Mitigating Environmental Impact of Cage Culture Through Integrated Cage-Cum-Cove Culture System in Tri An Reservoir of Vietnam

Eleventh Work Plan, Production System Design and Integration Research 4 (11PSDR4)
Final Report

Le Thanh Hung and Dinh The Nhan
Faculty of Fisheries
Nong Nam University
Ho Chi Minh City, Vietnam

Yang Yi
Aquaculture and Aquatic Resources Management
Asian Institute of Technology
Pathumthani, Thailand

James S. Diana and C. Kwei Lin
School of Natural Resources and Environment
University of Michigan
Ann Arbor, Michigan

Printed as Submitted

Abstract

A study was conducted at Truong Dang Cove of Tri An Reservoir during June 2003–June 2004 to assess the feasibility of an integrated cage-cum-cove system, to assess effects of cages on water quality and plankton abundance in both the cove and the main reservoir, to assess effects of cages on fish production in coves, and to assess effects of accumulated wastes on terrestrial vegetation.

Five 16-m^3 net-cages were set up at the middle of the cove for the culture of red tilapia (*Oreochromis niloticus* x *O. mossambicus*) and stocked at 50, 75, 100, 125, and 150 fish m^{-3} during 19 August 2003–17 January 2004. Water samples were collected at 20 sampling stations grouped into 6 locations at different distances from the cage sites for water quality analyses. Ten plots (1 x 1 m quadrat) were selected for sampling sediment and terrestrial vegetation, with five plots at the cage culture sites and five at random sites, for sampling soil and terrestrial vegetation before and after cage culture to determine vegetation biomass as well as nitrogen, phosphorus, and organic matter content of sediments.

Red tilapia grew well in cages, and cage wastes may have enhanced the growth performance of open-water fish in the cove. Nutrients released from cages to the cove did not significantly affect water quality in the main reservoir, and there were no significant accumulations of cage wastes on the cove bottom. Fish in the cove and terrestrial vegetation during the dry season may efficiently utilize the surplus nutrients derived from the cage culture.
The integrated cage-cum-cove culture system can enhance fish production in coves through cage-cultured fish and increased production of open-water fish by using wastes from cage culture. The integrated cage-cum-cove system can stock appropriate species composition in open water to more efficiently use cage wastes, manage the terrestrial vegetation to use the cage wastes at the cove bottom, and also allow the dry period of the cove to decompose organic cage wastes. However, cage culture in a cove is a new practice and needs more research to develop an environmentally sound integrated cage-cum-cove culture system.

Introduction

Cage culture has long been practiced in rivers, lakes, and reservoirs in Southeast Asia (Ling, 1977). In many cases, caged fish are fed with high protein diets; wastes derived from intensive cage culture cause pollution to the surrounding environment due to dissolved nutrients, uneaten feed, and metabolic byproducts (Beveridge, 1984; Ackefors, 1986; Lin et al., 1990). Cage culture has developed rapidly in Tri An Reservoir of Vietnam since the 1990s, with snakehead (*Channa striata*) as the major fish species for cage culture using trash fish as the main diets (Luu, 1998). Due to serious diseases of snakehead, the major cage culture species has recently changed to red tilapia (*Oreochromis niloticus* x *O. mossambicus*) since the culture of red tilapia is more profitable and less dependent on trash fish (People Committee, 2000). Environmental impacts of cage culture in reservoirs have become a major concern, because waste from cage culture is one of the major sources of pollution in Tri An Reservoir (Luu, 1998).

Another type of reservoir aquaculture is cove culture, in which fish are stocked and cultured in isolated bays of the reservoir using dams, barrier nets or bamboo screens (Pillay, 1990; Li and Xu, 1995; Beveridge, 1996). The ideal cove for aquaculture is one that contains mainly a littoral zone of 1–2 m depth with alternating flood and exposure during rainy and dry seasons. Coves in Tri An Reservoir are usually cultured using net-fences. Thus, most cove culture in Tri An Reservoir is practiced in extensive systems without fertilization and feeding, and the growth of stocked herbivorous and detritivorous species such as Chinese carps and Indian major carps is dependent on the natural foods derived from terrestrial vegetation in the inundated area, resulting in low fish production.

