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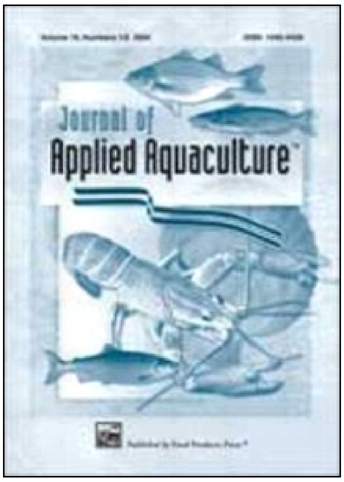

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Production Parameters and Economics of Small-Scale Tilapia Cage Aquaculture in the Volta Lake, Ghana

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To calculate the potential for cage aquaculture to create economic opportunities for small-scale investors on the Volta Lake, Ghana, a local NGO with technical support from the Government of Ghana ran two trials (one of four and one of six units) of small-scale cage aquaculture in the town of Dzemeni. Cages were built locally from available materials at a cost of approximately US$1000 per 48 m^3 cage. An indigenous line of Nile tilapia, Oreochromis niloticus*, was stocked either as mixed sex (first trial) or all-males (second trial) at an average rate of 103 fish/m^3 and grown on locally available pelleted feeds for approximately six months. Total costs averaged US$2038 per six-month production cycle. Gross yield ranged from 232 to 1176 kg/cage, averaging 460 kg/cage (9.6 kg/m^3). Final average weight of mixed sex populations (253.05 ± 47.43g) was significantly less than of all-males (376.7 ± 72.30g). Likewise, percentage of fish over 300 g at harvest was significantly lower in mixed-sex (38.3%) compared to all–male (75.7%) populations. Mortality resulting primarily from poor handling during transport and stocking averaged 70% and was a major determinate of production and profitability. To break even, harvested biomass of fish needed to exceed 15 kg/m^3. At 25 kg/m^3, small-scale cage aquaculture generated a net income of US$717 per cage per six months (ROI = 30.2%) on revenues of US$3,500.*

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Water quality in the area surrounding the cages was not negatively affected by aquaculture at the scale tested (5 tons of feed per six months).

KEYWORDS freshwater, small and medium scale enterprise, locally sourced inputs

INTRODUCTION

Along the Volta Lake in Ghana, increasing population, rising unemployment, and declining value of the capture fishery are driving efforts to identify viable investment opportunities that can increase revenues and promote sustainable economic growth (Abban et al. 2006). Cage aquaculture is practiced profitably in many parts of the world, generating jobs and making substantial contributions to fish supply (Hambrey 2006). The FAO (2007) estimates that the Atlantic salmon (*Salmo salar*) cage aquaculture industry alone produces over 1.2 million MT per annum. From interviews with the major producers, current output of cage aquaculture in sub-Saharan Africa, almost all of which is Nile tilapia, *Oreochromis niloticus*, can be estimated at about 5500 MT per annum, mostly from relatively large-scale projects in Ghana, Malawi, Uganda and Zimbabwe.

The Volta Lake is a reservoir on the Volta River created by the construction of the Akosombo Dam, completed in 1964. Temperature, flow rates, and water quality are generally high, while fertility of the water is relatively low, reflecting the lake's oligotrophic status (Abban & Biney 1996). The Government of Ghana has allocated 1 percent of the total surface area (8,700 km^2) of the lake to the development of cage aquaculture by (personal communication, Hon. Gladys Asmah, Ghana Minister of Fisheries, Accra, 30 March 2007). If the yields reported for cage aquaculture elsewhere in Africa—between 50 (personal communication, Patrick Blow, Lake Harvest Aquaculture, 31 October 2006) and 150 kg/m^3/9 months (personal communication, Karen Veverica, Jinja, Uganda, 21 November 2007)—can be replicated in Ghana, production from less than 100 ha of fish cages could just about match the current capture fishery output of about 90,000 MT (Asante 2006).

In Ghana, positive cash flows have been reported for medium-scale production systems that can achieve outputs of approximately 20 tonnes per month (240 TPA). The stocking, feeding, and cage construction technology piloted by these farms have proven to be generally suitable to smaller-scale investors as well and is being widely adopted in Stratum II of the Volta Lake (Figure 1) and between the Kpong and Akosombo Dams on the lower Volta River.

