Fisheries and Aquaculture Journal
ISSN: 2150-3508

Research Article Open Access

Optimum Harvest Time of the Nile Tilapia (*Oreochromis niloticus*) in Honduras: A Two Step OLS Procedure to Obtain the Growth Function

Wolfgang Pejuán*, Valeria Criollo and Patricio Enrique Paz

Departamento de Administración de Agronegocios, Universidad Zamorano, Tegucigalpa, Francisco Morazán, Honduras

Abstract

Several aquaculture firms in Honduras lack a profit function for tilapia production, which complicates their decision-making. Furthermore, several statistical procedures used to obtain a production function are too complex for these firms to implement on their own. Thus, a simple, yet efficient, model was developed for these firms to follow. The model for this function consists of a gross-margin function composed of an income and a cost function. The OLS procedure in this model differs from several studies by using the OLS obtained length-weight parameter, "b" as an input to estimate "k" in a second OLS regression. The latter regression is applied to a log-lin model of a weight-based von Bertalanffy growth function. The estimated length-weight exponent, "b" used in the growth function, the growth parameter per day, "k" and the mortality parameter per day, "z" are 2.92289, 0.00821 and 0.00086 respectively. The optimum harvest time estimated for one period is 199 Days after Stocking (DAS) when there is no restriction in the market for the size of fish and 208 DAS when minimum market length is 20 cm. The optimum harvest time for infinite time horizon is 117 DAS if there is no size restriction.

Keywords: Aquaculture; Gross margin; Growth parameter; Mortality parameter; Production function

Introduction

Fish farming in Honduras has had a significant boom in recent years, settling in third place within Latin American countries with the highest export level of tilapia fillets [1]. The efficient use of resources becomes necessary due to competition and knowing when to harvest is critical. The Pan-American Agricultural School, Zamorano and several aquaculture firms and tilapia producers located in Honduras lack a profit function for this species. Estimating a profit function to know the optimal time to harvest would avoid economic losses to firms and farmers. A growth function is part of the profit function and there are several ways to estimate it; each with its pros and cons. Some studies use Ordinary Least-Squares (OLS) using the length version of the Von Bertalanffy Growth Function (VBGF) to estimate the growth parameters: "k" the growth constant or curvature of the growth function and t_0, the initial estimated time of growth [2,3]. Other studies apply nonlinear regression either to the length version of the VBGF [4,5] or to the weight version of it [6].

Even though Nonlinear Least Squares (NLS) estimations can be more efficient compared to the OLS procedures in estimating tilapias growth function, not everyone easily applies nonlinear estimations, while OLS is more widely available, known and used. On the other hand, higher efficiency can be achieved estimating parameters directly from weight observations and a weight version of the VBGF, instead of estimating the growth parameters by using length observations and a length version of the VBGF, and later inserting these parameters into the weight version of the VBGF. This study focuses on obtaining the optimal harvest time for tilapia in Honduras using the case of the Aquaculture Unit of the Pan-American Agricultural School, Zamorano, Honduras, and estimating a profit function with a growth function estimated from a two-step OLS procedure (2S-OLS).

In previous studies, the optimal time to harvest tilapia in tropical areas has been in a range of 105 to 191 days [6]. The optimal time depends on, among others, tilapia growth, which is determined in the VBGF by the growth constant, "k" and the exponent of the weight-to-length ratio, "b". The yearly growth constant "k" reported in previous studies on tropical zones is in the range of 0.34 (0.0009 per day) and 19.64 (0.0538 per day) [7]. Similarly, studies have reported the exponent "b" within the range of 2.47 to 3.5 [8,9]. The importance of this study is to provide tilapia firms and farmers a simple and efficient methodology to avoid economic losses by determining the optimal harvest time through a model that is at their reach to estimate, which only uses OLS available in commercial spread sheets, to estimate their tilapia growth function to finally establish their profit function. However, it is important to highlight those different growing conditions and market parameters change the end result. Additionally, this study introduces tilapia weight distribution as a decision parameter as well as an analysis for a one time production and an end-to-end tilapia production batches in an infinite horizon setup.

Many tilapia farmers decide on the day to harvest on rule of thumb basis, making sure to comply with market constraints related to fish size. A common practice by the Aquaculture Unit is to harvest after six months in regular temperature conditions, where the weight per live tilapia is inferred to be between 190 and 300 g. This is coherent with the purchasing weights of the Minimarket and using the literature reported carcass yield between 75%-87%. The general objective of this study is to determine a profit function for tilapia producers to maximize profit using a simple and efficient procedure to estimate the growth function. Optimal time to harvest and profit sensibility analysis are provided to show different scenarios that farmers could face varying production function and market parameters. Financial losses by moving away from the optimal harvest time are provided. A one period as well as an infinite time period analysis for optimal time to harvest is specified [10].

***Corresponding author:** Wolfgang Pejuán, Profesor Asociado, Departamento de Administración de Agronegocios, Universidad Zamorano, Tegucigalpa, Francisco Morazán, Honduras, Tel: +504 22872000; E-mail: wpejuan@zamorano.edu

Received March 28, 2019; **Accepted** May 31, 2019; **Published** June 07, 2019

Citation: Pejuán W, Criollo V, Paz PE (2019) Optimum Harvest Time of the Nile Tilapia (*Oreochromis niloticus*) in Honduras: A Two Step OLS Procedure to Obtain the Growth Function. Fish Aquac J 10: 270. doi: 10.35248/2150-3508.19.10.270

Materials and Methods

Basic model development

The model is presented from the gross margin equation down to its components. Gross margin is the difference between total revenue and variable production costs eqn. (1).

$$GM_t = P_t Y_t - VC_t \tag{1}$$

where GM_t is gross margin at time "t" P_t is price per unit of weight of live tilapia at the farm-gate at time "t" Y_t is the tilapias production function (in weight units) at time "t" and VC_t is the variable cost at time "t".

Price schedule and percentiles: In several studies, the price varies depending on time due to the different sizes demanded by the market [11]. However, the price according to weight also changes according individual buyers of tilapia. Some buyers have a policy of just one price even when they have a weight restriction of a certain percentile, that is, a weight under which only a certain percent of the total fish offered will be accepted. The percentiles also vary by individual buyers. Other buyers do have a different price for the fish falling under the specified percentile.

Price: Prices in this study were divided in two classes, a single price and a weighted average price, both estimated at the level of the Zamorano Aquaculture unit. The tilapia carcass price at the point of sale-grocery store at Zamorano was transformed into the price of live tilapia at the processing station of the Zamorano Aquaculture Unit, where slaughtering, cleaning and transportation costs were subtracted from the carcass price. The person in charge of sales at the Minimarket at Zamorano was interviewed to get the schedule of prices according to size of tilapia. In addition, six tilapia buyers from the main popular markets (Mayoreo markets) in Tegucigalpa and San Pedro Sula were interviewed to get the weight price schedules for tilapia and percentiles.

Tilapia weight distribution: In order to estimate the optimal time to harvest with different percentile restrictions, a tilapia weight distribution was estimated. This is to aim for a mean weight and comply with the given percentile. The estimated distribution was a result of the best fit, according to the Akaike information criterion, with weights of the sampled fish at 220 days after stocking.

Production function: A Two-step OLS (2S-OLS) and a NLS estimation procedure produced the growth functions.

Two-step Ordinary Least Squares: The production function (Y_t) shown in eqn. (1), consists of the growth function in weight (W_t) and survival function (N_t) eqn. (2).

$$Y_t = W_t \times N_t \tag{2}$$

Where W_t is the weight (g) of a fish at time "t," and N_t is the number of fish at time "t".

Weight growth function: The weight growth function, or weight version of the von Betalanffy function, is obtained by merging the length version of the von Bertalanffy function eqn. (3) and the weight-length relationship equation eqn. (4) [12].

$$L_t = L\infty[1 - \mathrm{e}^{(-k(t-t_o))}] \tag{3}$$

Where L_t is length of the fish; L∞ or L_{max}, is the length of the longest fish in the experiment. "k" is the length growth constant or parameter (curvature), which is the growth rate of the fish, which translates to the rate at which the fish grows as time goes by; "t" is time after stocking, and t_0 is age of fish at length of zero (which is usually estimated as negative); and

$$W_t = q(L_t)^b \tag{4}$$

Where W_t is weight (g) of a fish at time "t" (in days after stocking (30 days after hatching)), "q" is the weight-length relationship constant, L_t is the length (cm) of the fish and "b" is the of weight-length relationship exponent. "b" is the constant length elasticity of weight, which measures the percentage change in weight of fish as a 1% change in the length of the fish.

After some algebra, the merging of Equations 3 and 4 results in the weight growth function eqn. (5).

$$W_t = W\infty[1 - e^{(-k(-t-t_o))}]^b \tag{5}$$

Where W∞, W_{max} or asymptotic weight (in g), is the weight of the heaviest fish in the experiment, "k" is the (daily) weight growth constant (curvature), "t" is time after stocking, and "t_0" is age of fish at weight of zero. The weight is given in grams (g) to better represent the weight of one fish. This would then be converted to an appropriate unit for total production according to the size of the pond. VBGF is also used for growth estimation of other species (i.e., snails, guinea pigs, steers) [8,13,14].

Non Linear Least Squares: The NLS procedure yielded the parameters "k" "t_0" and "b" with the "W_{max}" value included, before estimation of the other parameters, and taken as described above and following Equation 5 as the model.

The survival function: The survival function is the number of fish in a given time "t" eqn. (6):

$$N_t = N_o(e^{-zt}) \tag{6}$$

Where "N_0" is the initial number of tilapia introduced to the pond at time zero (stocking), "t_0" "e" is the Euler number or Napier constant and "z" is the mortality constant and "t" is time (days) after stocking.

Variable cost function: The variable cost function included three important components: initial costs, daily costs (at time "t") and harvesting costs. The initial cost included the purchase of fingerlings and filling of production ponds. The daily cost, which varies over time, includes inputs and labor activities such as feeding, water replacement, pond maintenance, and control of pond temperature and oxygen. Harvesting costs included activities of retrieving fish from the pond and moving the fish to the processing station of the Zamorano Aquaculture Unit.

