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# Effects of stocking density and feeding duration in cage-cum-pond-integrated system on growth performance, water quality and economic benefits of *Labeo victorianus* (Boulenger 1901) culture

**Anne Mokoro[1], Elijah Oyoo-Okoth[1,2], Charles C. Ngugi[3], James Njiru[1], Joseph Rasowo[4], Victoria Chepkirui-Boit[1] & David Manguya-Lusega[1]**

[1]Department of Fisheries and Aquatic Sciences, Moi University, P.O. Box 1125, Eldoret, Kenya
[2]Department of Aquatic Ecology and Ecotoxicology, Institute of Biodiversity and Ecosystem Dynamics, University of Amsterdam, Kruislaan 320, 1098, XH, The Netherlands
[3]Ministry of Fisheries Development, P.O. Box 58187-00200 Nairobi, Kenya
[4]School of Biological and Physical Sciences, Moi University, P.O. Box 3900 Eldoret, Kenya

**Correspondence:** E Oyoo-Okoth, Department of Fisheries and Aquatic Sciences, Moi University, P.O. Box 1125 Eldoret, Kenya. E-mail: elijaoyoo2009@yahoo.com

## Abstract

We evaluated the effect of varying cage stocking density (60, 90 and 120 fish m$^{-3}$) and feeding duration (10, 30 and 60 min) in a cage-cum-pond-integrated system on growth performance, water quality and economic benefits in *Labeo victorianus* culture. Interactions between stocking density and feeding duration significantly ($P < 0.05$) affected the fish growth performance and yields in the cages-cum-pond system. Stocking density of 60 fish m$^{-3}$ resulted in the highest growth in cages and in ponds regardless of the feeding duration, but produced lower yields than at stocking density 90 fish m$^{-3}$. The lowest Apparent Food Conversion Ratio (AFCR) in cages occurred at stocking density of 60 fish m$^{-3}$ and feeding duration of 30 min. Growth performance in the open ponds declined with increased feeding duration of the caged fish. Survival in cages and in the open ponds decreased with increased cage density, but was not affected by feeding duration. Low dissolved oxygen were recorded, at stocking density of 120 fish m$^{-3}$, the lowest DO occurred when feeding of caged fish lasted 60 min. Growth performance, water quality and economic benefits in *Labeo victorianus* culture positively respond to interaction between stocking density and feeding durations.

**Keywords:** Cages-cum-pond system, feeding duration, growth performance, *Labeo victorianus*, stocking density

## Introduction

Rearing fish in either cages or semi-intensive ponds alone may produce low yields to sustain profitability in commercial aquaculture, beside the obvious inefficient use of unit space. A management strategy based on the concept of integrating intensive and semi-intensive culture practices in cages and ponds simultaneously (cage-cum-pond-integrated system) has been suggested in an endeavour to increase unit fish production (Yi, Lin & Diana 1996; Yi & Lin 2001; Liti, Fulanda, Munguti, Straif, Waidbacher & Winkler 2005). In the system, part of the stocked fish is kept in cages, while the other part is nursed in the open water ponds. Fish in the cages are fed high protein artificial feeds (intensive part of the component), while fish in the open ponds are not fed. The uneaten artificial feed from the cage could be utilized by two different processes: direct consumption by pond fish and indirectly contributing to nutrients for natural feed after being decomposed. Therefore, the caged fish satisfy their bio-energetic needs from the cage wastes either directly as uneaten food or indirectly from natural pond productivity after decomposition (semi-intensive component). The aim is to optimize fish production per unit area (Lin, Jaiyen & Muthuwan 1989; McGinty 1991; Yi *et al.* 1996). The success of this system is dependent on the yields obtained from cages and open ponds, which is a function of food availability to fish in both cages and open ponds.

Protocols of feeding fish are currently based on the biomass or standing crop (CSC), which are determined by stocking density. Rearing fish at low densities below the carrying capacity may reduce the overall yields, while high stocking density beyond the CSC may impair the growth performance due to factors such as social interaction and deterioration of water quality, which can affect both the feed intake and conversion efficiency of the fish (Paspatis, Boujard, Maragoudaki, Blanchard & Kentouri 2003; Lupatsch, Santos, Schrama & Verreth 2010; Nhan, Wille, Hung & Sorgeloos 2010; Tolussi, HilDorf, Caneppele & Moreira 2010; Garr, Lopez, Pierce & Davis 2011). Studies have shown that optimal stocking density for obtaining the highest fish growth performance and yields depend upon the feeding regime (Zonneveld & Fadholi 1991; Lund, Steenfeldt, Herrmann & Pedersen 2011). Yet, in the cage-cum-pond-integrated system, the feed ration to be supplied is normally estimated based on the caged fish biomass (Liti *et al.* 2005) regardless of the amount of feeds that will be available to the fish in the open ponds. Moreover, feeding may be compromised for the fish in the cages and in the open ponds if the feed is available for a limited time. Performance of fish in the cages and open ponds may therefore be related to the duration of feed availability. Currently, information on the optimal duration of feeding for many species of fish stocked at various densities in ponds, cages or in the cage-cum-pond-integrated culture system is lacking. Yet, such information may be important to optimize fish growth performance in the cages and in the open ponds.

The aim of this study was to evaluate the effect of stocking density and feeding duration in a cage-cum-pond-integrated system on growth performance, survival, yields and water quality during the *Labeo victorianus* (Boulenger 1901) culture. The *L. victorianus* is a fast-growing, bottom-feeding omnivorous freshwater cyprinid endemic to Lake Victoria basin (Cadwalladr 1965; Greenwood 1966). It is a migratory species that spends most of its life in the lake and ascends the rivers to breed during the two rainy seasons, where it spawns in lateral flood pools and flooded marshland (Cadwalladr 1965). Due to its appreciated taste, it has long been the target of artisanal fishing, and has declined drastically in numbers with increasing fishing pressure. In the past, it was widely distributed in the shallow shoreline waters of Lake Victoria and its tributary rivers (Greenwood 1966), but during the course of forty years, it has gone from being the basis for the world's most important fishery of a potamodromous species (Cadwalladr 1965) to being limited to small catches at river inlets (Rutaisire & Booth 2005). This is illustrated in 204 metric tonnes of *L. victorianus* being caught between 1966 and 1967 (after the onset of the collapse), 20 tonnes between 1976 and 1977, and the species being nearly absent from catches by 1986 (Ochumba & Manyala 1992; Balirwa, Chapman, Chapman, Cowx, Geheb, Geheb, Kaufman, Lowe-McConnell, Seehausen, Wanink, Welcomme & Witte 2003). Responding to the declining stocks of this species, which is still in high market demand, the World Bank sponsorship in Kenya spearheaded by the Lake Victoria Environmental Management Project (LVEMP) is currently integrating it as an aquaculture species. Currently, few protocols for the aquaculture of this species are available (Rutaisire & Booth 2004; Oyoo-Okoth, Cherop, Ngugi, Chepkirui-Boit, Manguya-Lusega, Ani-Sabwa & Charo-Karisa 2011).