During the period between October 2005 and December 2007, Rural Wealth, a Ghanaian non-governmental organization (NGO), in a technical partnership with the Ghanaian Water Research Institute (WRI) and the

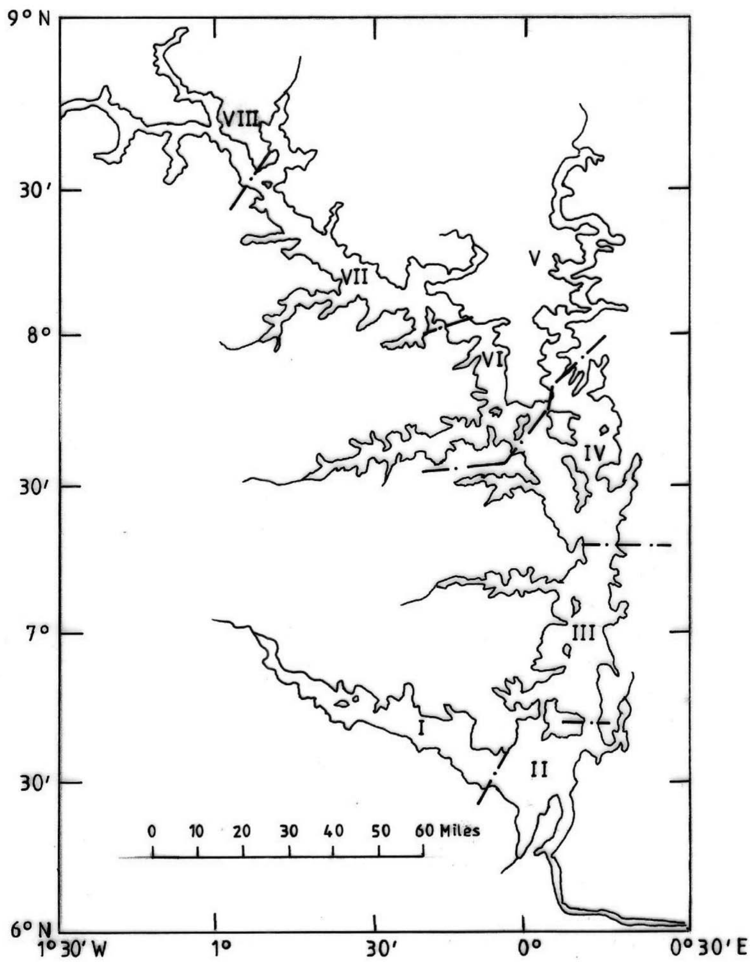

FIGURE 1 The Volta Lake indicating its management strata: I = Afram arm; II = lower main body; III = middle main body; IV = upper main body; V = Oti river arm; VI = lower Volta riverine body; VII = middle Volta riverine body; and VIII = ipper Volta riverine body (Petr & Vanderpuye 1964).

WorldFish Center, led a demonstration of small-scale cage aquaculture to identify key production constraints and technical difficulties, and test production capacity and economic viability over two six-month growout cycles.

MATERIALS & METHODS

The site (N 06° 36.150, E 000° 09.17) was in open water 0.5 km from shore, in the lee of a small-uninhabited island off of the fishing and trading community of Dzemeni, South Dayi District, Volta Region, Ghana, on the SW bank of

FIGURE 2 Small-scale cage culture installation near the fishing community of Dzemeni in the South of Lake Volta, Ghana.

the Volta Lake in Stratum II. For the first of two trials, four cages each of $6 \times 4 \times 2$ m deep (48 m^3) constructed of the typical 15-mm multifilament stretched mesh netting used in the local beach seine fishery attached to a pipe frame supported by floating plastic barrels were anchored in 8–10 m of water (Figure 2). The anchors were comprised of four 0.3 m^3 concrete blocks into each of which a 6.4 mm (1/4″) iron loop was cemented and to which were tied ropes connected to each corner of the floating cage framework from which the cage was suspended. Cages were constructed entirely of locally available materials (Figure 3) at an individual cost of approximately $1000 (Table 1). For the second trial, an additional two cages were installed for a total of six (Table 2).