The labor costs for feeding, maintenance, temperature and oxygen control, harvesting, and sacrifice were estimated by multiplying the average time (average of 3 observations (repetitions) in hours) spent in each activity times the wage per hour. The three observations were taken in a monthly manner to detect changes in the amount of time spent in the activity as the tilapia grew. Interpolations of time spent in an activity were used to fill the cost of the intermediate days for each activity. All the previous daily costs were added to obtain the cumulative cost at day "t" including the opportunity cost of capital. Finally, a quadratic function was regressed with the cumulative cost to obtain the variable cost function eqn. (7):

$$C_t = \beta_o + \beta_{1t} + \beta_2 t^2 \tag{7}$$

Parameter estimation for two-step ordinary least squares

The parameters of weight-length relationship ("q" and "b"), growth (by "k") and mortality "z" were estimated through OLS regression with data of variables measured in the field. Samples were taken for the length (cm) and weight (g) of tilapia using a ruler and a scale. The mortality constant "z" was obtained by regression using census data (population counts) at three points in time.

Estimating the weight-length relationship constant and exponent: To obtain the weight-length constant and exponent, "q" and "b," respectively, an OLS regression was estimated using the model in eqn. (8), which is eqn. (4) with the natural logarithm applied:

$$Ln\,Wt = Ln(q) + b\,Ln(L_t) \tag{8}$$

To verify the homoscedasticity assumption, the White test was applied.

Obtaining asymptotic weight parameter: The asymptotic weight parameter, "W_{max}" used was the weight of the largest fish in the population. This value was used because this is the highest value of the fish population specific to the local conditions; thus, the results of the regression would approach local conditions reality. If "W_{max}" of the largest fish recorded historically were to be used, there would be low correlation between the estimated and actual weights in the general population in the time interval of commercial growth because of the unusual fish weight used.

Estimating the growth constant: The growth constant, "k" can be estimated from either a length equation or a weight equation. In this manuscript it is estimated from the growth equation using an OLS regression model shown in eqn. (9), which is a rearrangement of eqn. (5) after the natural logarithm was applied:

$$-Ln\left[1 - \sqrt[b]{\frac{W_t}{W_\infty}}\right] = -kt_o + kt \tag{9}$$

Where "b" is inserted from the estimated regression in eqn. (9) and all other parameters and variables were defined in eqn. (5). The calculated parameter $\hat{\beta}_1$ is the parameter "k" and "t_0" can be estimated with $\hat{\beta}_0$ and "k". Again, the homoscedasticity assumption was tested. This is the second OLS regression applied in this study, the Two-step OLS procedure, which differs from the other studies applying the OLS methodology, the conventional OLS procedure, to estimate the growth function. The conventional OLS applying methodology of this type of studies apply OLS to the rearranged eqn. (3) after applying the natural logarithm to estimate "k" as shown in eqn. (10):

$$-Ln\left[1 - \frac{L_t}{L_\infty}\right] = -kt_o + kt \tag{10}$$

and use both this latter estimated "k" and the assumed (sometimes estimated) exponent "b" from eqn. (9) to insert them both in eqn. (5). However, if it is estimated, it uses the length growth equation instead of the weight growth equation.

Estimating the mortality index: To obtain the mortality index, "z" constant, the natural logarithms were applied to both sides of eqn. (6) and rearranged eqn. (11):

$$Ln\,N_t = LnN_0 - zt \tag{11}$$

The estimated parameter, $\hat{\beta}_1$ represents the negative value of "z" The Breuch-Pagan test for heteroscedasticity was applied due to few degrees of freedom because of the few censuses conducted. The reduced number of census taken was due to avoid stress caused by handling tilapia.

Obtaining the farm-gate price: The farm-gate price, price of live weight tilapia, was estimated by subtracting the processing and transportation costs from the price of live weight of fish at the processing area in the Aquaculture Unit, converted from the carcass price in the Mini-market at Zamorano. The conversion from the carcass price considered the percentage of carcass weight to live weight. Below is eqn. (12), the farm-gate price:

$$P_{1wa} = (\%carcassyld \times P_{cm}) - C_{pt} \tag{12}$$

Where: P_{lwa}: Price per gram of live weight in tilapia Aquaculture Unit Zamorano; % carcassyld: percent of carcass yield; P_{cm}: Price per gram of carcass weight in the Minimarket at Zamorano; C_{pt}: Costs per gram of processed and transported tilapia to the Minimarket at Zamorano.

Estimating the optimal time to harvest and gross margin

Gross margin maximization and optimal time were obtained using a commercial spreadsheet, maximizing the extended version of eqn. (1), eqn. (13):

$$GM_t = P \times W_\infty[1 - e^{(-k(t-t_o))}]^b \times [N_o \times e^{-zt}] - CV_t \tag{13}$$

Parameters estimated from regressions of eqn. (9-11,13,14) were substituted for each of the components in eqn. (15) to obtain the gross margin.

Comparison of regression procedures for estimating the growth constant

The conventional, the Two-step OLS, and the Nonlinear Least-Squares (NLS) procedures were compared in terms of Mean Square Error (MSE) in eqn. (5) as the criteria for selection of the model. Although one measurement of MSE is not definitive for claiming efficiency, it contributes to the selection of the model. The MSE, for each estimation method, used the observed and predicted weights of fish to estimate the sum of squared residuals and dividing them by the appropriate Degree of Freedom (DF). The DF for each estimation method is the difference of the number of observations and all estimated parameters in each estimation method. For both OLS procedures, the DF subtracted five units (i.e., W∞, k, t_0, b and q). The NLS estimator only subtracted 4 units since "q" was not estimated in this method.

Modeling optimal harvest time through several periods

When several production periods are taken into account and size of fish is not a driving force for time to harvest, the setup for optimal time to harvest changes since it is assumed that one batch is produced immediately after another. A general setup would be to maximize the present value of an infinite series of gross margin periods eqn. (14) by selecting the number of days to harvest in each production period. Time to harvest is expected to be reduced compared to a one period optimization because of the pressure to stock another batch of tilapia for production gives rise to a trade-off between the gain obtained by the additional number of batches sold within a fixed period of time (but with a lower gross margin in each period) when time to harvest is reduced, and the gain from a larger gross margin in each period (but with fewer number of batches within the same time period) when time to harvest is increased. The general rule for a one period optimization is to select the time to harvest where marginal unit of time revenue is equal to marginal unit of time cost. The general rule for an infinite time horizon optimization is to select time to harvest where marginal unit of time profit (gross margin, in this case) is equal to average unit of time profit (gross margin). Given the concavity of the growth function and the convexity of the variable cost function, the previous rule in the infinite time horizon can only happen when time to harvest is reduced compared to the one period optimization. The above is gross margin optimization and optimal time for infinite periods were obtained by using spread sheet software applied to eqn. (14):

$$PVGM_t = \left[PW_\infty[1-e^{(-k(t-t_0))}]^b[N_o \times e^{-zt}] - VC_t\right]\left[\left(\frac{1}{it}\right)\right] \tag{14}$$

Where: PVGMt: is the present value of an infinite series of gross margins of time length “t” and i: daily opportunity cost of capital.

The previous combinations of percentile weights, prices, and estimation procedures gave rise to the estimation of optimal days to harvest and gross margins to five scenarios aforementioned (2S-OLS and NLS with different percentile weights and prices).

Price, input costs and parameter sensitivity analysis: The sensitivity analysis determined the optimum time and gross margin due to changes in the price of the product, the parameters of the production function, input costs and opportunity cost. The sensitivity of the optimal time and gross margin are specifically evaluated by a declining or incremental change of 20% and 40% in the price of tilapia, on the production function parameters, or input costs, ceteris paribus.

Losses: Losses (forgone gross margins) in the Aquaculture Unit represent the difference in gross margins between the optimum harvest time and other times, where other times were positive and negative variations of 20, 40 and 80 days from the time to reach a minimum percentile weight.

Location and limitations of study

This study was located at the Zamorano University Aquaculture Unit at 900 m.a.s.l., with an annual average temperature of 24ºC. The 120 m^2 earthen pond with green water and minimal water exchange was stocked with 800 units of a mono sex tilapia population with a male tendency at 30 days after hatching. Mono sex male populations are more productive than mixed populations and are the usual practice done by tilapia farmers. This type of production is considered semi-intensive, which small to medium scale producers use. Stocking was in June of 2014 and harvesting was in February 2015, 280 days after stocking. November through January were relatively cold months, which reduced fish stimulus to feed, thus growth diminished compared to normal years. This specific condition happens approximately every 3 years. The limitations of this study are circumscribed within these characteristics described above because the different production and market conditions generate different growth functions and market parameters, respectively.

Sampling

It was important to periodically monitor the growth and health of the 800 fish stocked in the pond of the Aquaculture Unit. Sampling and censuses were conducted at different times, to measure different variables for monitoring and for the study at hand. Systematic sampling of the variables weight (g) and length (cm) were performed to estimate the constants “q”, “b” and “k”. Sampling periods were spaced by approximately 40 days, with 50 fish sampled each time. Systematic sampling was used to avoid bias, because people generally tend to catch larger fish (i.e., fattest or longer fish).

The sample size is a result from using a finite population sample size formula. The standard deviation used was obtained from previous measurements at around 60 days after stocking to have sensible measurements from the beginning. However, the sensible measurements for weights for harvesting would be past 120 days. Therefore, a much larger standard deviation was assumed, 50 g. In addition, the confidence level and error used were of 95% and 5 g. The null hypothesis was the additional cost of the feed in the period of 40 days in periods later than 100 days after stocking. The alternative hypothesis was the value of the marginal product, change in weight from previous sample measurements in the period multiplied by the price of the product. This yielded a sample size of 33. However, it was taken to 50 fish to get more precision. Mortality rate estimation was made possible by the three censuses of fish in the pond. The census was conducted approximately every 140 days. The last census was done at harvest time. The mortality rate can change drastically if sound management practices are not followed.

Management practices

Management practices were taken from the experience at the Aquaculture Unit. Field practices conducted from June 2014 to March 2015 include sexing, stocking, predator control, standardization of population, feeding and harvest. Due to the importance of feeding in costs of tilapia production, it is specified below.

Feeding: The fish diets should have a food balance for the development of fish [15]. Normally, fish are fed with floating pellets. The pellets are used as reference to see if the fish were still hungry or not, and control the amount of food these were given. Feeds supplied in the pond of this study contained 38% and 28% crude protein. From month one to three feed with 38% crude protein was used, and after three months fish were given feed with 28% crude protein. For daily feeding, the following protocol was followed:

The amount of feed given was estimated relative to fish body weight. Below is eqn. (15) or feed the fish biomass:

$$Daily \quad ration \quad = \quad N_t \times W_t \times (\%live \quad weight) \tag{15}$$

Where: % live weight: percentage of food relative to body weight (approximately 3% in the first 3 months and 2% in the other months) and is adjusted by continuous observations of feed intake. The fish were fed twice a day at 9:00 a.m. and 2:00 p.m.