## Materials and methods

### Experimental facility

The study was conducted at Moi University, Eldoret Kenya (0°34′13.8″N and 35°18′49.8″E) at the Chepkoilel Fish Farm from June to December 2010. The cages used in this study were 3-$m^3$ floating cages consisting of a wooden frame (2 × 1.5 × 1 m) covered with a half-inch wire mesh. Each cage had a polyvinyl chloride (pvc) ring of 30 cm diameter feeding tray to prevent direct spillage of the artificial experimental feed (sinking pellets). Twenty-seven, 200 $m^2$ earthen ponds of 1.0 m depth in the shallow end and 1.5 m depth in the deeper ends, were used in this study. Liming ($CaCO_3$) was applied at 2500 kg $ha^{-1}$ to all the experimental ponds at the beginning of the experiment. Water was added weekly to the ponds to replace water loss due to seepage and evaporation.

## Experimental procedure

Broodstock of the *L. victorianus* (mean weight = 521.4 ± 34.3 g) were obtained from the Kenya Marine and Fisheries Research Institute laboratory and transferred to the hatchery at the Fish Farm. Larvae were obtained through induced breeding and semi-natural spawning. They were cultured for a period of 42 days in a hatchery. During the culture period, the larvae were fed *Artemia* nauplii. Water temperature in the hatchery was maintained at 27 ± 0.2°C using a thermostat heater. After 42 days, the juveniles were netted from the hatchery and transferred to holding net cages suspended in one pond in the fish farm and acclimatized to pond conditions for 48 hours. Mixed sex juveniles were then sorted out and randomly stocked in the experimental cages and open ponds. The stocking weights of the juveniles were 23.7 ± 2.6 g. The study applied a 3 × 3 factorial design with three stocking densities in cages (60, 90 and 120 fish $m^{-3}$ designated SD1, SD2 and SD3 respectively) and three feeding durations (10, 30 and 60 min designated T1, T2 and T3 respectively) as factors. All treatments were executed in triplicate. The open ponds were stocked with juveniles at a stocking density of 2 fish $m^2$. The fish were hand fed the sinking artificial experimental diet for 10, 30 and 60 min uninterrupted in the morning (beginning 0800 h) and in the evening (beginning 1700 h). Feed were supplied at 2.5% of the caged biomass per day (trial unpublished data). The percentage composition of the experimental diet is shown in Table 1. Fish were cultured for a period of 150 days.

Samples for monitoring fish growth and making feeding adjustments were taken every 2 weeks. A total of 20 fish were sampled from each pond and a similar number from the cages using seine and dip nets respectively and bulk weighed. Daily feed ration was calculated and adjusted after each sampling.

**Table 1** Ingredients and chemical composition (g $kg^{-1}$ as fed basis) of experimental diets used for feeding *Labeo victorianus*

| Ingredients | Percentage incorporation |
|---|---|
| Fish meal | 22.0 |
| Soybean meal | 18.8 |
| Wheat floor | 31.2 |
| Corn grain (extrusion-cooked) | 21.2 |
| Perch liver oil | 2.4 |
| Binders (Cassava) | 2.0 |
| Vitamin/mineral premix[a] | 1.2 |
| Salt (Nacl) | 1.2 |
| Chemical analysis | |
| Dry matter | 91.9 |
| Crude protein | 25.8 |
| Crude lipid | 6.0 |
| Ash | 7.2 |
| Crude fiber | 6.6 |
| NFE[b] | 46.3 |
| Gross energy (kJ $g^{-1}$)[c] | 17.6 |

[a] Commercial formula (mg premix $kg^{-1}$ diet). Uniŏn de Empresas de Piensos MINAGRI, Cuba. Vitamins: retinol, 12 500 000 IU; thiamine, 10 000 mg; riboflavin, 20 000 mg; pyridoxine, 10 00 mg; cyanocobalamine, 40 mg; ascorbic acid (Stay C), 500 000 mg; cholecalciferol, 2400 000 IU; a tocopherol, 100 000 mg; pantothenic acid, 40 000 mg; choline chloride, 1600 000 mg; folic acid, 2000 mg; nicotinic acid, 140 000 mg; biotin, 1000 mg; inositol, 300 000 mg; paraminobenzoic acid, 35 000 mg. Minerals (mg): cobalt, 200; copper, 2000; iron, 20 000; iodine, 1500; manganese, 40 000; zinc, 20 000; selenium, 100.

[b] NFE (nitrogen free extracts) = 100 − (protein% + lipid% + ash % + fiber%).

[c] GE (gross energy): calculated using conversion factors 23.0, 38.1 and 17.2 kJ $g^{-1}$ for protein, lipids and carbohydrates (Tacon 1993).

### Water quality analyses

Water samples for pond water quality analysis were taken bi-weekly from four different locations (near inlet and outlet, in the middle of the pond and close to the shore along the pond length) in each pond and within the cages, approximately two hours after morning and evening feeding using 1.12-m long column sampler (Boyd & Tucker 1992). Samples from the ponds and those from the cages were pooled separately to provide an integrated sample; then, a sub sample was drawn from the integrated sample for the analysis of the various water quality parameters. The samples were filtered through Whatman glass filter paper GF/F and analysed for total ammonia nitrogen (TAN) by the indophenol blue method and phosphate phosphorus ($PO_4$-P) by the standard ascorbic acid method. Water quality analyses were performed according to procedures adopted from the American Public Health Association (APHA 1998). Dissolved oxygen (DO) was measured *in situ* in the cages and in ponds, using a calibrated JENWAY 3405 electrochemical analyser (Barloword Scientific Ltd, Essex, United Kingdom) every day. The equipment was calibrated using de-ionized water before readings were taken.

### Calculation of growth, survival and FCR

Growth in weight of the fish was expressed as growth per day and as specific growth rate (SGR). The SGR (% body weight $day^{-1}$) was calculated using the formula (ln $(W_2)$–ln $(W_1)$)/number of days)*100 where $W_2$ and $W_1$ are weights on day $t_2$ and $t_1$ respectively. In cages, survival was estimated by checking the cages daily for dead fish, which were removed on daily basis after recording their number. The per cent survival in cages was calculated by subtracting the number of dead fish from the initial number stocked. In ponds, survival was determined at the end of the experiment by completely draining the pond and counting the remaining fish in the pond and per cent survival determined as a percentage of the stocked fish. Apparent Feed Conversion Ratio (AFCR) was calculated per cage by dividing the total feed fed by the production. On termination of the experiment, fish were harvested and yields computed for cages, open ponds and the total.

### Statistical analyses

>Before statistical analysis, normality of the data was determined using Shapiro-Wilk test, while homogeneity of variance was ascertained using Levene's test. Data on the interactions between stocking density and feeding durations on the final mean weight, SGR, survival and AFCR were analysed using Two-Way ANOVA with stocking density (60, 90 and 120 fish $m^{-3}$) and feeding durations (10, 30 and 60 min) as factors. Interactions between stocking density and feeding durations on the water quality data were analysed using repeated measures ANOVA considering sampling date/time as repeated measures factor besides the main factors. Multiple comparisons for significantly different means was performed using Tukey test. All the statistical analyses were performed using the SPSS 17.0 for Windows software package. Differences were considered significant at $P < 0.05$.