Mixed-sex fingerlings (first trial) and all-male fingerlings (second trial) derived from a selected line of *Oreochromis niloticus* produced at the Ghanaian Aquaculture Research and Development Centre (ARDEC) in Akosombo, and reported by WRI to grow some 10–15% faster than the local wild stock, were stocked at rates ranging from 3000 up to 9000 fish per cage (63 to 188 fish/m^3), but heavy mortalities incurred as a result of poor transport and handling and resulted in effective stocking rates of between 20 and 100 fish/m^3 with fingerlings of between 13 and 32 g (Table 2). Dead fish found floating in the cages were removed daily and recorded to give an estimate of mortalities.

Fish in cages were fed locally available (GAFCO Inc.) floating extruded pelleted aquafeed containing approximately 30% crude protein. Fish were

FIGURE 3 Pilot small-scale cage aquaculture pilot design tested at Dzemeni, Ghana, from June 2006 through December 2007. Empty 250 l plastic barrels provide floatation to a 6 × 4 × 2 m (48 m^3) 15-mm mesh net suspended from a frame of galvanized pipe bolted into welded brackets.

TABLE 1 Construction Costs for a 48 m³ Small-Scale Aquaculture Cage Manufactured from Locally Available Materials in Dzemeni, Ghana (1 USD = 0.92 Ghana ₵)

Item	Description	Quantity	Unit cost	Amount (Ghana ₵)
Galvanized pipe	1.5″–2″	12	18	216
Floats	Plastic barrel (250 l)	8	30	240
Nets	15 mm stretched mesh	40 m	4.375	175
Shackles		16	3	48
Hapa nets	40 m	0.5	100	50
Rope	10 mm	2 coils	20	20
	6 mm	1 coil	5	5
Anchors	0.3 m³	6	5	30
Welding			50	50
Cage cover net	6 m × 5 m	1	12	12
Labour		1	30	30
Total				876

fed at a declining rate of 10% down to 2% of estimated average bodyweight according to the recommendations of Hepher (1988) based on monthly average weight of a sample of at least 50 fish from each cage. The total daily ration was divided among three feedings administered by hand.

After 133 to 153 days, cages were harvested, fish graded according to size class (>300 g, 200–300 g, <200 g), counted, weighed, and sold to local fish traders. Wholesale prices varied according to size class with >300 g fish sold at Ghana Cedis ¢ 3.50 per kg (1 US$ = 1.12 ¢), 250–300 g fish sold at ¢2.80, and <200 g fish sold at ¢1.50 per kg. Production and price parameters were then compiled and tabulated to analyze the economic performance of small-scale cage culture in the lower Volta Lake.

During the first trial, water quality was monitored every two months. In an attempt to estimate the impacts of cage aquaculture on water quality,

TABLE 2A Fish Stocking, Growth, and Harvest Data for the First (Mixed Sex) of Two Pilot Nile Tilapia 48 m³ Cage Aquaculture Trials Conducted at Dzemeni in Stratum II of the Volta Lake, Ghana

	Cage 1	Cage 2	Cage 3	Cage 4
Date Stocked 2006	27/10	08/12	31/10	31/10
No. Stocked	4000	6000	7000	2780
Avg. wt at stocking (g)	13.4 ± 10.33	25.0 ± 4.14	12.9 ± 7.97	31.7 ± 15.02
Avg. wt at harvest (g)	207.5 ± 59.98	277.5 ± 42.36	219.7 ± 88.27	307.5 ± 134.19
Grow-out (days)	153	147	133	152
Biomass GR (kg/day)	2.69	9.05	7.1	4.14
No. Fish at harvest	1946	4639	1079	1647
Survival (%)	48.70	77.3	15.4	59.2
SGR*	1.79	1.64	2.13	1.49
FCR	2.64	2.50	3.51	2.97
Gross yield (kg/cage)	324.7	1175.7	247.1	402.5
Net yield (kg/cage)	270.9	1025.7	221.3	314.3

TABLE 2B Fish Stocking, Growth, and Harvest Data for the Second (All-Male) of Two Pilot Nile Tilapia 48m^3 Cage Aquaculture Trials Conducted at Dzemeni in Stratum II of the Volta Lake, Ghana