Results and Discussion

The parameters “q”, “b”, “k” and “t_0” calculated with the conventional, 2S-OLS, and NLS estimating procedures are reported in Table 1. Table 1 also shows the mortality constant, which is separate from the estimation procedure and thus, same for all of them.

Parameters	Symbol	Conventional estimation	Two-step OLS	Nonlinear Least Squares
Length-weight exponent	b	2.92289	2.92289	1.51193
Length-weight relationship constant	q	0.02408	0.02408	Not Applicable
Growth constant (per day)	k	0.00651	0.00814	0.00587
Mortality constant (per day)	z	0.00086	0.00086	0.00086
Age at weight zero	t0	−54.5787	−38.64676	−12.5359

Table 1: Tilapia production function parameters estimated from different estimating procedures from data collected at the Aquaculture Unit of Zamorano, Honduras, July 2015.

Weight-length relationship constant and exponent

These parameters determine the relationship between length and weight of the tilapia. The exponent "b" is estimated at 2.92289 and the constant "q" is 0.02408. These two parameters were the same for the conventional estimation and Two-step OLS because it is the same procedure, however, it is usually assumed at a value of three for the conventional. The value of the constant "q" was not taken into account in terms of growth, following the Von Bertalanffy model. The value of the exponent "b" for the conventional and Two-step OLS is similar to previous studies in a range of 2.5 to 3.5. However, it is different for the NLS estimation. The change in values depends on the area where it occurs and its weather conditions [7]. The value of "b" in Mexico is 2,649. In Thailand, the exponent "b" is approximately 3 [6]. The value of the exponent "b" is significant for all estimation procedures (Conventional and Two-step OLS (n=400, s.e.=0.0221, R^2=0.9778); and NLS (n=399, s.e.=0.2093, R^2=0.9615)).

Growth constant and initial time parameter: The "k" parameter determines the weight gain per day of tilapia. This constant varied according to the estimation procedure. The Two-step OLS estimate was 0.008138 per day (2.97 per year). This value is different from previous studies, due to changing environmental conditions by region and production season, however, within the range of those studies. In Sinaloa, the constant "k" is 0.007 per day (2.55 per year) [5]. The "k" constant in Hidalgo, Mexico is 0.000912 per day (0.33 per year) [3], and in Piura, Peru is 0.0043 per day (1.57 per year) [16]. The parameter value "k" for all estimation procedures is significant (Conventional (n=399, s.e.=0.0001, R^2=0.8606); Two-step OLS (n=399, s.e.=0.0002, R^2=0.7821); NLS (n=399, s.e.=0.0003, R^2=0.9615). The initial time parameter, "t_0" also varied across the estimation methods, with the Two-step procedure being closer to the 30 day period from eclosion to stocking.

Mortality index

This parameter determines the population number in time "t" of the tilapia. The estimated "z" in the study is 0.00086. Poor water quality due to lack of periodic replacement of oxygen causes stress in fish. Under these conditions, the defenses of tilapia decrease and as well as the ability to produce lymphocytes or immune cells to fight pathogens. The decrease in defenses sometimes result is death, decreasing the fish population, or decrease in growth [17]. Therefore, the time between water changes should not exceed six weeks. The estimated annual survival rate in the Aquaculture Unit in Zamorano is 73% with the survival formula, while it was at 79% within the growing period of 280 days. This rate is similar to the ones observed in studies in Mexico and Nigeria where survival is 76% per year for both studies [18]. The parameter value "z" is significant (n=3, s.e.=0.0037, R^2=0.9995) and the model presents no heteroscedasticity.

Price

Polanco reported that the prices of tilapia in Zamorano's Minimarket does not vary according to size and that the sizes have historically ranged from 136 g to 272 g per eviscerated, gill less and scale less fish. Currently, the Mini-market most frequently demands 182 g fish. The accepted percent of underweight fish is 2% for the smallest weight and 5% for higher weights.

The Mayoreo buyers have a price discount for underweight tilapia that varied from 20%-35%, with a mean of 25%. Their mean percent of acceptance of underweight tilapia is of 5.5% with an almost unanimous percentile of 227 g of eviscerated gill free fish with scales. Buyers indicated that smaller weight tilapia is a demand typical of smaller towns but not in major cities. However, major cities still sell those small fish with the underweight fish purchase. Also, markets like industrial free zones where numerous lower income workers seek for budget-friendly meals are a destination for this type of smaller weight tilapia. Some boarding schools and military barracks fall also in this category. Carcass yield of 100 harvested fish was 85%, removing viscera, gills and scales and 88.8% when removing viscera and gills.

These results give rise to five scenarios of interest of percentile weight restrictions of processed tilapia with varying price restrictions and carcass yield for the scope of tilapia producers intended in this study. The scenarios are the following: 1) A single price with no weight restriction and 85% carcass yield; 2) A two-percentile weight of 136 g, one price and 85% carcass yield; 3) A five-percentile weight of 182 g, one price and 85% carcass yield; 4) A five-percentile weight of 227 g, one price and 88.8% carcass yield; and 5) A five-percentile weight of 227 g with a weighted-average price and 88% carcass yield. All scenarios include the 2S-OLS and NLS estimation procedures. The first scenario is to find a general sense of what a tilapia producer would do in the case where no weight restrictions were in place. Scenarios 2 and 3 are for the tilapia producers selling in smaller towns where there are no price schedules. Scenario 5 is for tilapia producers selling in a major city with and without a price schedule. The weighted-average price resulted in 98.75% of the regular price.

Longer and heavier fish will gain greater acceptance by an affluent market [11], however, major cities in Honduras would only discount for underweight tilapia. This study used the price of live weight of tilapia at the processing site at the Aquaculture Unit at Zamorano of \$2.42 kg^{-1} (\$0.00242 g^{-1}) for scenarios 1 through 4 and the discounted weighted-average price in scenario 5. For these prices, the carcass price at the Minimarket of \$3.50 kg^{-1} was adjusted by the carcass weight yield (that varies by scenario), transportation costs to the Mini-market and processing costs. A summary table of the processing costs per weight and per fish is presented in Table 2.

Processing activity includes activities of sacrifice, gutting, washing, transportation and other inputs such as chlorine and gasoline. Processing and transportation costs amounted to \$0.000552/g or \$0.11 per fish. Economies of scale apply to the processing activities; however, costs for this study were estimated with the amount of time spent on the activity at the scale of 629 harvested fish, wage rate of \$1.09/hour and transportation costs for Zamorano. This cost can be adjusted for any other operation operating a different scale and running the model with the adjusted cost. The single and weighted average prices of live

Activities/inputs	Unit	Quantity	Cost/unit	Total
Peeling	h^{φ}/fish	0.039	1.09	0.04242
Stunning	h/fish	0.002	1.09	0.00212
Gutting	h/fish	0.042	1.09	0.04545
Washing	h/fish	0.014	1.09	0.01515
Storing	h/	0.002	1.09	0.00242
Transportation	h	0.0003	1.09	0.00035
Gasoline	$L^{£}$	0.0019	0.95	0.00182
Water	m^3	0.004	0.01	0.00003
Chlorine	g	0.0024	0.2	0.00048
Total per fish				0.11024
Total per kilogram				0.552
φ : Hour; £: Liter.				

Table 2: Processing costs at Aquaculture Unit in Zamorano (USD) and transportation costs to the Zamorano Minimarket per fish and per kilogram, July 2015.

weight tilapia at the Processing Unit were obtained using eqn. (14) and are presented below eqn. (16):

$$P_{pva} = \left\{ \begin{matrix} (0.85 \times \$3.5kg^{-1}) - \$0.552kg^{-1} = \$2.42kg^{-1} \sin gle \quad price \\ (0.85 \times 0.9875 \times \$3.5kg^{-1}) - \$0.552kg^{-1} = \$2.39kg^{-1}\, weighted \quad price \end{matrix} \right\} \quad (16)$$

Production function

The tilapia growth function for 2S-OLS and NLS for the Aquaculture unit at Zamorano was obtained by replacing the parameter values in eqn. (5) and is presented below eqn. (17):

$$W_t = \left\{ \begin{matrix} 343[1 - e^{(-0.00814(t-(-38.6)))}]^{2.92}\; 2S - OLS \\ 343[1 - e^{(-0.00587(t-(-12.5)))}]^{1.51}\; NLS \end{matrix} \right\} \quad (17)$$

The growth function "W_t" above is expressed in grams per fish. The maximum weight or "W∞" belonging to the largest fish in the pond was 343. Fiallos indicated growth in a warm season stimulates the rapid growth of tilapia and this happens in several species of fish, not only in tilapia [19,20]. Growth in grams obtained in this study indicates that 180 days after stocking tilapia would reach a weight of 200 g. A previous study in Zamorano, in a different production season, which covers the months from March to August, indicates that tilapia reaches 300 g in 180 days [20]. Figure 1 shows the growth of tilapia as a function of time at the Aquaculture Unit in Zamorano.

The survival function of tilapia was determined using eqn. (6), which yields the number of live fish at time "t" in the Aquaculture Unit of Zamorano. The survival function at time "t" eqn. (18) replaces the initial density per hectare for "N_0" from eqn. (6) and includes −0.00086 for "z" as shown below:

$$N_t = 66,667(e^{-0.00086t}) \quad (18)$$

The product of the growth and survival functions yields the production function. The production functions are shown below eqn. (19):

$$Y_t \left\{ \begin{matrix} 343[1 - e^{(-0.00814(t-(-38.6)))}]^{2.92} x 66,667 \quad (e - 0.00086t) \quad 2S - OLS \\ 343[1 - e^{(-0.00587(t-(-12.5)))}]^{1.51} x 66,667 \quad (e - 0.00086t) \quad NLS \end{matrix} \right\} \quad (19)$$

The tilapia production function as a function of time for one hectare at the Aquaculture Unit of Zamorano is presented in Figure 2. The decline in the production function is due to the mortality.