An enterprise was used to determine the revenue, costs and returns of the cage-cum-pond system under different stocking densities and feeding durations. The profitability of the enterprise was analysed using the net returns above variable costs. The break-even price was calculated using the formula

$$Break\ even\ price = \frac{Fixed\ cost\ per\ unit}{1-(Variable\ cost\ per\ unit/Seling\ Price\ per\ unit)}$$

Sensitivity analyses were used to simulate the net returns due to variation in alternative market prices and yield variability as well as to evaluate the impact of alternative prices of variable inputs (i.e. alternative costs of fingerlings, feed prices and cost of labour) on break-even prices. During sensitivity analysis, The Excel Package, What-if Analysis, 1 way and 2-Way Table were used to explore the variability of single and combined variables respectively affecting the yield variability or break-even prices accordingly.

## Results

Growth performance and feed utilization parameters for *L. victorianus* in cages and open ponds under varying treatments during the 150-day experimental period are presented in Table 2. A two-way ANOVA was conducted that examined the effect of stocking density and feeding duration on growth performance parameters (Final mean weight and SGR) (Table 3, Fig. 1). Our dependent variables, means, were normally distributed for the groups formed by the combination of the stocking density and feeding duration as assessed by the Shapiro-Wilk test. There was homogeneity of variance between groups as assessed by Levene's test for equality of error variances. There was a significant interaction between the effects of stocking density and feeding duration on final mean weight and SGR of fish in the ponds and cages ($P < 0.05$, Table 3, Fig. 1). Simple main effects analysis showed that in both the cages and the ponds, the final mean weight and SGR of fish were high at stocking density 60 fish $m^{-3}$ regardless of the feeding duration ($P < 0.05$), while at stocking density of 120 fish $m^{-3}$, the final mean weight and SGR of caged fish increased significantly ($P < 0.05$) with increasing feeding duration. In contrast to the above trends in cages, the final mean weight and SGR of fish in open ponds at stocking density 90 and 120 fish $m^{-3}$ reduced with increasing feeding durations of the caged fish.

There was no significant interaction between the effects of stocking density and feeding duration on the survival of fish in the ponds and cages ($P > 0.05$, Table 3). Simple main effects analysis showed that both in the cages and in the ponds, increased stocking density resulted in reduced survival of fish. Fish survival in cages was highest

**Table 2** Effects of interactions between stocking density and feeding duration on the growth performance parameters of *Labeo victorianus* in the ponds and cages (Means ± SEM)

| | | Final mean weight (g) | | SGR (% day$^{-1}$) | | Survival (%) | | AFCR (g consumed/g gain) in cages |
|---|---|---|---|---|---|---|---|---|
| **Stocking density** | **Feeding duration** | **Cages** | **Ponds** | **Cages** | **Ponds** | **Cages** | **Ponds** | |
| SD1 | T1 | $398.0 \pm 11.5^{e}$ | $185.2 \pm 9.8^{e}$ | $1.91 \pm 0.04^{e}$ | $1.38 \pm 0.03^{e}$ | $94.3 \pm 1.3^{c}$ | $93.4 \pm 1.1^{c}$ | $1.6 \pm 0.1^{b}$ |
| | T2 | $397.4 \pm 11.8^{e}$ | $186.2 \pm 10.2^{e}$ | $1.89 \pm 0.02^{e}$ | $1.37 \pm 0.02^{e}$ | $95.3 \pm 1.4^{c}$ | $93.5 \pm 0.7^{c}$ | $1.4 \pm 0.2^{a}$ |
| | T3 | $402.5 \pm 12.2^{e}$ | $176.2 \pm 10.1^{e}$ | $1.91 \pm 0.03^{e}$ | $1.35 \pm 0.03^{e}$ | $94.3 \pm 2.1^{c}$ | $93.4 \pm 0.7^{c}$ | $1.3 \pm 0.1^{a}$ |
| SD2 | T1 | $360.1 \pm 12.7^{d}$ | $188.2 \pm 11.7^{e}$ | $1.82 \pm 0.05^{d}$ | $1.38 \pm 0.10^{e}$ | $89.9 \pm 2.8^{b}$ | $91.2 \pm 2.4^{b}$ | $1.8 \pm 0.2^{c}$ |
| | T2 | $397.3 \pm 11.9^{e}$ | $185.9 \pm 11.9^{e}$ | $1.88 \pm 0.05^{e}$ | $1.37 \pm 0.04^{e}$ | $90.7 \pm 1.1^{a}$ | $94.5 \pm 1.1^{b}$ | $1.6 \pm 0.2^{b}$ |
| | T3 | $409.3 \pm 11.3^{f}$ | $168.4 \pm 8.9^{d}$ | $1.93 \pm 0.04^{f}$ | $1.30 \pm 0.04^{d}$ | $88.3 \pm 3.1^{ab}$ | $94.8 \pm 1.1^{c}$ | $1.4 \pm 0.1^{a}$ |
| SD3 | T1 | $205.0 \pm 13.2^{a}$ | $99.2 \pm 16.5^{c}$ | $1.43 \pm 0.04^{a}$ | $0.95 \pm 0.08^{c}$ | $85.3 \pm 5.1^{a}$ | $73.2 \pm 6.3^{a}$ | $2.5 \pm 0.4^{e}$ |
| | T2 | $237.0 \pm 13.9^{b}$ | $82.9 \pm 10.9^{b}$ | $1.55 \pm 0.05^{b}$ | $0.85 \pm 0.07^{b}$ | $84.7 \pm 4.1^{a}$ | $74.5 \pm 3.1^{a}$ | $2.0 \pm 0.2^{d}$ |
| | T3 | $242.0 \pm 10.3^{c}$ | $71.4 \pm 11.3^{a}$ | $1.61 \pm 0.03^{c}$ | $0.74 \pm 0.09^{a}$ | $86.3 \pm 5.1^{a}$ | $74.8 \pm 3.4^{a}$ | $2.1 \pm 0.4^{d}$ |

Values with different letters down the column differ significantly ($P < 0.05$) based on Two-Way ANOVA test followed by Tukey HSD test.

**Table 3** Two-Way ANOVA results showing the interactions between stocking density and feeding duration on the growth performance parameters of *Labeo victorianus* in the ponds and cages

| | Final mean weight (g) | | | | SGR (% day$^{-1}$) | | | | Survival (%) | | | | AFCR (g consumed/ g gain) in cages | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cages | | Ponds | | Cages | | Ponds | | Cages | | Ponds | | Cages | |
| **Treatments** | **F** | ***P*-value** | **F** | ***P*-value** | **F** | ***P*-value** | **F** | ***P*-value** | **F** | ***P*-value** | **F** | ***P*-value** | **F** | ***P*-value** |
| Interaction | | | | | | | | | | | | | | |
| Stocking density × feeding duration | 4.555 | 0.010 | 4.243 | 0.012 | 4.079 | 0.016 | 2.563 | 0.042 | 0.729 | 0.492 | 0.979 | 0.314 | 5.144 | 0.015 |
| Main effects | | | | | | | | | | | | | | |
| Stocking density | 588.912 | 0.000 | 155.284 | 0.000 | 424.180 | 0.000 | 450.842 | 0.000 | 5.217 | 0.024 | 5.146 | 0.022 | 12.115 | 0.007 |
| Feeding duration | 45.999 | 0.000 | 8.061 | 0.002 | 15.728 | 0.000 | 10.264 | 0.001 | 1.134 | 0.424 | 2.147 | 0.314 | 13.192 | 0.008 |