	Cage 1	Cage 2	Cage 3	Cage 4	Cage 5	Cage 6
Date Stocked 2007	31/1	6/7	7/3	31/08	18/07	7/7
No. Stocked	7500	8200	7500	9000	6000	6000
Avg. wt at stocking (g)	22.92 ± 9.75	22.88 ± 8.75	12.45 ± 4.92	12.45 ± 4.90	20.08 ± 9.32	20.13 ± 9.34
Avg. wt at harvest (g)	369.70 ±155.50	452.2 ±230.32	Net caught on bottom and torn open; Last sample 10/01/08 avg wt 318 g	Net slashed by fishers; last sample 25/10/07 avg wt 86.2 g	Poisoned by fishers; last sample 23/12/07 avg wt 284 g	308.1 ±141.23
Grow-out (days)	169	147				130
No fish at harvest	1480	523				1542
Survival (%)	20	6.4				25.7
SGR*	1.65	2.03				2.10
FCR	2.64	2.5				8.05
Gross yield (kg/cage)	324.7	232				503.4
Net yield (kg/cage)	270.94	44.38				389.68

*Specific growth rate (%/day) = ln average final weight – average initial weight/growth period (days).

sampling stations were located 10 m upstream and 30 m downstream of the cage installation. Temperature and pH were measured in the field with a temperature probe and a HACH EC 20 portable pH meter, respectively. Samples for analysis in the laboratory were collected from near the top of the water column, at mid-cage depth (1 m) and near the bottom in 300 ml plain glass bottles, kept in a cold dark box during transportation, and stored in a refrigerator until the analyses were completed. In the laboratory, electrical conductivity was measured with a Cyberscan 510 meter and turbidity was measured with a HACH 2100 P Turbidimeter. All other analyses followed standard methods (APHA/AWWA/WEF 1998): diazotization for NO_2-N; hydrazine reduction for NO_3-N; direct nesslerization for total ammonia nitrogen; stannous chloride for phosphate; and the Azide modification of Winkler for dissolved oxygen.

RESULTS

Production and growth data from the trials are shown in Table 2 and Figure 4. Two cages were sabotaged by locals and another was damaged when it became fouled with a submerged tree when the water level was low and then ripped open, releasing the fish, when the water level rose again. For those cages that survived the entire trial, gross yield ranged from 232 to 1176 kg/cage/6 months (5–25 kg/m^3), averaging 456 ± 329.5 kg/cage (9.5 kg/m^3). Overall, survival was low in all cages, averaging 29 ± 28.4% among those that were not damaged or robbed, most of which was incurred

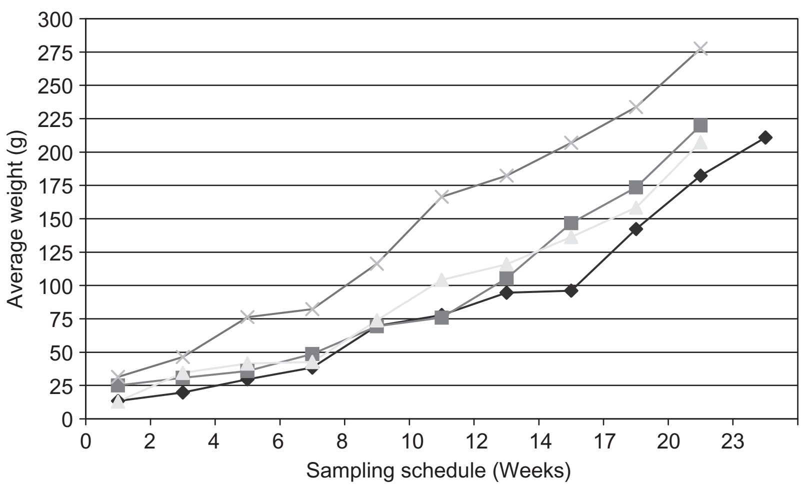

FIGURE 4A Growth pattern of mixed sex *Oreochromis niloticus* in four 48 m^3 cages in the Volta Lake, Ghana; fish stocked at approximately 40 fish/m^3 were fed a commercial diet over a culture period of six months in 2006/2007.