Mean square error comparison of regression procedures

The MSE for the conventional, Two-step OLS procedure and NLS estimators are 1257, 1022 and 929, respectively. As expected, the NLS have a lower MSE. However, the Two-step OLS procedure is directly applicable with accessible spread sheet software, lower MSE than the conventional procedure and not lagging far behind the NLS in terms of MSE. In addition, NLS did not perform as well as the 2S-OLS in terms of mean residual values at each time interval of the applicable harvesting range. Thus, results for the 2S-OLS are the ones to consider when making decisions [21].

Cumulative variable cost function

The estimated cumulative variable cost function is shown below eqn. (20):

$$\begin{aligned} &C_t = 3142.50 + 20.87t + 0.236t^2 \\ &stderr\,(33.736) \quad (0.562) \quad (0.0020) \\ &n = 276 \quad R^2 = 0.9993 \end{aligned} \quad (20)$$

This cumulative variable cost function (USD) shows the estimated initial cost and enables to obtain the daily cost increase. The actual initial costs are shown in Table 3. The initial costs are important accounting for 18% of total variable costs at 231 days after stocking. The cost of fingerlings in the Aquaculture Unit in Zamorano differs by species (i.e., *O. niloticus*, *Oreochromis* spp.) [22].

Optimal time to harvest

The gross margin function without any restriction on the size of tilapia for the Aquaculture Unit in Zamorano is the following eqn. (21):

$$\mathrm{GM_t} = \left\{ \begin{matrix} 0.00242 \text{ x } 343 \left[1 - \mathrm{e}^{\left(-0.00814(\mathrm{t}-(-38.6))\right)}\right]^{2.92} \\ \text{x } 66{,}667\ (\mathrm{e} - 0.00086\mathrm{t}) - (3{,}142.50 + 20.87\mathrm{t} + 0.236\mathrm{t}^2) \\ \text{for 2S} - \text{OLS} \\ \\ 0.00242 \text{ x } 343 \left[1 - \mathrm{e}^{\left(-0.00587(\mathrm{t}-(-12.5))\right)}\right]^{1.51} \\ \text{x } 66{,}667\ (\mathrm{e} - 0.00086\mathrm{t}) - (3{,}142.50 + 20.87\mathrm{t} + 0.236\mathrm{t}^2) \\ \text{for NLS} \end{matrix} \right\} \quad (21)$$

The spread sheet yielded different days after stocking as the optimal times to harvest for the different scenarios and estimating procedures (Table 4). The optimal harvest time for a single period harvest with no restriction on the size of tilapia (scenario 1) is 199 and 183 days for 2S-OLS and NLS procedures, respectively. The mean live weights at those harvesting days are 217 and 192 g, respectively [23]. However, this size of the fish (135 and 110 g of percentile weight for 2S-OLS and NLS, respectively) would not be accepted in any market, and the price

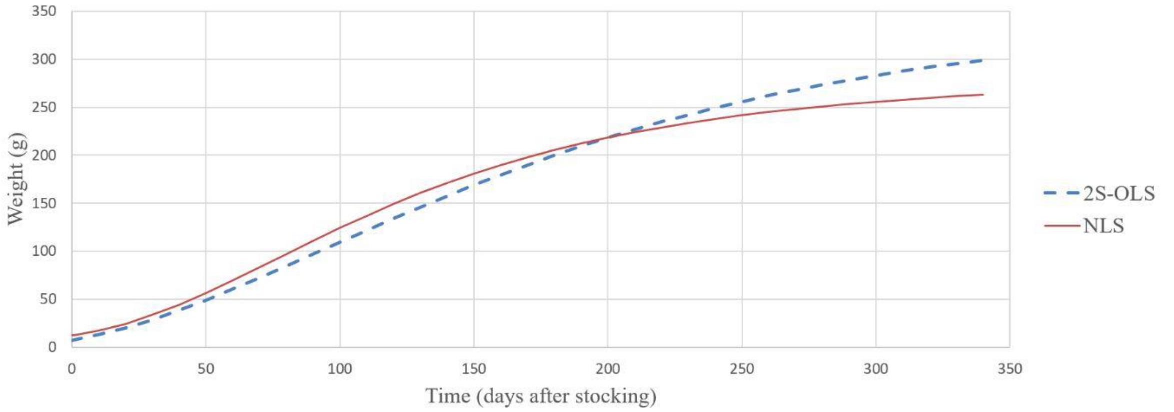

Figure 1: Tilapia growth as a function of time for Two-step OLS (2S-OLS) and Nonlinear Least Squares (NLS) estimating procedures in the Aquaculture Unit of Zamorano, Honduras. (From June 2014 to March 2015).

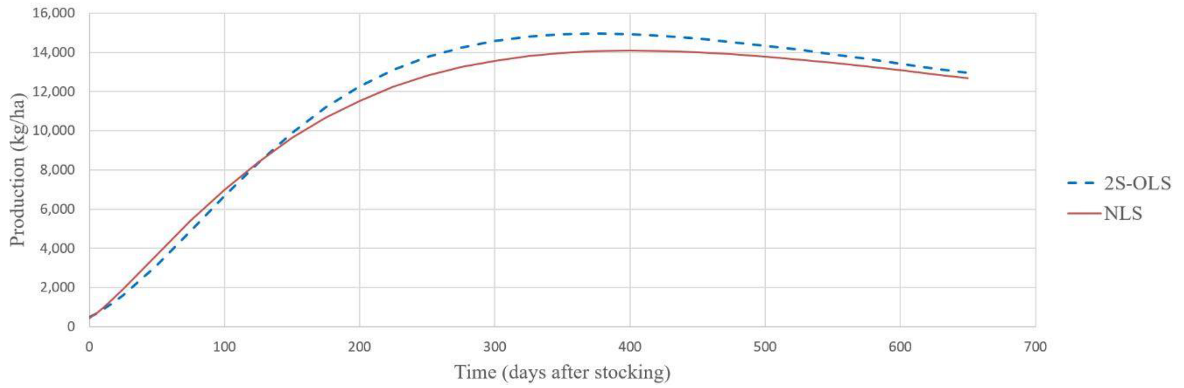

Figure 2: Tilapia production function for one hectare (initial stock of 66,667) as a function of time for Two-step OLS (2S-OLS) and Non Linear Least Squares (NLS) estimating procedures in the Aquaculture Unit of Zamorano, Honduras. (From June 2014 to March 2015).

Activities	Unit	Cost/unit	Quantity	Total
Electricity for pump during stocking	kWh⁶	1.2	250	300
Fingerling	unit	0.04	66,667	2,666
Labor in stocking	hour/ha	1.09	10	11
First day feeding	day	33	1	33
Total				3,010
6: Kilowatt per hour.				

Table 3: Initial variable cost per hectare (USD) for tilapia production, in the Aquaculture Unit of Zamorano, Honduras, August 2015.

Scenario	Processed percentile weight (g)	Live percentile weight (g)	Live mean weight (g)	Percent underweight (%)	Procedure	Optimum harvest time (days)	Harvest time to reach percentile weight (days)	Gross margin at optimum harvest time ($)	Gross margin to reach percentile weight ($)	Equilibrium days (Gross margin=0)	Annual present value equivalent ($)
1	115	135	217	2	2S-OLS	199	199	16,207	16,207	373	35,367
1	94	110	192	2	NLS	183	183	14,640	14,640	359	34,629
2	136	161	243	2	2S-OLS	231	231	15,560	15,560	373	23,072
2	136	161	243	2	NLS	259	259	11,663	11,663	359	15,380
3	182	214	286	5	2S-OLS	306	306	9,608	9,608	373	10,674
3	182	214	286	5	NLS	359	359	59	59	359	56
4	227	256	328	5	2S-OLS	0	476	0	−20,602	373	0
4	227	256	328	5	NLS	0	590	0	−50,860	359	0
5	227	256	328	5	2S-OLS	0	476	0	−21,042	370	0
5	227	256	328	5	NLS	0	590	0	−51,259	357	0

Table 4: Optimum time to harvest, gross margin at optimal time and time to reach percentile weight, equilibrium days and annual present value equivalent of different scenarios varying in processed percentile weights, percentage of underweight fish and estimating procedure at the Aquaculture Unit of Zamorano, Honduras, July 2015.

would be zero; thus, the driving force for harvesting is the minimum size of tilapia. Scenario 1 is therefore not realistic and was excluded from the sensitivity analysis. However, eqn. (19) for 2S-OLS is best seen through graphics. The revenue, cost and gross margin functions as functions of time for the Aquaculture Unit of Zamorano are presented in Figure 3. For a minimum size, a restriction on the price yields the following eqn. (22):

$$\mathrm{GM_t} = \left\{\begin{array}{c} \mathrm{Price} \times 343\left[1-e^{(-0.00814\,(t-(-38.6)))}\right]^{2.92} \times 66{,}667 * e^{-0.00086t} - (3{,}142.50 + 20.87t + 0.236t^2) \\ \text{if } t \geq X^{\square} \text{ days for 2S} - \text{OLS procedure and scenario Y} \\ 0 \times 343\left[1-e^{(-0.00814\,(t-(-38.6)))}\right]^{2.92} \times 66{,}667 * e^{-0.00086t} - (3{,}142.50 + 20.87t + 0.236t^2) \\ \text{if } t < X \text{ days for 2S} - \text{OLS procedure and scenario Y} \\ \\ \mathrm{Price} \times 343\left[1-e^{\left(-0.00587(t-(-12.5))\right)}\right]^{1.51} \times 66{,}667 * e^{-0.00086t} - (3{,}142.50 + 20.87t + 0.236t^2) \\ \text{if } t \geq X \text{ days for NLS procedure and scenario Y} \\ 0 \times 343\left[1-e^{\left(-0.00587(t-(-12.5))\right)}\right]^{1.51} \times 66{,}667 * e^{-0.00086t} - (3{,}142.50 + 20.87t + 0.236t^2) \\ \text{if } t < X \text{ days for NLS procedure and scenario Y} \\ \\ \begin{array}{cccc} \text{Scenario Y} & \text{Procedure} & \text{Price} & X^{\square} \\ 2 & 2S-OLS & 0.00242 & 231 \\ 2 & NLS & 0.00242 & 259 \\ 3 & 2S-OLS & 0.00242 & 306 \\ 3 & NLS & 0.00242 & 359 \\ 4 & 2S-OLS & 0.00242 & 476 \\ 4 & NLS & 0.00242 & 590 \\ 5 & 2S-OLS & 0.00239 & 476 \\ 5 & NLS & 0.00239 & 590 \end{array} \end{array}\right\} \quad (22)$$

The optimal time to harvest for processed tilapia of a two-percentile weight of 136 g (Scenario 2) is 231 and 259 days for 2S-OLS and NLS, respectively. These times are sensible periods to keep tilapia growing for relatively cold years and are profitable. For a five-percentile weight of 182 g (Scenario 3), time prolongs to 306 and 359 days for 2S-OLS and NLS, respectively. These times are out of tilapia farmers usual harvesting time periods although still profitable in the 2S-OLS. For a five-percentile weight of 227 g, time excessively prolongs to 476 and 590 days to grow the fish to the required size for 2S-OLS and NLS, respectively [24]. These times are by far out of tilapia farmers normal harvesting time periods and it is not profitable; thus, it is better to not produce. Optimal time to harvest tilapia with a two-percentile of 136 g of processed tilapia is 32 days later than the time with no restriction. This is due to the relationship of actual growth function, and product price and marginal cost relationship in the non-restricted case.