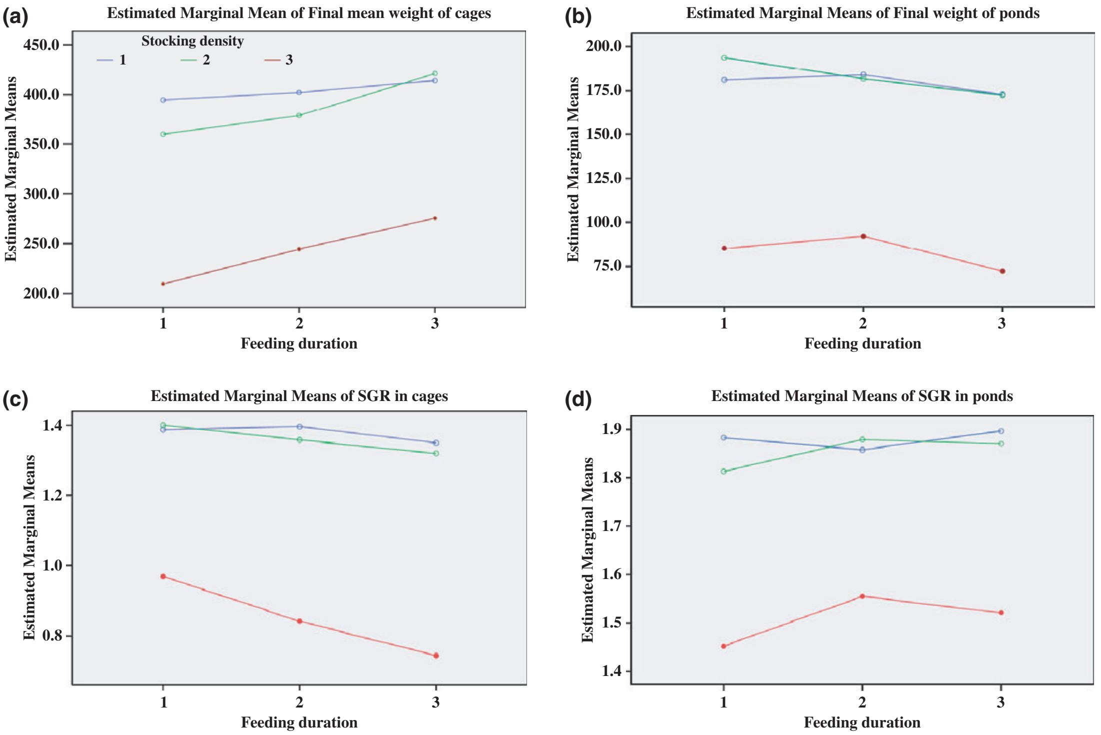

**Figure 1** Interactions between stocking density and feeding duration on the marginal means of the growth parameters in cages (left panel) and ponds (right panel).

(>94%) at stocking density of 60 fish m$^{-3}$ and reduced to about 85% in cages stocked at a density of 120 fish m$^{-3}$. Similar trends in survival were discerned for fish stocked in open water, although the lowest survival was 73% at a stocking density of 120 fish m$^{-3}$.

The AFCR was also significantly ($P < 0.05$) affected by the interaction between the stocking density and feeding durations (Tables 2 and 3). The lowest AFCR in cages occurred in fish stocked at 60 fish m$^{-3}$ when feeding lasted 30 and 60 min. However, the highest AFCR in caged fish occurred when stocking density was 120 fish m$^{-3}$ and feeding done for 10 min.

Water quality data in the cages and open ponds are presented in Table 4. A repeated-measure ANOVA conducted to examine the effect of stocking density and feeding duration on water quality parameters is shown in Table 5. Generally, the concentration of DO and TAN was higher in the cages than in the ponds, while $PO_4$-P did not demonstrate any significant differences between the ponds and cages as well as among treatments ($P > 0.05$). Furthermore, the concentration of DO in the cages and ponds demonstrated significant ($P < 0.05$) interaction effects between stocking densities and feeding durations ($P < 0.05$). The DO in cages and ponds reduced at each stocking density when the feeding duration was increased. TAN increased in the ponds and in the cages with increased stocking density, but remained unaffected by changes in the feeding durations.

Yield of fish in the cage-cum-pond-integrated system and the enterprise budget for different treatments is provided in Table 6. Increased feeding durations had no effect on the yields obtained from the cages and the open ponds at stocking density of 60 fish m$^{-3}$. Total yields were higher in treatment with stocking density of 90 fish m$^{-3}$ albeit at this stocking density total yields increased in response to increased feeding durations. The lowest total fish yields occurred in treatments with stocking density of 120 fish m$^{-3}$. The total investment and operational costs increased due to increasing stocking density and feeding durations. Net returns above both the total cost (TC) and total variable cost (TVC) were significantly better in fish reared at density of 90 fish m$^{-3}$, although

**Table 4** Effects of interactions between stocking density and feeding duration on water quality parameters of *Labeo victorianus* in the ponds and cages (Means ± SEM). Values with different letters down the column differ significantly ($P < 0.05$) based on Repeated measure ANOVA test followed by Tukey test

| Stocking density | Feeding duration | DO (mg $L^{-1}$)1 | | TAN (mg $L^{-1}$)2 | | $PO_4$-P (mg $L^{-1}$)3 | |
|---|---|---|---|---|---|---|---|
| | | Cages | Ponds | Cages | Ponds | Cages | Ponds |
| SD1 | T1 | $5.6 \pm 0.3^f$ | $5.1 \pm 0.1^g$ | $0.32 \pm 0.03^a$ | $0.25 \pm 0.02^a$ | 0.22 ± 0.03 | 0.22 ± 0.04 |
| | T2 | $5.2 \pm 0.2^e$ | $4.1 \pm 0.2^f$ | $0.33 \pm 0.03^a$ | $0.24 \pm 0.02^a$ | 0.23 ± 0.04 | 0.23 ± 0.03 |
| | T3 | $5.0 \pm 0.3^e$ | $3.5 \pm 0.2^e$ | $0.34 \pm 0.02^a$ | $0.23 \pm 0.03^a$ | 0.21 ± 0.06 | 0.22 ± 0.05 |
| SD2 | T1 | $4.8 \pm 0.2^e$ | $3.4 \pm 0.2^e$ | $0.52 \pm 0.05^b$ | $0.45 \pm 0.02^b$ | 0.19 ± 0.09 | 0.20 ± 0.08 |
| | T2 | $4.2 \pm 0.2^d$ | $3.3 \pm 0.2^e$ | $0.60 \pm 0.05^c$ | $0.46 \pm 0.01^b$ | 0.21 ± 0.07 | 0.20 ± 0.05 |
| | T3 | $4.0 \pm 0.1^d$ | $2.9 \pm 0.1^d$ | $0.60 \pm 0.06^c$ | $0.46 \pm 0.03^b$ | 0.21 ± 0.05 | 0.21 ± 0.04 |
| SD3 | T1 | $3.6 \pm 0.2^c$ | $2.5 \pm 0.1^c$ | $1.16 \pm 0.02^e$ | $0.73 \pm 0.02^c$ | 0.22 ± 0.04 | 0.22 ± 0.05 |
| | T2 | $3.1 \pm 0.1^b$ | $2.1 \pm 0.1^b$ | $0.95 \pm 0.02^d$ | $0.70 \pm 0.03^c$ | 0.23 ± 0.07 | 0.22 ± 0.07 |
| | T3 | $2.3 \pm 0.1^a$ | $1.7 \pm 0.1^a$ | $0.92 \pm 0.05^d$ | $0.75 \pm 0.04^d$ | 0.18 ± 0.09 | 0.19 ± 0.08 |

Means with the same letters as superscripts down the column are not significantly different ($P > 0.05$).