An integrated cage-cum-pond system has been developed by Lin et al. (1990) and practiced for catfish-tilapia (Lin et al., 1990; Lin and Diana, 1995) and for tilapia-tilapia (McGinty, 1991; Yi et al., 1996; Yi and Lin 2001). This integrated system reuses wastes derived from caged fish as a valuable resource to generate natural food for culture of filter-feeding species. Similar concepts can be introduced to reservoirs to develop an integrated cage-cum-cove system in Tri An Reservoir. In this integrated cage-cum-cove system, uneaten feed from cages can be used by fish in the open water of coves. Dissolved nutrients and metabolic products from cages can stimulate the natural food production in cove. Accumulated wastes on cove bottoms can serve as fertilizers for enhancing the growth of terrestrial vegetation when waters recede during the dry season, and terrestrial vegetation can enhance natural food production after inundation during the wet season. Therefore, the integrated cage-cum-cove system can minimize environmental pollution caused by cage culture in reservoirs.

Therefore, the objectives of this study were to:

1) Assess the feasibility of the integrated cage-cum-cove system;
2) Assess effects of cages on water quality and plankton abundance in both the cove and the main reservoir;
3) Assess effects of cages on fish production in coves; and
4) Assess effects of wastes accumulating on the cove bottom on terrestrial vegetation.

METHODS AND MATERIALS

This study was conducted at Truong Dang Cove of Tri An Reservoir during June 2003–June 2004. Truong Dang Cove is located at $17^0 05'$ N and $11^0 13'$ E. The cove is usually flooded during August–September and dries during June–July. Cove construction usually takes place during July–October by partitioning the reservoir with a barrier net fixed across the cove mouth. In this case, the net is hung from a steel cable strung between floats. Floats are made of oil drums (1.2 x 0.6 x 0.6 m), which are placed every 4 m along the steel cable. To prevent fish escape, the top of the barrier net is extended about 0.8 m above the water surface and the net bottom is embedded in bottom mud by heavy stone bags. Mesh size of the barrier net is 2.2 cm, which allows ample water exchange and passage of forage fish and prawns from the main reservoir. Truong Dang Cove exhibits large fluctuations in water depth and corresponding water surface area. During June 2002-May 2003, the water depth and surface area varied from 0 to 9 m and 0 to 7.44 ha, respectively, and the average water surface area of the cove was 5.24 ha during the main culture season from October 2002 to May 2003 (Luong and Yi, in press). The fish culture season in the cove ranges from 6 to 8 months per year, depending upon the annual hydrological regime of the reservoir.

Five net-cages of 4.0 m x 4.0 m x 2.0 m in size were set up at the middle of the cove, 200 m from the both the net fence and shore and 20 m separated from each other (Figure 1). Red tilapia fingerlings of 20 g size were stocked at densities of 50, 75, 100, 125 and 150 fish m^{-3} in cages on 19 August 2003, and were harvested on 17 January 2004. Red tilapia were fed *ad libitum* with pelleted feed (30% and 24% crude protein) three times daily during the first and second half of the culture period, respectively. Red tilapia were not sampled during the experiment, to reduce stress on the fish. No fish were stocked in the cove, but the cove net remained open during August and September to allow fish in the main reservoir to enter to the cove.

Twenty water sampling stations were selected: three in the main reservoir, 400 m away from the cages (main-reservoir stations); three at the cove mouth near the net fence, 200 m away from the cages (near-fence stations); three between the net fence and the cages, 50 m away from the cages (cage-fence stations); five in the cages (cage stations); three between the cages and shore, 50 m away from the cages (cage-shore stations); and three near the shore, 200 m away from the cages (near-shore stations) (Figure 1). Water samples were taken monthly from the 20 stations around 0900–1000 h for analyses of total ammonia nitrogen (TAN), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), and chlorophyll *a* (APHA et al., 1985). Two composite water samples of 50 L were taken at each station for phytoplankton and zooplankton, respectively. Phytoplankton was concentrated by adding Lugol's solution, while zooplankton was concentrated by filtering through a 25-µm net and fixed in 4% formalin. The number of phytoplankton and zooplankton was counted in 125 selected grids of a Sedgewick-Rafter counting cell.