Therefore, the Aquaculture Unit would harvest the tilapia before 231 days when the market accepts tilapia of any size due to its relatively rapid growth, while it would not harvest before 231 days when it does not accept tilapia lower than the aforementioned weight due to the

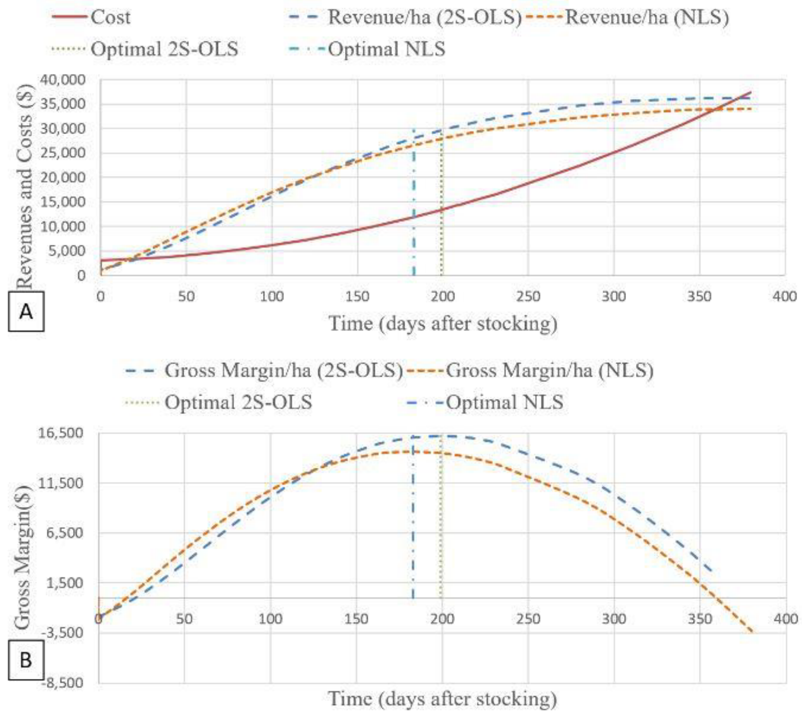

Figure 3: A) Revenue and cost function for tilapia production without a minimum length requirement for Two-step OLS (2S-OLS) and Non Linear Least Squares (NLS) estimating procedures at the Aquaculture Unit, Zamorano, Honduras, 2015. B) Gross margin function for tilapia production without a minimum length requirement for 2S-OLS and NLS estimating procedures at the Aquaculture Unit, Zamorano, Honduras, 2015.

price drop to zero. At less than the 231 days, the probability to find live tilapia less than 160 g is larger than 0.02, which is larger than what the Minimarket is willing to bear, and the price for that tilapia is zero. Similarly, at less than 306 days and 476 days, the probability to find tilapia less than 214 and 256 g, respectively, is larger than 0.05, which is larger than what the Minimarket is willing to bear, and the price for that tilapia is zero [25]. Equation 20 for 2S-OLS is best seen through graphics. The revenues, costs and gross margin functions for tilapia production dependent on time for the Aquaculture Unit in Zamorano are shown in Figure 4.

Weight distribution and acceptance of fish at the minimarket

The weight distribution used is the Beta distribution with parameters $\alpha 1=1.9131$and $\alpha 2=1.44$, and the minimum varies according to the target percentile weight. However, the maximum varied in a fixed amount, the range in the original time distribution.

Here the figure of the beta distribution of the weight of a tilapia population in the Aquaculture Unit at Zamorano whose probability of obtaining a minimum weight of 161 g is 97.9% is shown in Figure 5.

Optimum harvest time of tilapia for infinite periods

The optimal harvest time for end-to-end batches of tilapia production with no minimum size restriction using an infinite period horizon is 117 and 87 days for 2S-OLS and NLS procedures, respectively [26]. This end-to-end infinite period optimal time is, as expected, lower than the one time batch production of tilapia with no size restriction with an 82 and 96 days difference for the 2S-OLS and NLS procedures, respectively. These times to harvest would hypothetically produce higher gross margins. However, the resulting processed mean size of the fish is 110 and 78 g for 2S-OLS and NLS, respectively, which would not be accepted in any market, and the price would be zero; thus again, the driving force for harvesting is the minimum size of tilapia.

Inputs	Costs ($)	Percentage
Food 38%	2,019	12
Food 28%	9,116	52
Energy for water exchange	1,201	7
Labor	1,740	10
Initial costs	3,117	18
Final costs	364	2
Total costs	17,558	100

Table 5: Summary of the accumulated variable cost and percentage of total variable costs at the optimal harvest time in the Aquaculture Unit, August 2015.

Cost breakdown at optimum harvest time

The cost behavior varies over time. However, the cost breakdown at the optimal harvest time taking into account the opportunity cost "i" and the importance of each input and the total cost is detailed in Table 5. The feed costs are the most important ones adding up to 64% of total variable costs. In previous studies, labor, initial cost (purchase and stocking of fingerlings) and final cost (labor of harvest) have been excluded, and feed costs accounted for 90% of total variable costs [20].

Profits are maximized where the marginal physical product is equal to the ratio of the marginal factor cost and price [27]. By increasing the price of the product, the slope will be lower (flatter), thus, the optimum time to harvest will increase due to the concavity of the production function. Profits would increase because the proportion of marginal costs will be lower in relation to income.

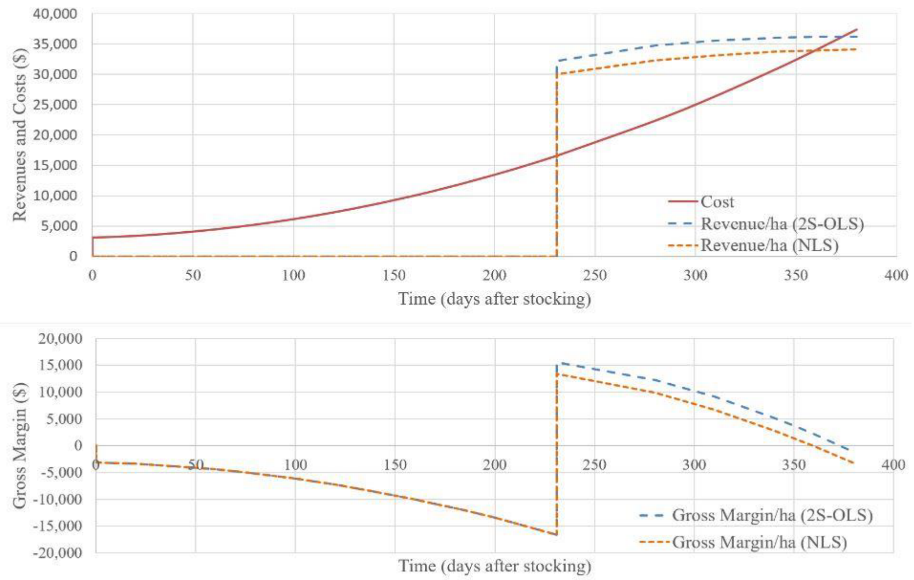

Figure 4: A) Function of revenue and production costs taking into account the minimum requirements of the market in terms of size tilapia for Two-step OLS (2S-OLS) and Nonlinear Least Squares (NLS) estimating procedures at the Aquaculture Unit Zamorano, Honduras, from June 2014 to March 2015. B) Function gross margin of production taking into account the minimum requirement in terms of market size tilapia at the Aquaculture Unit Zamorano, Honduras, from June 2014 to March 2015.

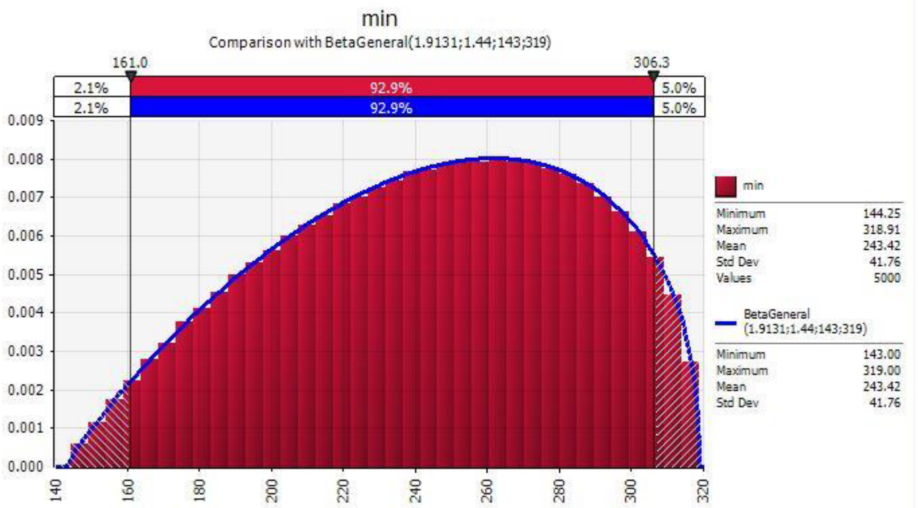

Figure 5: Beta Distribution of the weight of a population of tilapia in the Aquaculture Unit at Zamorano whose probability of obtaining a live weight lower than 161 g, September 2015.

Gross margin and optimal time sensitivity analysis

Using a spread sheet, a sensitivity analysis of the optimal time to harvest and gross margin were performed due to changes in parameters, prices and costs, which varied in both directions in 20 and 40 percent.