[1] DO = Dissolved oxygen.

[2] TAN = Total ammonia nitrogen.

[3] SRP = Soluble reactive phosphorus.

**Table 5** Repeated measure ANOVA results showing the interactions between stocking density and feeding duration on the water quality parameters of *Labeo victorianus* in the ponds and cages

| Treatments | DO (mg $L^{-1}$)[1] | | | | TAN (mg $L^{-1}$)[2] | | | | $PO_4$-P (mg $L^{-1}$)[3] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cages | | Ponds | | Cages | | Ponds | | Cages | | Ponds | |
| | F | *P*-value | F | *P*-value | F | *P*-value | F | *P*-value | F | *P*-value | F | *P*-value |
| Interaction | | | | | | | | | | | | |
| Stocking density×feeding duration | 4.655 | 0.032 | 5.233 | 0.027 | 1.223 | 0.243 | 1.433 | 0.156 | 0.534 | 0.734 | 0.923 | 0.512 |
| Main effects (P-value) | | | | | | | | | | | | |
| Stocking biomass | 15.422 | 0.000 | 19.76 | 0.000 | 6.798 | 0.001 | 13.564 | 0.000 | 1.132 | 0.327 | 1.344 | 0.399 |
| Feeding duration | 8.224 | 0.003 | 21.123 | 0.000 | 3.122 | 0.093 | 1.567 | 0.126 | 0.562 | 0.576 | 0.996 | 0.501 |

[1] Dissolved oxygen.

[2] Total ammonia nitrogen.

[3] Phosphate phosphorus.

the highest net returns occurred at stocking density 90 fish $m^{-3}$ at feeding duration of 30 min. At a stocking density of 60 fish $m^{-3}$, net returns above TVC and TC decreased with increasing feeding duration. There were negative net returns above TVC at stocking density of 120 fish $m^{-3}$. Break-even price at stocking density 60 fish $m^{-3}$ and 90 fish $m^{-3}$ was below the selling price of fish locally (US $ 2.2); however, at stocking density of 120 fish m−3, the investment posted negative returns at a selling price of US $ 2.2.

Figure 2 indicates how various market prices could affect the net returns of alternative production levels. For the range of market prices given, production below 5 tonnes $ha^{-1}$ $year^{-1}$ does not appear to be profitable unless the market price of *Labeo* is US $ 2.5. Conversely, a production of 50 000 tonnes ha−1 year−1 operations appears to show a profit throughout most of the range of market prices, and the magnitude of the potential profits is relatively large. The results of sensitivity analysis of the break-even prices due to alternative pricing of single variable inputs are presented in Fig. 3. The farmers can still operate profitably when the cost of feeds, fingerlings and labour is increased by 60%, 240% and 120% respectively.

**Table 6** Enterprise budget (in US $) of different stocking densities and feeding durations of *Labeo victorianus* in a cage-cum-pond-integrated system

| Parameters | Unit | SD1T1 | SD1T2 | SD1T3 | SD2T1 | SD2T2 | SD2T3 | SD3T1 | SD3T2 | SD3T3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Net fish yield in cages | kg $ha^{-1}$ $crop^{-1}$ | 8107 | 8180 | 8198 | 10, 489 | 11, 675 | 11, 710 | 7554 | 8672 | 9022 |
| Net fish yield in ponds | kg $ha^{-1}$ $crop^{-1}$ | 3114 | 3134 | 2962 | 3089 | 3162 | 2874 | 1307 | 1112 | 961 |
| Total fish yield | kg $ha^{-1}$ $crop^{-1}$ | 11, 220 | 11, 314 | 11, 161 | 13, 578 | 14, 838 | 14, 583 | 8861 | 9784 | 9983 |
| Unit cost of fish | US $ | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| Total Gross receipts | US $ | 24, 685 | 24, 891 | 24, 554 | 29, 872 | 32, 643 | 32, 083 | 19, 495 | 21, 524 | 21, 964 |
| Variable costs | | | | | | | | | | |
| Labeo fingerling costs | US $ | 1440 | 1440 | 1440 | 1728 | 1728 | 1728 | 1990 | 1990 | 1990 |
| Cost of feeds | US $ | 5520 | 5520 | 5520 | 5704 | 5704 | 5704 | 6348 | 6348 | 6348 |
| Field labour | US $ | 2700 | 2900 | 3000 | 3100 | 3250 | 3670 | 3750 | 3900 | 4250 |
| Cost of equipment | US $ | 1000 | 1000 | 1000 | 1200 | 1200 | 1200 | 1500 | 1500 | 1500 |
| Transport cost to the market | US $ | 1000 | 1000 | 1000 | 1100 | 1100 | 1100 | 1300 | 1300 | 1300 |
| DAP | US $ | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| Urea | US $ | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 |
| Agricultural lime | US $ | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| Miscellaneous | US $ | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 |
| Sub-total variable costs | US $ | 14, 510 | 14, 710 | 14, 810 | 15, 682 | 15, 832 | 16, 252 | 17, 738 | 17, 888 | 18, 238 |
| Interest on operating cost | US $ | 1741 | 1765 | 1777 | 1882 | 1900 | 1950 | 2129 | 2147 | 2189 |
| Total variable cost (TVC) | US $ | 16251 | 16475 | 16587 | 17564 | 17732 | 18202 | 19867 | 20035 | 20427 |
| Fixed costs | | | | | | | | | | |
| Amortization | US $ | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 |
| Interest on fixed cost | US $ | 540 | 540 | 540 | 540 | 540 | 540 | 540 | 540 | 540 |
| Total fixed cost | US $ | 3540 | 3540 | 3540 | 3540 | 3540 | 3540 | 3540 | 3540 | 3540 |
| Total cost (TC) | US $ | 19, 791 | 20, 015 | 20, 127 | 21, 104 | 21, 272 | 21, 742 | 23, 407 | 23, 575 | 23, 967 |
| Net returns above TVC | US $ | 8434 | 8416 | 7966 | 12309 | 14911 | 13881 | –372 | 1489 | 1537 |
| Net returns above TC | US $ | 4894 | 4876 | 4426 | 8769 | 11371 | 10341 | –3912 | –2051 | –2003 |
| Break-even price | US $ | 0.92 | 0.93 | 0.98 | 0.63 | 0.52 | 0.56 | –20.94 | 5.23 | 5.07 |

Major budget assumptions: Interest rates on fixed cost = 18%.

Production assumption: Stock advanced fingerlings to grow out in one season per year.

Marketing assumption: Sell in the round in wholesale markets hauling in a pickup bed.

Land assumption: Own the land no other economic use only land charge for property taxes.