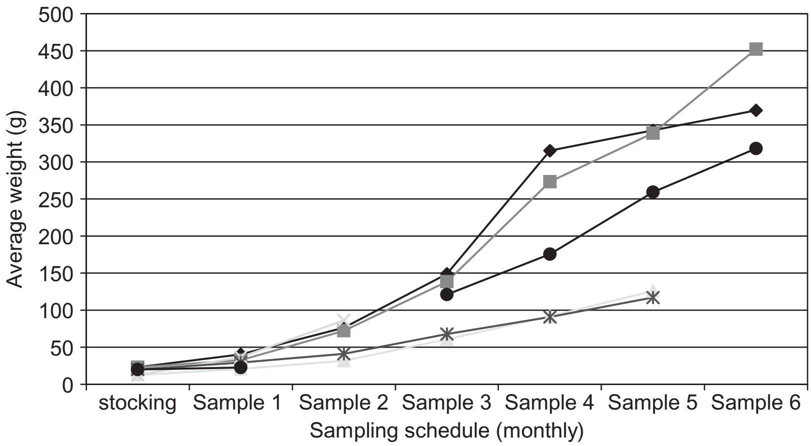

FIGURE 4B Growth pattern of all-male *Oreochromis niloticus* in six 48 m^3 cages in the Volta Lake, Ghana; fish stocked at approximately 40 fish/m^3 were fed a commercial diet over a culture period of six months in 2007. Three cages were damaged or sabotaged and harvested early.

as a result of poor fish conditioning, handling and transport during stocking. Only about 30% of the mortalities floated up and were counted, at least another 40% sank or went unnoticed.

Only the cage from which more than one tonne of fish (>96 fish weighing 24.5 kg per m^3) was harvested made a significant profit (Table 3). Food conversion ratios (FCR) were between 2.5 and 8.1 with an average of 3.54 (Table 2). Feed was the major component of cost, averaging over 50% of the total (Table 4). Fingerling purchase was another major cost, accounting for an average of 27% of the total.

The WRI Akosombo improved strain exhibited an average specific growth rate in cages of 1.83% body weight per day (Table 2), but showed significant variation in final weight at harvest, ranging between 60 and 500 g. Final weight of mixed sex populations averaged 253.05 ± 47.43 g, significantly ($P < 0.05$) less than the 376.7 ± 72.30 g achieved in the all-male populations. Likewise, percentage of fish over 300 g at harvest was

TABLE 3 Economic Analysis of Tilapia Aquaculture Cages Operated for Approximately Six Months in Stratum II of the Volta Lake (Ghana ¢; 1 US$ = 1.12 Ghanac ¢)

	Cage 1	Cage 2	Cage 3	Cage 4	Cage 5	Cage 6	Cage 10
Fixed cost*	109.5	109.5	109.5	109.5	109.5	109.5	109.5
Variable costs	1,760.76	2,700.00	2,458.70	1,468.06	1,598.0	1,867.0	1,687.0
Total cost	1,870.26	2,809.50	2,568.20	1,577.56	1,707.5	1,978.5	1,756.5
Revenue	812.82	3,527.04	741.3	1,207.50	1,136.4	812.00	1,760.1
Net Income	−1, 057.44	717.54	−1,826.90	−370.06	−574.1	−895.50	4.50

*For the cage, amortized over four years.

TABLE 4 Cost of Production, Revenue,s and Return on Investment (ROI) for a 48 m^3 Aquaculture Cage in Stratum II of the Volta Lake Stocked at a Density of 125 Fish/m^3 (77.32% Survival Rate) and Cultured for 147 Days (1 US$ = 0.92 Ghana ¢)

	Quantity	Unit Value (GH¢)	Amount (GH¢)
Cost Elements			
Cage (amortized over 4 yrs)	1/2	219.00	109.5
Fingerlings	6000	0.12	720.00
Feed	3000	0.49	1470.00
Labor (pers mos)	6	60.00	360.00
Marketing			50.00
Transportation			100.00
Total cost			**2809.50**
Revenues			
Total harvest (kg)	1176	3.00	3528
Net Income			**718.54**
ROI			**25.6%**

significantly lower in mixed-sex (38.3%) compared to all-male (75.7%) populations. Overall, small fish (<200 g) averaged 17.5 ± 19.73%, medium fish (200–300 g) averaged 27.1 ± 9.9%, and large fish (300–500 g) averaged 54.4 ± 24.1% of the harvest by weight (Table 6). The average price received from fishmongers on the shore within an hour after harvest was ¢3.14 per kg (approximately US $3.00) live weight.

Although water level varied by up to 1.2 m and flow rate was at times nearly undetectable, water quality in the vicinity of the cages (Table 5) was generally stable and remained within the limits for good tilapia growth throughout the trials (Boyd 1990). No fish deaths attributable to poor water quality were recorded. In addition, there was no obvious impact of aquaculture on water quality in the immediate vicinity of the cages (Figure 5).