Sensitivity to parameter variation and the price of tilapia

The sensitivity analysis shows the movements of the optimal time and the gross margin to different parameter values, prices and costs. The sensitivity analysis is mainly done for the two percentile weights of eviscerated fish that are profitable, 136 and 182 g; however, all percentile weight information is shown on the Tables 6 and 7. The optimal time and gross margin varies differently depending on the changed parameter [28,29]. The Zamorano Unit gross margin and optimum time sensitivity due to changes in the price of tilapia and constants "b," "k," "z," are in Tables 6 and 7.

Price sensitivity: The price is a value that can be changed, either by customer perception as to product quality, time of year and the policies imposed by the Government of Honduras. Due to these possible reasons of price change, it was necessary to evaluate the sensitivity of the gross margin and the optimal time to harvest estimated with changes in the price of tilapia. Gross margin decreased by $12,865 and $14,195 for a 40% decrease in price, which yields an average reduction of 1.38% and 2.46% in gross margin for a 1% reduction in price, for percentiles 136 and 182 g of eviscerated fish, respectively. The optimal time does not decrease because the size restriction makes the time to harvest the same at 231 and 306 days after stocking all the way through a 40% decrease in

Variable changed	Percentage of price or of constant	Percentile weight of eviscerated fish (g)							
		136				182			
		Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)	Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)
		2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS
Price	140	231	259	28,425	24,242	306	359	23,803	13,635
Price	120	231	259	21,992	17,953	306	359	16,705	6,847
Price	100	231	259	15,560	11,663	306	359	9,608	59
Price	80	231	259	9,127	5,373	306	359	2,511	−6,729
Price	60	231	259	2,695	−916	306	359	−4,587	−13,517
"b" exponent	140	231	259	11,411	7,623	306	359	7,110	−2,318
"b" exponent	120	231	259	13,414	9,574	306	359	8,336	−1,151
"b" exponent	100	231	259	15,560	11,663	306	359	9,608	59
"b" exponent	80	231	259	17,860	13,901	306	359	10,927	1,313
"b" exponent	60	231	259	20,324	16,298	306	359	12,295	2,614
"k" constant	140	231	259	22,944	17,554	306	359	14,305	3,938
"k" constant	120	231	259	19,930	15,032	306	359	12,554	2,397
"k" constant	100	231	259	15,560	11,663	306	359	9,608	59
"k" constant	80	231	259	9,487	7,223	306	359	4,812	−3,452
"k" constant	60	231	259	1,646	1,504	306	359	−2,527	−8,619
"z" constant	140	231	259	13,104	8,983	306	359	6,063	−3,883
"z" constant	120	231	259	14,307	10,293	306	359	7,789	−1,973
"z" constant	100	231	259	15,560	11,663	306	359	9,608	59
"z" constant	80	231	259	16,863	13,095	306	359	11,525	2,220
"z" constant	60	231	259	18,219	14,593	306	359	13,546	4,519

Table 6: Sensitivity matrix of harvest times (days) and gross margins (in US dollars ($)) for Two-step Ordinary Least Squares (2S-OLS) and Non Linear Least Squares (NLS) models, for different percentile weights of eviscerated fish, at different percentage values of price and estimated constants "b" (weight and length relationship exponent), "k" (growth constant) and "z" (mortality constant) at the Aquaculture Unit of Zamorano, Honduras, July 2015.

Variable changed	Percentage of price or of constant	Percentile weight of eviscerated fish (g)							
		227^{δ}				227^{Υ}			
		Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)	Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)
		2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS
Price	140	476	590	−6,526	−38,099	476	590	−6,526	−38,099
Price	120	476	590	−13,564	−44,480	476	590	−13,564	−44,480
Price	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
Price	80	476	590	−27,640	−57,241	476	590	−27,640	−57,241
Price	60	476	590	−34,678	−63,622	476	590	−34,678	−63,622
"b" exponent	140	476	590	−6,526	−38,099	476	590	−21,658	−51,818
"b" exponent	120	476	590	−13,564	−44,480	476	590	−21,351	−51,540
"b" exponent	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
"b" exponent	80	476	590	−27,640	−57,241	476	590	−20,730	−50,976
"b" exponent	60	476	590	−34,678	−63,622	476	590	−20,415	−50,690
"k" constant	140	476	590	−6,526	−38,099	476	590	−19,755	−50,170
"k" constant	120	476	590	−13,564	−44,480	476	590	−20,147	−50,531
"k" constant	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
"k" constant	80	476	590	−27,640	−57,241	476	590	−23,054	−52,718
"k" constant	60	476	590	−34,678	−63,622	476	590	−27,407	−55,605
"z" constant	140	476	590	−6,526	−38,099	476	590	−26,290	−57,045
"z" constant	120	476	590	−13,564	−44,480	476	590	−23,773	−54,299
"z" constant	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
"z" constant	80	476	590	−27,640	−57,241	476	590	−18,078	−47,895
"z" constant	60	476	590	−34,678	−63,622	476	590	−14,861	−44,172

δ: Single price; ϒ: Weighted average price according to price schedule.

Table 7: Sensitivity matrix of harvest times (days) and gross margins (in US dollars ($)) for Two-step Ordinary Least Squares (2S-OLS) and Non Linear Least Squares (NLS) models, different percentile weights of eviscerated fish, and two different price assumptions, at different percentage values of price and estimated constants "b" (weight and length relationship exponent), "k" (growth constant) and "z" (mortality constant) at the Aquaculture Unit of Zamorano, Honduras, July 2015.

price, and still have a positive margin of $2,965 for the lower percentile weight but a loss of $4,587 for the higher percentage weight (182 g).

On the other hand, gross margin increased by $12,865 and $14,195 for a 40% increase in price, which is equivalent to an average increase of 2.07% and 3.69% in gross margin for a 1% increase in price for percentiles 136 and 182 g of eviscerated fish, respectively. Optimal time does not increase even for this increase in price. Gross margin is sensitive to changes in price while optimal time is not sensitive to an increase in price. The increase in price causes an increase only in gross margin due to two reasons: 1) Even when the marginal cost to marginal revenue (price) ratio is reduced if price increases, and due to the concavity of the production function with respect to time and the need to match the above ratio to the marginal physical product to maximize gross margin, the equality can only happen by increasing time; however, the price ratio decrease was not enough to go above the minimum time to get to the percentile eviscerated weight; on the other hand, 2) Costs would have a lower proportion than revenue and gross margin increases.

Weight-length relationship exponent sensitivity: The exponent "b" is a value that is not expected to change significantly according to previous studies; however, for completeness of the sensitivity analysis with significant variation in it, it is presented. Gross margin increased by $4,764 and $2,687 for a reduction of 40% in the exponent "b" which yields an average increase of 0.51% and 0.47% in gross margin for a 1% reduction in the exponent "b" for percentiles 136 and 182 g of eviscerated fish, respectively. The optimal time remains the same due to the same reason of the tilapia size restriction. On the other hand, gross margin decreased by $4,149 and $2,498 for a 40% increase in the exponent "b" which is equivalent to an average reduction of 0.67% and 0.65% in gross margin for a 1% increase in the exponent "b" for percentiles 136 and 182 g of eviscerated fish, respectively. Optimal time does not increase even for this decrease in exponent "b". Gross margin and optimal time are not sensitive to changes in exponent "b". By increasing exponent "b", the growth-time function contracts downward and to the right without a significant change in shape (concavity), causing increased time, decreased average value product and reduces gross margin. Contrarily, by reducing the exponent "b," the function expands upward and to the left, causing an increase in average value product, increasing gross margin. However, due to the size restriction, time to harvest remains the same but with a higher gross margin.

Growth constant sensitivity: The constant "k" was varied because it is a parameter that can change by season, year and management practices in the field. Gross margin decreased by $13,914 and $12,135 for a reduction of 40% in constant "k" which is equivalent to an average reduction of 1.49% and 2.11% in gross margin for a 1% reduction in the constant "k," for percentiles 136 and 182 g of eviscerated fish, respectively. The optimal time remains the same due to the same reason of the tilapia size restriction. On the other hand, gross margin increased by $7,384 and $4,697 for a 40% increase in "k" which is equivalent to an average increase of 1.19% and 1.22% in gross margin for a 1% increase in the constant "k" for percentiles 136 and 182 g of eviscerated fish, respectively. The optimal time remains the same. The tendency to sell at a low weight because of a low margin and the need for the minimum size makes the time to harvest very stable for this parameter.

In short, gross margin is sensitive to variation in the constant "k" while the time is not sensitive. By increasing the value of "k" the growth-time function expands upward and to the left, being more concave than the original, where the optimum time decreases because, of a faster growth, fewer time is needed to achieve the same marginal physical product. Thus, the average value product is higher and gross margin increases [30]. Contrarily, by decreasing the value of "k" the average value product decreases decreasing gross margin. However, due to the size restriction, time to harvest remains the same but with a lower gross margin. This parameter is important in different growing conditions because the same price ratio is possible to achieve by having a higher "k" and with a higher mean weight for tilapia than the market requires reaching the minimum percentile weight. It means that in warmer growing conditions, the percentile weight might not be the driving force for the optimal harvest time, and instead would be the relative price ratio. In this case, a 40% increase was not enough to increase the optimal days to harvest.

Mortality index sensitivity: The mortality rate statistic, "z" can vary by poor field management practices or any adverse and unexpected weather conditions. Because of this sensitivity to change in "z," it was evaluated. Gross margin increased by $2,659 and $3,938 for a 40% reduction in "z" which is equivalent to an average increase of 0.29% and 0.68% in gross margin for a 1% reduction in "z" for percentiles 136 and 182 g of eviscerated fish, respectively. The lower mortality causes an increase in the number of fish harvested increasing the gross margin. Due to lower death rate, the optimal time increases by 5 days because the production function with respect to time expands upward and to the left with a less concave shape, therefore, the marginal physical product necessary to equate the marginal cost to price ratio occurs at a later time. Gross margin decreased by $2,456 and $3,545 for the 40% decrease in "z" which is equivalent to the average decrease of 0.40% and 0.92% in gross margin for a 1% decrease in "z" for percentiles 136 and 182 g of eviscerated fish, respectively. However, time to harvest also remains the same even with an increase in "z" of 40% due to the same reason of the restriction in the size of the fish. Gross margin is slightly sensitive to variation in the constant "z" while time is not sensitive. By decreasing the value of constant "z" the optimum time to harvest increases due to a greater number of fish, thus, marginal revenue and gross margin increases.