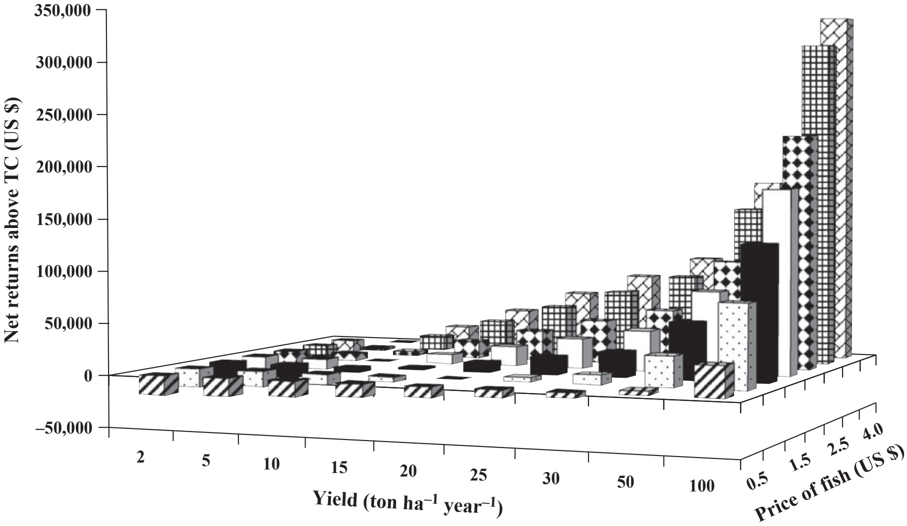

**Figure 2** Sensitivity analysis of net returns due to variations in the alternative market prices and yield variability.

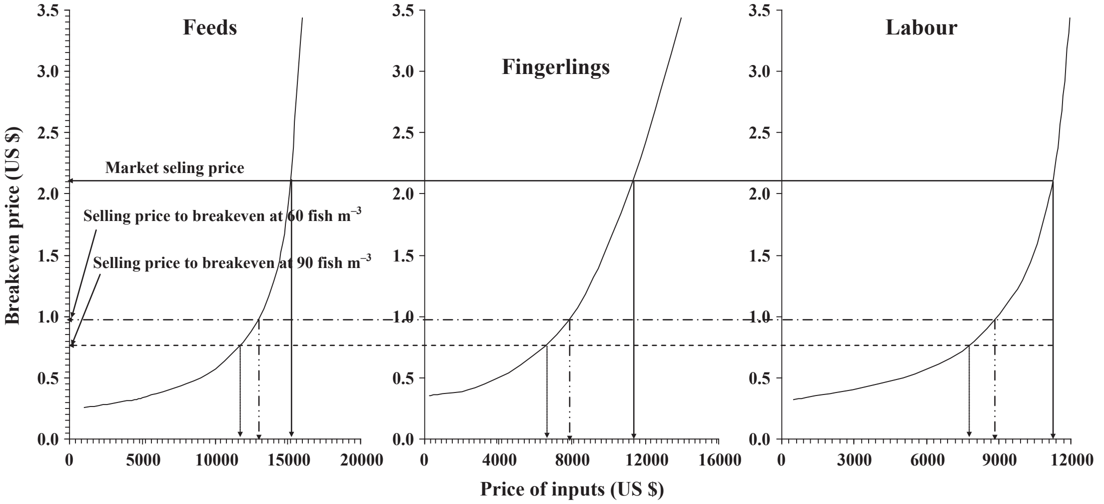

**Figure 3** Sensitivity analysis of the projected breakeven prices to alternative prices of single variable inputs of production.

We also simulated the changes in break-even price when two variable inputs increased simultaneously (Table 7). For the operations which have break-even prices at market selling price of US $ 2.20, there are many combinations of feed, fingerling and labour prices, which yield break-even prices lower than fish selling price of US $ 2.20.

## Discussion

In this study, the final mean weight of caged *L. victorianus* ranged from 200 to 450 g, while those in the pond ranged between 70 and 220 g after 150 days of culture. To the best of our knowledge, no study is available reporting on the final mean weights of *L. victorianus* in cages and in the ponds. However, mean weights of up to 450 g in cages are higher than those obtained for Nile tilapia in the same environment (e.g. Liti *et al.* 2005; Waidbacher, Liti, Fungomeli, Mbaluka, Munguti & Straif 2006). The interaction between stocking density and feeding duration was found to affect the growth performance of fish. Highest total fish performance in terms of final mean weight and SGR was achieved in cage treatments having stocking density of 90 fish $m^{-3}$ and the growth performance increased with increasing feeding duration. At stocking density of 60 fish $m^{-3}$, feeding duration did not affect fish growth in both the cages and ponds probably because the caged fish and fish in the open ponds fed to satiation as food was not limiting. Growth of fish in pond-cage-integrated system has been positively correlated with the amounts of uneaten feeds generated from the cages (Yi & Lin 2001; Liti *et al.* 2005). The improved growth performance of caged fish at longer feeding duration could be due to longer availability of the feeds in the cage water column that allowed fish to feed to satiation before the pellets sank down to the open pond. At a stocking density of 120 fish $m^{-3}$, growth of caged fish was generally low regardless of the feeding duration, probably due to constraints in space and increased competition for supplied feed by the fish. In addition, it has been suggested that high densities impair visual location of food and prevent physical access by making it difficult for fish to follow a trajectory towards the feed pellets (Paspatis *et al.* 2003).

The interaction between stocking density and feeding duration did not affect fish survival. However, survival of fish in cages and in the open ponds decreased with increasing stocking density, being lowest at stocking density of 120 fish $m^{-3}$. The survival was not significantly affected by feeding duration, suggesting that fish responded to changes in stocking density rather than feeding duration. High mortality in fish at high stocking density has been reported for many species of fish and is due to limitation of space, increased stress levels due to higher social interactions, reduction in water quality due to increased metabolic waste products as well as reduced feed intake efficiency (Merino, Piedrahita & Conklin 2007; Lupatsch

