncillo at 5 % reduction in nutrient loading and for Talisay at 15 % reduction in nutrient loading (Table V). It should be noted that these results implies inefficiency, so caution is warranted for Options Z_2 and Z_3.

Table IV. Ranking of Options Z_1, Z_2 and Z_3 at 5 %, 10 %, and 15 % reduction in nutrient loadings in Agoncillo, Laurel, San Nicholas, and Talisay, Philippines based on net revenue per cage per year.

Municipality	5 % reduction in nutrient loading			10 % reduction in nutrient loading			15 % reduction in nutrient loading		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
Agoncillo	2.5	2.5	1	2.5	2.5	1	2.5	2.5	1
Laurel	2	1	3	2	1	3	2	1	3
San Nicholas	2	1	3	2	1	3	2	1	3
Talisay	2	1	3	3	1	2	3	2	1

Note: Z_1 - Reduction in the number of cages
Z_2 - Reduction in feeding ration
Z_3 - Reduction in stocking density

Table V. Ranking of Options Z_1, Z_2 and Z_3 at 5 %, 10 %, and 15 % reduction in nutrient loadings in Agoncillo, Laurel, San Nicholas, and Talisay, Philippines based on cost or incentive per year.

Municipality	5 % reduction in nutrient loading			10 % reduction in nutrient loading			15 % reduction in nutrient loading		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
Agoncillo	1	3	2	3	1	2	3	1	2
Laurel	3	1	2	3	1	2	3	1	2
San Nicholas	3	1	2	3	1	2	3	1	2
Talisay	3	1	2	3	1	2	3	2	1

Note: Z_1 - Reduction in the number of cages
Z_2 - Reduction in feeding ration
Z_3 - Reduction in stocking density

Improved waste management entails additional costs to reduce the impacts of nutrient pollution in Taal Lake fish cage industry. Single-line positioning of cages and the use of aerator (Options Z_4 and Z_5) do not reduce the nutrient loadings but rather mitigate harm to fish production. In the implementation of single-line positioning of cages, individual operators will incur additional cost of at least PhP 1,430 per cage per year. This option could result in a better water exchange inside and outside the surface area in cages. Properly spaced cages could make nutrient concentration more diluted. On the other hand, an estimate of PhP 176,256 per year for each municipal government is needed in implementing Option Z_4. The success of this strategy lies with the participation of all operators in Taal Lake and strong 'political will' of the LGU officials. An aerator can be employed during critical condition when the dissolved oxygen level dip below the acceptable level (5 mg/L). An aerator costs about PhP 30,000 per unit and is replaced after 9 years with a salvage value of 20 % of the initial cost. An estimate of PhP 6,000 per year on operating and maintenance costs is needed. Given the high cost of this strategy, many operators are hesitant in employing this strategy. They believe that it is only applicable in ponds and not in a deep lake.

Agoncillo and Laurel are expected to have the most localized effects of nutrient pollution. The use of fish medicine or anti-stress medication by operators in these two municipalities supports such claim. In this regard, timing of stocking is also critical for the survival of fingerlings in cages. Since the transition of monsoon winds from northeast to southwest (May and October) the temperature is higher than normal range and fish kill is most likely to occur, a cropping cycle between September and April maybe the best period to culture fish in Taal Lake.

CONCLUSION

Indeed, the current structure of right ownership and the inherent nature of the fish cage production technology influences the water quality in Taal Lake. There is incompatibility in the lake's resource uses since operators rely on water both as an input into the production and as a place to put waste. The current intensity and nature of cage production is not coherent with the standard set for the allowable cage areas. Changes in the intensity of production activities are central to the suggestions elicited through the survey.

A change in the municipal regulations may change the unreceptive behavior of many operators towards changing to sustainable production practices. With the congestion of cages in San Nicholas, Laurel, and Agoncillo areas, it may be possible that more owners will exit or transfer production in the Talisay area. Moving away from the highly concentrated cage areas is promising for expanding the cage production. The role of caretakers is essential in reducing the technical inefficiencies in the use of inputs, specifically feed.

The open-access problem is predictable with the inherent characteristics of the Taal Lake ecosystem. Externalities, such as nutrient pollution and decreasing biodiversity, are inevitable with the current fish production technology. The choice left is to accept a certain level of pollution as a trade-off for the benefits gained from use of the lake's resources and services. Even at the optimal level of inputs and output, nutrient losses are certain. The enforcement of property rights is not sufficient to attain cage production efficiencies. As a result, exclusion through prices and transaction costs may be necessary. Finding a better cage culture technology that minimizes the production and transaction costs is promising and practical. However, a cheaper production process may not be that appealing to the current dominant operators who will lose their incentives once the least-cost technology succeeds. Of great importance also is the need to interpret and modify existing laws and regulations, determining who pays for fixed costs and whose preferences count? Developments in the institutional structures warrant future technological changes in the fish cage production system.

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ENDNOTES

[a] Adopted from Jacinto *et al*. [13], assuming a 1.96 kg N per person per yr and 0.29 kg P per person per yr loss.

[b] Adopted from Clemente and Wilson [4], assuming a 6.48 kg N per ha per yr and 0.96 kg P per ha per yr loss and a 10% filtration of nutrients by the watershed vegetations.

[c] One limitation of the *C-D* is that it does not have stage III of the production function.

[d] Y=output; X_i=inputs; β_i = factor productivities; A = constant. Error terms are omitted.

[e] H_o: $B_i = 0$. T-statistics is computed as B_i/se.

[f] Significant at 12 % level.

(g) The net stocking density (SDa), derived as stocking density at stocking (SD) less fingerling mortality at stocking (SD_m) was used instead of the actual SD to account for the uncertainty and risk of getting zero output.

(h) Significant at 5 % level. $H_o: B_i = 0$.

(i) Geometric mean:

$$g(X_i) = e^{\left[\left(\frac{1}{n}\right)*\sum \ln X_i\right]}$$

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.

(j) Derived by equating the MP_{X_i} to the X_i input and output price ratio.