DISCUSSION

Improper handling and transport of tilapia fingerlings to be stocked in the cages was the major cause of low yields and profits. Typical survival rate in small-scale tilapia cage culture is in the range of 70–80% (Mikolosek et al. 1997, De La Cruz-Del Mundo 1997), although survival as low as 60% has been associated with stocking densities in excess of 70 fish per m^2 (Yi, Kwei Lin, & Diana 1996). In a similar artisanal cage system tested in Côte d'Ivoire by Gorissen (1992), stocking mortality in 30 m^3 cages stocked with 30 g fingerlings at 100 per m^3 was only 5.2%, implying that the problems encountered at Dzemeni can be remedied with proper fish handling techniques, even under rustic conditions. Simple linear regression of the number of marketable fish at harvest against net profit ($y = 1.2x + 2521$; $R^2 = 0.54$) calculated that a farmer using a system similar to that tested at Dzemeni

TABLE 5 Mean ± Standard Deviation of Water Quality Parameters at a Fish Cage Site in Dzemeni on the Volta Lake Measured Bimonthly (n = 10) at Mid-Cage Depth (1 m) for the Period June 2006–December 2007

Temp. °C	pH	Turbidity (NTU)	Transparency (cm)	Electrical Conductivity (µS cm^{-1})	NO_2-N (mgL^{-1})	NO_3-N (mgL^{-1})	NH_4-N (mgL^{-1})	PO_4-P (mgL^{-1})	DO (mgL^{-1})
30.5 ± 1.30	7.72 ± 0.61	3.28 ± 0.57	140 ± 18.8	59.29 ± 1.627	0.008 ± 0.007	0.41 ± 0.42	0.18 ± 0.14	0.17 ± 0.11	7.90 ± 1.27

TABLE 6 Proportion of Large (>300 g), Medium (250–300 g), and Small (<250 g) Fish Obtained through Six Months of Growout in 48 m^3 Cages in the Volta Lake, Ghana

	Percentage Composition Per Cage Per Location						
Size category	Cage 1	Cage 2	Cage 3	Cage 4	Cage 5	Cage 6	Cage 7
Small	49	11	42	7	6	2	13
Medium	32	32	32	42	19	17	16
Large	19	57	26	51	75	81	71

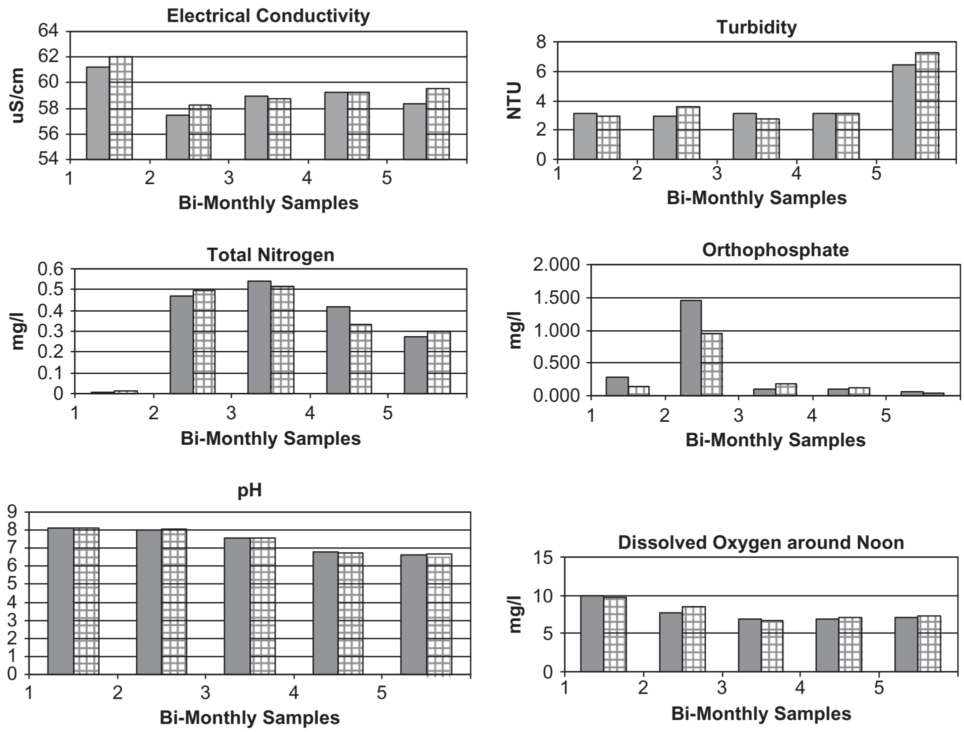

FIGURE 5 Trends in key water quality parameters sampled every eight weeks 10 m above (solid bar on the left) and 30 m below (hashed bar on right) a 192-m^3 cage aquaculture facility holding 1.83 MT of fish at final harvest.

would need to produce over 50 fish with an average weight of over 300 g per cubic meter of cage volume to break even.