**Table 7** Sensitivity analysis of break-even price to alternative prices of variable inputs. All prices are in US $

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (a) Break-even to alternative fingerling prices and feed costs | | | | | | | | | | |
| | Cost of fingerlings | | | | | | | | | |
| Fees price | | 0.21 | 0.21 | 0.22 | 0.22 | 0.23 | 0.23 | 0.24 | 0.26 | 0.41 |
| 1000 | 0.22 | 0.22 | 0.23 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.46 | |
| 2000 | 0.24 | 0.25 | 0.26 | 0.26 | 0.27 | 0.28 | 0.29 | 0.32 | 0.58 | |
| 4000 | 0.30 | 0.30 | 0.32 | 0.33 | 0.34 | 0.36 | 0.37 | 0.41 | 1.32 | |
| 7000 | 0.38 | 0.39 | 0.41 | 0.43 | 0.46 | 0.48 | 0.51 | 0.58 | 4.01 | |
| 10, 000 | 0.47 | 0.48 | 0.51 | 0.55 | 0.58 | 0.63 | 0.68 | 0.82 | 4.21 | |
| 12, 000 | 0.71 | 0.74 | 0.82 | 0.91 | 1.02 | 1.17 | 1.36 | 2.03 | 9.03 | |
| 15, 000 | 0.21 | 0.21 | 0.22 | 0.22 | 0.23 | 0.23 | 0.24 | 0.26 | 20.41 | |
| (b) Break-even to alternative fingerlings prices and field labour | | | | | | | | | | |
| | Cost of fingerlings | | | | | | | | | |
| | | 250 | 500 | 1,000 | 1,500 | 2,000 | 2,500 | 3,000 | 4,000 | 5,000 |
| Cost of labour | 1000 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 | 0.35 | 0.38 |
| 2000 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 | 0.33 | 0.35 | 0.38 | 0.42 | |
| 4000 | 0.32 | 0.33 | 0.35 | 0.36 | 0.38 | 0.40 | 0.42 | 0.46 | 0.52 | |
| 8000 | 0.48 | 0.49 | 0.52 | 0.56 | 0.60 | 0.64 | 0.70 | 0.84 | 1.06 | |
| 12, 000 | 0.88 | 0.93 | 1.06 | 1.21 | 1.42 | 1.72 | 2.17 | 4.59 | 39.00 | |
| 15, 000 | 2.50 | 2.95 | 4.59 | 10.41 | 39.00 | 56.79 | 73.72 | 91.95 | 101.32 | |
| (c) Break-even to alternative feed prices and field labour | | | | | | | | | | |
| | Cost of feeds | | | | | | | | | |
| | | 1000 | 2000 | 4000 | 7000 | 10, 000 | 12, 000 | 15, 000 | 20, 000 | 25, 000 |
| Cost of labour | 1000 | 0.20 | 0.21 | 0.24 | 0.29 | 0.36 | 0.44 | 0.65 | 3.17 | 6.11 |
| 2000 | 0.21 | 0.22 | 0.25 | 0.31 | 0.40 | 0.50 | 0.78 | 13.85 | 20.87 | |
| 4000 | 0.24 | 0.25 | 0.29 | 0.36 | 0.50 | 0.65 | 1.25 | 2.41 | 6.61 | |
| 8000 | 0.31 | 0.33 | 0.40 | 0.56 | 0.96 | 1.79 | 5.84 | 10.72 | 16.38 | |
| 12, 000 | 0.44 | 0.50 | 0.65 | 1.25 | 13.85 | 22.41 | 30.87 | 40.42 | 56.28 | |
| 15, 000 | 0.65 | 0.78 | 1.25 | 13.85 | 21.52 | 30.87 | 40.53 | 50.32 | 70.23 | |

*et al.* 2010; Tolussi *et al.* 2010). The observed reduction in fish survival at high density suggests negative growth response of *L. victorianus* to increased densities beyond the critical standing crop.

The interactions between the stocking density and feeding duration affected the DO concentration. This may suggest that DO is depleted in water due to respiration of fish and decomposition of the feeds.The high concentration DO in cages and in the ponds stocked at a density of 120 fish $m^{-3}$ could be due to respiration and excretion of high quantity of nitrogenous wastes by large number of stocked fish (Boyd 1982, 1990) in a limited unit space. Indeed, increased stocking density has been reported to result in reduced water circulation in the cages, which eventually lowers dissolved oxygen (Yi & Lin 2001). Any uneaten feeds could exacerbate the water quality problems in the cages and in open ponds. This is because uneaten feeds normally decompose to yield higher amounts of urea or ammonia metabolic waste products, which could affect the TAN in the culture units (Boyd 1982). The interaction between stocking density and feeding duration did not significantly affect TAN. However, TAN was affected by variation in the stocking density but not due to variation in feeding duration. Any uneaten feed may exacerbate water quality problems because they normally decompose to yield higher amounts of urea or ammonia metabolic waste products, which affect the TAN in the culture units (Boyd 1982, 1990). Although water quality for culturing *L. victorianus* remained unknown, the water quality parameters at stocking density 60 and 90 fish $m^{-3}$ were within the culture ranges of most warm water species of fish e.g. tilapia and catfish (Boyd 1990, 1998; Walker 1994), while at stocking density of 120 fish $m^{-3}$, most of the water quality parameters were beyond the ranges for culture of most warm water species of fish and therefore unfavourable. These results suggest that stocking at 120 fish $m^{-3}$ results in negative water quality on the fish under culture.

Highest total fish yield was achieved in treatments with stocking density 90 fish $m^{-3}$ and the yield increased with increasing feeding duration. At this density, highest yield was accounted for by the better yields obtained from the cages. Higher resident time of food for the caged fish could explain the increased yields due to increasing feeding duration as already noted. In this study, the total investment and operational costs were affected by stocking density and feeding duration in the culture units. For all treatments, net returns above both the TC and TVC were significantly better in fish reared at 90 fish $m^{-3}$, but were the best at a feeding duration of 30 min. At the lower rearing density of 60 fish $m^{-3}$, net returns above TVC and TC reduced with increasing feeding duration due to lower economic return from the fish associated with reduced harvest weight of fish. Economic returns at 120 fish $m^{-3}$ were lower than at 90 and 60 fish $m^{-3}$ probably due to high feed costs, low survival and poor growth response. The enterprise budget analysis of diets in the present study indicated that it is economically feasible to culture *L. victorianus* in a cage-cum-pond system when moderate levels of cage stocking density (90 fish $m^{-3}$) and feeding duration of 30–60 min are used.

We also performed sensitivity analysis, which involves the use in the budget of alternative assumptions or values for market prices and production costs to calculate and assess their impacts on yield, total costs, break-even price, or net returns. Sensitivity analysis of net returns and alternative production levels revealed that over the range of market prices explored, net returns are typically negative for low scale of operations and positive for higher scale of operations. Sensitivity analysis of break-even prices for alternative of budget item values showed that increase in price of feeds had the greatest impacts on the break-even prices than fingerlings and labour. This corroborates the findings of several other researchers (De Silva 1992; Shang 1992; Chamberlain & Hopkins 1995; Madu, Sogbesan & Ibiyo 2003). Sensitivity analysis also suggests that varying the feed price can cause substantial changes in the break-even price, about twofold the impact of a similar change in fingerling price and labour costs respectively. When several key items from the budgets were varied to determine their impacts on break-even prices, the results suggested that several combinations of outputs would still be profitable. There are a few potentially profitable combinations for the marginally feasible, cage-cum-pond operation. Larger size of operation seems to enjoy economies of scale leading to reduction in the break-even cost of producing *L. victorianus* by spreading the operating cost over each marketable fish. Our results suggest that to reap economic benefits in *L. victorianus* culture, farmers must be able to operate at low input prices to maximize net returns and operate at low break-even prices.

In conclusion, we demonstrated that the growth performance, yield and economic return of *L. victorianus* were significantly affected by the interactions between stocking density and feeding duration. At low stocking density (60 fish $m^{-3}$), feeding duration had no impact on growth performance, survival, yields and water quality. At a stocking density of 90 fish $m^{-3}$, increasing feeding duration resulted in increased growth performance and yield from cages with growth performance and yields in open ponds, which optimized economic benefits from the cage-cum-pond-integrated system. This study concludes that for optimal production in a cage-cum-pond-integrated culture system to be achieved, stocking density of 90 fish $m^{-3}$ and feeding duration of 30–60 min should be considered.

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## References

APHA (American Public Health Association). (1998) *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association. Washington D.C.