Sensitivity analysis of the optimal time to harvest and gross margin in relation to the change in costs

The tendency of the sensitivity for increasing and decreasing percentage change in cost is similar across all cost items, except for feed of 28% protein because of fish larger consumption on later growth stages. The optimal time is not sensitive and gross margin is slightly sensitive to the percentage change in costs for one at a time change in 1% feed of 38% crude protein, labor, fingerlings, electric power and opportunity cost. The change in cost per 1% change in the cost of feed of 28% crude protein is the exception, which generates a slight sensitivity in gross margin and small increase in optimal harvest time. This difference is due to the significant change in quantity supplied per day over time of this feed on later stages and a high reduction in costs. The change in gross margin and optimal time to feed costs, energy, labor, fingerlings, electric power, and opportunity costs are shown in Tables 8-11.

Increasing costs should only decrease optimal time to harvest due to the increased marginal cost to marginal revenue ratio, which occurs at an earlier time in a concave production function with respect to time. Therefore, with a size restriction, optimal time remains at 231 and 359 days after stocking by increases in costs for percentile weights of 136 and 182 g, respectively; and gross margin reduces as observed throughout Tables 8-11. However, with cost reductions the time remains the same, except for the feed of 28% crude protein.

The maximum observed sensitivity of the gross margin and the optimum time to harvest as a response to a change in an input, is due to the change in the cost of food of 28% crude protein. The cost of feed of 38% crude protein, labor, fingerlings, water pump power and opportunity costs only affect the gross margin and not the time to

Variable changed	Percentage change	Percentile weight of eviscerated fish (g)							
		136				182			
		Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)	Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)
		2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS
Feed 38%	140	231	259	14,575	10,766	306	359	8,957	−168
Feed 38%	120	231	259	15,067	11,214	306	359	9,282	−54
Feed 38%	100	231	259	15,560	11,663	306	359	9,608	59
Feed 38%	80	231	259	16,052	12,111	306	359	9,934	172
Feed 38%	60	231	259	16,545	12,560	306	359	10,259	285
Feed 28%	140	231	259	11,296	6,068	208	359	12,848	−11,734
Feed 28%	120	231	259	13,428	8,866	208	359	14,500	−5,838
Feed 28%	100	231	259	15,560	11,663	208	359	16,152	59
Feed 28%	80	231	259	17,692	14,460	215	359	17,831	5,955
Feed 28%	60	236	259	19,837	17,258	236	359	19,837	11,851
Labor	140	231	259	15,410	11,490	306	359	9,395	−201
Labor	120	231	259	15,485	11,576	306	359	9,501	−71
Labor	100	231	259	15,560	11,663	306	359	9,608	59
Labor	80	231	259	15,635	11,750	306	359	9,715	188
Labor	60	231	259	15,710	11,836	306	359	9,821	318

Table 8: Sensitivity of harvest time and gross margin for Two-step Ordinary Least Squares (2S-OLS) and Nonlinear Least Squares (NLS) models with different percentile weights of eviscerated fish, varying percentage changes in input prices: 38% crude protein feed and 28% crude protein feed, and labor, at the Aquaculture Unit in Zamorano, Honduras, July 2015.

Variable changed	Change (%)	Percentile weight of eviscerated fish (g)							
		136				182			
		Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)	Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)
		2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS
Fing	140	231	259	14,438	10,534	306	359	8,467	−1095
Fing	120	231	259	14,999	11,098	306	359	9,038	−518
Fing	100	231	259	15,560	11,663	306	359	9,608	59
Fing	80	231	259	16,121	12,227	306	359	10,178	636
Fing	60	231	259	16,682	12,792	306	359	10,749	1,213
Energy power	140	231	259	15,440	11,543	306	359	9,488	−61
Energy	120	231	259	15,500	11,603	306	359	9,548	−1
Energy	100	231	259	15,560	11,663	306	359	9,608	59
Energy	80	231	259	15,620	11,723	306	359	9,668	119
Energy	60	231	259	15,680	11,783	306	359	9,728	179
Interest	140	231	259	15,401	11,464	306	359	9,330	−323
Interest	120	231	259	15,481	11,564	306	359	9,470	−131
Interest	100	231	259	15,560	11,663	306	359	9,608	59
Interest	80	231	259	15,638	11,761	306	359	9,745	247
Interest	60	231	259	15,716	11,859	306	359	9,881	434

Table 9: Sensitivity of harvest time (days) and gross margin (US dollars ($)) for Two-step Ordinary Least Squares (2S-OLS) and Non Linear Least Squares (NLS) models with different percentile weights of eviscerated fish, varying percentage changes in input prices: fingerlings (Fing), water pump energy, and opportunity cost in interest, at the Aquaculture Unit in Zamorano, Honduras, July 2015.

harvest when there is a size restriction on fish. These costs only affect gross margin because without the restriction, optimal harvest time would be at 199 days; therefore, with increasing costs, the tendency would be to reduce time, however, the restriction becomes binding at 231 days. If costs decrease, the gross margin will be higher. In general, the sensitivity of the gross margin is low to a change in individual input costs.

Loss calculation for the production period taking into account the minimum size requirements for tilapia market

Forgone margin associated with deviations to the time to reach percentile weight were determined through changes in the gross margin equation eqn. (21) shown in Table 12. The gross margin at optimal harvest time is actually zero when the gross margin at days to reach percentile weight is negative. This is because it is an option of growing and bears a loss, or not growing at all; however, Table 12 presents gross margin and forgone margin for time to reach the percentile weight of eviscerated fish to present more information. The forgone margin depends on the gross margin at the deviation time relative to the days needed to reach percentile weight after stocking. As expected, any decrease in time to reach percentile weight creates a loss because fish would not be accepted.

Implications

The 2S-OLS procedure yielded a more sensible procedure to follow for decision-making. This produced a higher prediction capacity in the

Variable changed	Change (%)	Percentile weight of eviscerated fish (g)							
		227^{δ}				227^{Y}			
		Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)	Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)
		2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS
Feed 38%	140	476	590	−19,338	−47,411	476	590	−19,778	−47,809
Feed 38%	120	476	590	−19,970	−49,135	476	590	−20,410	−49,534
Feed 38%	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
Feed 38%	80	476	590	−21,234	−52,585	476	590	−21,674	−52,984
Feed 38%	60	476	590	−21,867	−54,310	476	590	−22,306	−54,709
Feed 28%	140	476	590	−42,514	−85,607	476	590	−42,954	−86,006
Feed 28%	120	476	590	−31,558	−68,234	476	590	−31,998	−68,633
Feed 28%	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
Feed 28%	80	476	590	−9,646	−33,487	476	590	−10,086	−33,886
Feed 28%	60	476	590	1,310	−16,114	476	590	870	−16,512
Labor	140	476	590	−20,968	−51,335	476	590	−21,408	−51,734
Labor	120	476	590	−20,785	−51,098	476	590	−21,225	−51,496
Labor	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
Labor	80	476	590	−20,419	−50,623	476	590	−20,859	−51,022
Labor	60	476	590	−20,237	−50,386	476	590	−20,676	−50,785

δ: Single price; Y: Weighted average price according to price schedule.

Table 10: Sensitivity of harvest time and gross margin for Two-step Ordinary Least Squares (2S-OLS) and Non Linear Least Squares (NLS) models with different percentile weights of eviscerated fish, and two different price assumptions, varying percentage changes in input prices: 38% crude protein feed and 28% crude protein feed, and labor, at the Aquaculture Unit in Zamorano, Honduras, July 2015.

Variable changed	Change (%)	Percentile weight of eviscerated fish (g)							
		227^{δ}				227^{Y}			
		Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)	Harvest time (days)	Harvest time (days)	Gross margin ($)	Gross margin ($)
		2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS	2S-OLS	NLS
Fing	140	476	590	−21,786	−52,074	476	590	−22,226	−52,473
Fing	120	476	590	−21,194	−51,467	476	590	−21,634	−51,866
Fing	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
Fing	80	476	590	−20,010	−50,254	476	590	−20,450	−50,652
Fing	60	476	590	−19,418	−49,647	476	590	−19,858	−50,045
Energy power	140	476	590	−20,722	−50,980	476	590	−21,162	−51,379
Energy	120	476	590	−20,662	−50,920	476	590	−21,102	−51,319
Energy	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
Energy	80	476	590	−20,542	−50,800	476	590	−20,982	−51,199
Energy	60	476	590	−20,482	−50,740	476	590	−20,922	−51,139
Interest	140	476	590	−21,275	−51,897	476	590	−21,715	−52,296
Interest	120	476	590	−20,937	−51,376	476	590	−21,377	−51,775
Interest	100	476	590	−20,602	−50,860	476	590	−21,042	−51,259
Interest	80	476	590	−20,270	−50,350	476	590	−20,710	−50,748
Interest	60	476	590	−19,942	−49,844	476	590	−20,382	−50,243

δ: Single price; Y: Weighted average price according to price schedule.

Table 11: Sensitivity of harvest time (days) and gross margin (US dollars ($)) for Two-step Ordinary Least Squares (2S-OLS) and Nonlinear Least Squares (NLS) models with different percentile weights of eviscerated fish, and two different price assumptions, varying percentage values of price, percentage changes in input prices: fingerlings (Fing), water pump energy, and opportunity cost in interest, at the Aquaculture Unit in Zamorano, Honduras, July 2015.

applicable harvesting range. Tilapia producers that harvest all fish at once in sites in Honduras with earthen ponds, green water, and minimal water exchange in relatively cold years will be driven to optimal time to harvest by minimum size tilapia that the market requires. This is independent if the tilapia produces one batch per year or if it produces end-to-end batches. This is an inference derived from the comparison of optimal harvest time of a one-time production or an end-to-end batch, which uses infinite optimization time set-up, to the production with the restricted optimization.

In the weight-restricted cases, the tilapia producer should take into account the fish weight distribution and target for the mean weight that will reach the percentile weight that the market is accepting. These type of producers should direct their sales to small towns or specific markets that accept the smaller weight fish such as industrialized zones, boarding schools and military barracks. In warmer years, the farmer needs to re-evaluate if the minimum size of tilapia is still a driving force to maximize margins or if it will be only a requirement. The driving force in these years might be the relative price ratio and still making sure the minimum sizes are met. A new study with the procedure given here would need to be repeated for one warmer year. Tilapia producers should also be aware in those relatively cold years that going past the mark of one year in raising one group of tilapia will result in negative margins.