Typical FCR in *O. niloticus* cage aquaculture systems in Africa is between 1.4 and 2.5 (Beveridge 2004; personal communication, Patrick Blow, Lake Harvest Aquaculture, Zimbabwe, October 2006; personal communication, Steve Murad, Tropo Farms, Ghana, November 2008; personal communication, Karen Veverica, FISH Project, Uganda, January 2009). The higher than usual FCRs realized at Dzemeni were the result of a high percentage of fines in the feed and possible variability in its proximate analysis, coupled to the ±40%

overestimation of the number of fish in each cage as a result of undetected mortality, and thus over-feeding. If the Akosombo strain of *O. niloticus* used in this study has the physiological capacity to achieve a mid-range FCR of 1.6 (Beveridge 2004), then an average of 47% of the feed inputs to the cages was wasted. At an average of 52% of total production costs, a 47% savings in feed would add an additional ¢700 to the bottom line, substantially improving the economics of the system.

In contrast to the findings of Green & Teichert-Coddington (1994), VeraCruz & Mair (1994), Mair et al. (1995), and Kamaruzzaman et al. (2009), but consistent with those of Macintosh et al. (1988), Little, Bhujel, and. Pham (2003), and personal communications with commercial cage culturists in Africa (Mark Amechi, Tropo Farms, Ghana, November 2008; Patrick Blow, Lake Harvest Aquaculture, Zimbabwe, April 2009), all-male populations performed significantly ($P < 0.05$) better than mixed sex even up to the relatively modest weight of 300 g. Taken together for purposes of business planning, the overall average specific growth rate of 1.8% body weight per day (mixed sex; virtually unlimited feed) compares favorably with the 1.5% body weight per day calculated from a range of intensive caged tilapia growout trials reported by Balarin & Haller (1982) and El-Sayed (2006), with 1.1 percent realized in low-volume/high-density cages stocked with mixed sex *O. niloticus* in Uganda (Personal Communication, Karen Veverica, FISH Project, Uganda, January 2009) and even the 2.2 percent per day for all male fish produced at Lake Harvest (personal communication, Patrick Blow, Lake Harvest Aquaculture, Zimbabwe, October 2006).

Despite the difficulties encountered, the technical feasibility of the cage culture system was successfully demonstrated. The cages proved sufficiently robust to survive most of the prevailing natural conditions in the Volta Lake. Acts of vandalism and theft are a further risk to which fish cages are sometimes subjected. Prevalence varies with the socio-cultural and economic context, governance, and the type of development, e.g., scale, equitability of benefits sharing, impacts on livelihoods of other stakeholders. If the causes can be understood, it may be possible to mitigate their impact (Beveridge 2004). According to the data collected at Dzemeni, a minimally profitable 48 m^3 small-scale cage aquaculture system in Ghana would have to produce at least 1 ton of fish at an FCR of less than 2.5. With WRI technical assistance, some 20 small-scale investors in the lower Volta River basin are at the time of writing (January 2009) applying the cage aquaculture technology tested at Dzemeni.

During the first trial, 4990 kg of feed were added to the ecosystem, with no detectable effects of cage aquaculture on water quality in the vicinity of the production site. The lack of any clear correlation between water quality parameters that might be expected to fluctuate together (e.g., dissolved oxygen and nitrogen, electrical conductivity, and turbidity) implies that external influences such as currents, localized flooding events, seasonal water level declines, and *inter alia* seem to have an overriding influence on the parameters measured at the production intensity tested. Such observations have often been made in the vicinity of small cage developments. At higher density, cages will undoubtedly have impacts on water quality, indicating the need for careful site selection and ultimately some type of zoning system for cage aquaculture in the Volta Lake and monitoring to support an adaptive management system.

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