Balirwa J.S., Chapman C.A., Chapman L.J., Cowx I.G., Geheb I.G., Geheb K., Kaufman L., Lowe-McConnell R.H., Seehausen O., Wanink J.H., Welcomme R.L. & Witte F. (2003) Biodiversity and fishery sustainability in the Lake Victoria Basin: an unexpected marriage? *BioScience* **53**, 703–715.

Boyd C.E. (1982) *Water Quality Management for Pond Fish Culture*. Elsevier, The Netherlands, 318 pp.

Boyd C.E. (1990) *Water Quality for Ponds in Aquaculture*. Birmingham Publishing Company, Birmingham, AL, USA, 62 pp.

Boyd C.E. (1998) *Water Quality for Pond Aquaculture. Research and Development Series No. 43*. International Center for Aquaculture and Aquatic Environments, Alabama Agricultural Experiment Station, Auburn University, Alabama.

Boyd C.E. & Tucker C.S. (1992) *Water Quality and Pond Soil Analysis for Aquaculture. Alabama Agricultural Experiment Station*. Auburn University, AL. Birmingham Publishing, p 482.

Cadwalladr D.A. (1965) The decline in the *Labeo victorianus* (Boulenger) (Pisces: Cyprinidae) fishery of Lake Victoria and an associated deterioration in some indigenous fishing methods in the Nzoia river, Kenya. *East African Agricultural Forestry Journal* **30**, 249–256.

Chamberlain G.W. & Hopkins J.S. (1995) Reducing water use and feed cost in intensive ponds. *World Aquaculture* **25**, 29–32.

De Silva S.S. (1992) Supplementary feeding in semi-intensive aquacultue systems. In: *Farm Made Aquafeeds*. Proceedings of the FAO/AADCP. Regional Expert econsultation on on-farm aquafeeds, (ed. by M.B. New, A.G.J. Tacon & I. Csavas), pp 24–60, 14–18 December 1992, Bangkok, Thailand FAO-RAPA/AADCP, Bangkok, Thailand, 434 pp..

Garr A.L., Lopez H., Pierce R. & Davis M. (2011) The effect of stocking density and diet on the growth and survival of cultured Florida apple snails, *Pomacea paludosa*. *Aquaculture* **311**, 139–145.

Greenwood P.H. (1966) *The Fishes of Uganda*. The Uganda SocietyKampala.

Lin C.K., Jaiyen K. & Muthuwan V. (1989) Integration of intensive and semi-intensive aquaculture: concept and example. *Thai Fishery Gazette* **43**, 425–430.

Liti D.M., Fulanda B., Munguti J.M., Straif M., Waidbacher H. & Winkler G. (2005) Effects of open-pond density and caged biomass of Nile Tilapia (*Oreochromis niloticus* L.) on growth, feed utilization, economic returns and water quality in fertilized ponds. *Aquaculture Research* **36**, 1535–1543.

Lund I., Steenfeldt S.J., Herrmann B. & Pedersen P.B. (2011) Feed intake as explanation for density related growth differences of common sole Solea solea. *Aquaculture Research*. In Press. doi:10.1111/j.1365-2109.2011.03040.x

Lupatsch I., Santos G.A., Schrama J.W. & Verreth J.A.J. (2010) Effect of stocking density and feeding level on energy expenditure and stress responsiveness in European sea bass *Dicentrarchus labrax*. *Aquaculture* **298**, 245–250.

Madu C.T., Sogbesan A.O. & Ibiyo L.M.O. (2003) Some non-conventional fish feed resources in Nigeria. In: *National Workshop on Fish Feed and Feeding Practice in Aquaculture* (ed. by A.A. Eyo), pp. 73–83. Published by FISON, NIFFR, FAO-NSPFS, Nigeria.

McGinty A.S. (1991) Tilapia production in cages: effects of cage size and number of noncaged fish. *Progressive Fish-Culturist* **53**, 246–249.

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

Nhan D.T., Wille M., Hung L.T. & Sorgeloos P. (2010) Effects of larval stocking density and feeding regime on larval rearing of giant freshwater prawn (*Macrobrachium rosenbergii*). *Aquaculture* **300**, 80–86.

Ochumba P.B.O. & Manyala J.O. (1992) Distribution of fishes along the Sondu-Miriu River of Lake Victoria, Kenya with special reference to upstream migration, biology and yield. *Aquaculture and Fisheries Management* **23**, 701–719.

Oyoo-Okoth E., Cherop L., Ngugi C.C., Chepkirui-Boit V., Manguya-Lusega D., Ani-Sabwa J. & Charo-Karisa H. (2011) Survival and physiological response of *Labeo victorianus* (Pisces: Cyprinidae, Boulenger 1901) juveniles to transport stress under a salinity gradient. *Aquaculture* **319**, 226–231.

Paspatis M., Boujard T., Maragoudaki D., Blanchard G. & Kentouri M. (2003) Do stocking density and feed reward level affect growth and feeding of self-fed juvenile European sea bass? *Aquaculture* **216**, 103–113.

Rutaisire J. & Booth A.J. (2004) Induced ovulation, spawning, egg incubation, and hatching of the cyprinid fish *Labeo victorianus* in captivity. *Journal of World Aquaculture Society* **35**, 383–391.

Rutaisire J. & Booth A.J. (2005) Reproductive biology of ningu, *Labeo victorianus* (Pisces: Cyprinidae), in the Kagera and Sio Rivers, Uganda. *Environmental Biology of Fishes* **73**, 153–162.

Shang Y.C. (1992) The role of aquaculture in the world fisheries. Presented at the World Fisheries Congress at Athens, Greece, 3–8 May, 1992, 30 pp.

Tacon A.G.J. (1993) *Feed Ingredients for Warmwater Fish: Fish Meal and Other Processed Feedstuffs*. FAO Fish Circ. No. 856, FAO, Rome, Italy.

Tolussi C.E., HilDorf A.W.S., Caneppele D. & Moreira R.G. (2010) The effects of stocking density in physiological parameters and growth of the endangered teleost species piabanha, *Brycon insignis* (Steindachner, 1877). *Aquaculture* **310**, 221–228.

Waidbacher H., Liti D., Fungomeli M., Mbaluka R.K., Munguti J. & Straif M. (2006) Influence of pond fertilization and feeding rate on growth performance, economic returns and water quality in a small-scale cage-cum-pond integrated system for production of Nile tilapia (*Oreochromis niloticus* L.). *Aquaculture Research* **37**, 594–600.

Walker T. (1994) *Pond Water Quality Management: A Farmer's Handbook*. Turtle Press Pty Ltd, Tas, Australia.

Yi Y. & Lin C.K. (2001) Effects of biomass of caged Nile tilapia (*Oreochromis niloticus*) and aeration on the growth and yields in an integrated cage cum-pond system. *Aquaculture* **195**, 253–267.

Yi Y., Lin C.K. & Diana J.S. (1996) Effects of stocking densities on growth of caged Nile tilapia (*Oreochromis niloticus*) and on yield of small tilapia in open pond water in earthen ponds. *Aquaculture* **146**, 205–215.

Zonneveld N. & Fadholi R. (1991) Feed intake and growth of red tilapia at different stocking density in ponds in Indonesia. *Aquaculture* **99**, 83–94.