Model	Time deviation (days)	Percentile weight of eviscerated fish (g)					
		136			182		
		Harvest time (days)	Gross margin ($)	Forgone margin ($)	Harvest time (days)	Gross margin ($)	Forgone margin ($)
2S-OLS	80	311	9,018	6,542	386	−2,217	11,825
	40	271	13,096	2,464	346	4,304	5,304
	20	251	14,545	1,015	326	7,119	2,489
	−20	211	−14,535	30,095	286	−23,170	32,778
	−40	191	−12,637	28,197	266	−20,632	30,240
	−80	151	−9,355	24,915	226	−16,070	25,678
NLS	80	339	2,983	8,680	439	−14,232	14,291
	40	299	7,979	3,684	399	−6,591	6,650
	20	279	9,979	1,684	379	−3,137	3,196
	−20	239	−17,478	29,141	339	−30,720	30,779
	−40	219	−15,341	27,004	319	−27,730	27,789
	−80	179	−11,581	23,244	279	−22,262	22,321
Model	Time deviation (days)	Percentile weight of eviscerated fish (g)					
		227^{δ}			227^{Y}		
		Harvest time (days)	Gross margin ($)	Forgone margin ($)	Harvest time (days)	Gross margin ($)	Forgone margin ($)
2S-OLS	80	556	−40,574	19,972	556	−40,994	19,952
	40	516	−30,196	9,594	516	−30,627	9,585
	20	496	25,298	−45,900	496	−25,733	4,691
	−20	456	−51,633	31,031	456	−51,633	30,591
	−40	436	−47,644	27,042	436	−47,644	26,602
	−80	396	−40,179	19,577	396	−40,179	19,137
NLS	80	670	−74,711	23,851	670	−75,090	23,831
	40	630	−62,424	11,564	630	−62,813	11,554
	20	610	−56,550	5,690	610	−56,944	5,685
	−20	570	−77,630	26,770	570	−77,630	26,371
	−40	550	−72,668	21,808	550	−72,668	21,409
	−80	510	−63,256	12,396	510	−63,256	11,997

δ: Single price; Y: Weighted average price according to price schedule.

Table 12: Forgone margin and gross margin for Two-step Ordinary Least Squares (2S-OLS) and Non Linear Least Squares (NLS) associated with deviations to the time to reach percentile weight at the Aquaculture Unit of Zamorano, Honduras, July 2015.

Finally, all these results can drastically change if water management is not handled well for oxygen levels and high mortality occurs.

Conclusion

1. The Two-step OLS procedure to obtain the von Bertalanffy growth function has a lower mean squared error than the traditional procedure and lower mean values for residuals at the interesting harvest time periods than the Nonlinear Least-Square (NLS) procedure; in addition that it is directly applicable with an accesible spread sheet program. The 2S-OLS performed better in the harvesting range than the NLS.
2. The growth parameters of tilapia depend on season and weather conditions of the region in which it will occur. The growth parameters of this study differ from those performed in other weather conditions. The growth constant, "k" (in days), for the season from June to March at the Aquaculture Unit at Zamorano is 0.008137, which is approximately 2.67 in years. The exponent "b" is of 2.92.
3. Tilapia survival in the Aquaculture Unit in Zamorano is typical of tropical America where good field practices are met. The "z" constant, the mortality rate constant, at the Aquaculture Unit in Zamorano is 0.00086; this represents a survival of 73% at the end of one year.
4. The production function for the Aquaculture Unit in Zamorano with the 2S-OLS procedure is: $Y_t = 343[1 - e^{(-0.00814(t-(-38.6))}]^{2.92} \times 66,667(e^{-0.00086t})$.
5. The cumulative variable cost function as a function of time (days) increase significantly: $C_t = 3,142.50 + 20.87t + 0.236t^2$ The most significant variable costs are feed and labor. The feed costs represent 54% of variable costs accrued at the time of optimal harvest time.
6. Minimum size requirements are the drivers of optimal harvesting times for earthen ponds, green water, and minimal water exchange in relatively cold years. One tilapia batch per year or end-to-end batches without minimum size requirements yield lower optimal harvesting days than with the constraint.
7. The optimal time to harvest tilapia obtained in this study is different from others throughout the tropics because of the different parameters obtained in the revenue and cost functions. The optimal time to harvest tilapia in the Aquaculture Unit at Zamorano is 231 and 306 days after stocking for 136 and 182 processed percentile weights, respectively, due to the minimum size requirements that the Minimarket in Zamorano could have at different times. The optimal harvest time, for one batch and end-to-end batches with infinite periods without taking into account the limiting size required, is 199 and 117 days, respectively. It is not profitable to grow tilapia in relatively cold weather for major cities neither due to size requirements nor past the 373 days after stocking.

References

1. Bilsborough S, Mann N (2006) A Review of Issues of Dietary Protein Intake in Humans. Int J Sport Nutr Exerc Metab 16: 129-152.
2. Clucas IJ, Ward AR (1996) Post-Harvest Fisheries Development: A guide to Handling/Preservation, Processing and Quality. Natural Resource Institute pp: 443.
3. Eyo AA (2001) Fish Processing Technology in the Tropics. Published by National Institute for Freshwater Fisheries Research (NIFFR). New Bussa, Nigeria pp: 403.
4. Abolagba OJ, Melle OO (2008) Chemical Composition and Keeping Qualities of a Scaly Fish Tilapia (Oreochromis niloticus) Smoked with Two Energy Sources. African J Gen Agric 4: 113-117.
5. Nelson JS (2006) Fishes of the World. 4th edition. Hoboken (New Jersey, USA): John Wiley & Sons pp: 601.
6. Al-Jedah JH, Ali MZ, Robinson RK (1999) The nutrition importance of local communities of fish caught off the coast of Attar. Nutr Food Sci 2888-2894.
7. Parelman MA (2015) Omegas: Dissecting the Science on Omega-3 Supplements. Great valley publishing company, Today's Dietitian 17: 14.
8. FDF (2007) Federal Department of Fisheries. Fisheries statistics of Nigeria pp: 49.
9. Amosu AO, Bashorun OW, Babalola OO, Olowu RA, Togunde KA (2012) Impact of climate change and anthropogenic activities on renewable coastal resources and biodiversity in Nigeria. J Ecol Nat Environ 4: 201-211.
10. Amosu AO, Hammed AM, Togunde KA, Joseph OO, Adekoya A (2017) Possible Aquaculture Development in Nigeria: Evidence for Commercial Prospects. J Agr Sci Tech-Iran B 7: 194-205.
11. Dandajo MA, Garba R, Bahyo EJ, Komolafe GO (2004) Practical manual in Food Technology, Nutrition and Dietetics for Schools and Industries 2nd Edition Kaduna-Nigeria. National Science and Technology Forum, Kaduna Polytechnic.
12. AOAC (2012) Official methods of analysis. Association of official analytical chemist. 19th edition, Washington DC, USA.
13. ICMSF (2002) International Commission on Microbiological Specifications for Foods. Micro-Organisms in Foods 7. Microbiological Testing in Food Safety Management. Kluwer Academic Plenum Publishers. New York pp: 199.
14. Duncan DB (1955) Multiple range and multiple F test. Biometrics 11: 1-42.
15. FAO (2005) Post-harvest changes in fish. In: FAO Fisheries and Aquaculture Department, Food and Agriculture Organization, Rome, Italy.
16. Hansen TL, Gill T, Rontved SD, Huss HH (1996) Importance of autolysis and microbiological activity on quality of cold-smoked salmon. Food Res Int 29: 181-186.
17. Tokur B, Ozkutuk S, Atıcı E, Ozyurt G, Ozyurt CE (2006) Chemical and Sensory Quality Changes of Fish Fingers, Made From Mirror Carp (Cyprinus carpio L., 1758), During Frozen Storage (−18^{0}C). Food Chem 99: 335-341.
18. Giron-calle J, Alaiz M, Millan M, Ruiz-gutienez V, Viague E (2002) Bound malondialdehyde in foods: bioavailability of N-2-propenals of lysine. J Agric Food Chem 50: 6149-6198.
19. Adeniyi OD, Bawa AA (2006) Mackerel (Scomber scrombrus) oil extraction and evaluation as raw materials for industrial utilization. Leonardo J Sci 8: 33-42.
20. Chakrabarty MM (2003) Chemistry and Technology of Oil and fats. Allied publisher 1: 760.
21. Chebet J, Kinyanjui T, Cheplogoi PK (2016) Impact of frying on iodine value of vegetable oils before and after deep frying in different types of food in Kenya. Int J Sci Innov Res 5: 193-196.
22. Ogundiran MB, Adeniyi SO (2012) Determination of Fat Contents, Iodine Values, Trace and Toxic Metals in Commonly Consumed Frozen Fish in Nigeria. American Journal of Food Technology 7: 34-42.
23. Bako HY, Mohammad JS, Waziri PM, Bulus T, Gwarzo MY, et al. (2014) Lipid profile of Alloxan-induced diabetic Wistar Rats treated with Methanolic extract of Adansonia digitata fruit pulp. Sci World J 9: 19-24.
24. ISO (2013) International Organization for Standardization (ISO 3657). Animal and Vegetable fats and oils: Determination of Saponification value pp: 10.
25. Kirk RS, Sawyer R (1991) Pearson's Composition and Analysis of Foods, 9th edition. (Student edition), England: Addision Wesley Longman Ltd pp: 708.
26. Nielsen J (1994) Enhancing the explanatory power of usability heuristics. Proc ACM CHf'94 Conf. (Boston, MA, April 24-28).
27. Aurand LW, Wood AE, Wells MR (1987) Food Composition and Analysis. Van Nostrand Reinhold, New York pp: 20-23.
28. Lynch SM, Frei B (1993) Mechanisms of copper and iron dependent oxidative modification of human low-density lipoprotein. J Lipid Res 34: 1745-1751.
29. Tarladgis BG, Watts BM, Yonathan M (1960) Distillation method for the determination of malonaldehyde ın rancid foods. J Am Oil Chem Soc 37: 44-48.
30. Audley MA, Shetty KJ, Kinsella JE (1987) Isolation and properties of phosphilase A from Pollock muscle. J Food Sci 43: 1771-1775.