Ten plots (1 x 1 m quadrat) were selected for sampling sediment and terrestrial vegetation. Five plots were at the bottom of the five cages, while the other five plots were randomly selected in the littoral drawdown area. Samples were collected from the top 5-cm of sediments before flooding in July 2003, after water withdrawal in May 2004, and before flooding in July 2004, while terrestrial vegetation samples were collected before flooding in July 2003 and 2004. Terrestrial vegetation biomass was estimated by drying collected vegetation in an oven at 105 °C for 24–48 hours. Red tilapia were sampled randomly at stocking and harvest from each cage, while feed samples were collected from each batch. Moisture, total nitrogen (TN) and total phosphorus (TP) contents of sediment, feed and red tilapia samples were determined (Yoshida et al., 1976), while organic matter content in the sediment samples was also analyzed (Boyd, 1995).

A GPS navigator (MLR SP24) was used to record the location of selected water sampling stations and plots for sediment and terrestrial vegetation samples.

Data were analyzed statistically by linear regression, t-test, one-way ANOVA, and repeated measures ANOVA (Steele and Torrie, 1980) using SPSS 11.0 statistical software (SPSS, Chicago, USA). Differences were considered significant at an alpha level of 0.05. All means were given with ± 1 standard error (SE).

RESULTS

Fish Growth Performance

Survival of red tilapia, ranging from 73.3% to 89.8%, was not correlated to stocking density ($P > 0.05$; Table 1). Red tilapia exhibited density-dependent growth (Figure 2). Mean weight at harvest and mean daily weight gain were larger at lower stocking density ($Y = -1.316X + 609.23$, $Y = -0.0091X + 3.9022$, respectively, $n = 5$, $r^2=0.9892$, $P < 0.001$), while net fish yield increased with increasing stocking density ($Y = 0.2354X + 12.6380$, $n = 5$, $r^2=0.9845$, $P < 0.001$). Gross fish yield reached 773–1,502.0 kg cage^{-1} or 58.4–113.5 kg m^{-3} year^{-1} (Table 1). FCR was quite high, ranging from 3.2 to 3.6.

A total of 2,484 kg fish was harvested from the cove at the end of March 2004. Harvested fish species include marble goby (*Oxyeleotris marmorata* Bleeker), common carp (*Cyprinus carpio*), rohu (*Labeo rohita*), snakehead, tilapia (*Oreochromis spp.*), and silver barb (*Puntius vittatus*). The harvested weight of silver barb was highest (1,600 kg) among all species, followed by common carp (375 kg), rohu (263 kg), tilapia (90 kg), marble goby (89 kg), and snakehead (67 kg).

Waste Loading from Cages

Nutrient inputs in cages increased with increasing stocking density of red tilapia, ranging from 103.7 to 189.7 kg N cage^{-1} and from 24.0 to 43.9 kg P cage^{-1}. The amounts of nitrogen and phosphorus harvested by red tilapia also increased with increasing stocking density of red tilapia in cages, from 17.6 to 33.4 kg N, and 2.2 to 4.2 kg P cage^{-1} (Table 2). Total nutrient inputs to the five cages were 723.9 kg N and 167.4 kg P, and nutrients contained in red tilapia were 129.9 kg N and 16.4 kg P. The retention of nutrients by red tilapia increased from 17.0% to 19.3% N and 9.2% to 10.7% P as stocking density increased from 50 to 125 fish m^{-3}, then decreased to 17.6% N and 9.6% P as stocking density further increased to 150 fish m^{-3} (Table 2). Nutrients harvested by red tilapia were 17.9% N and 9.8% P, thus most nutrients input from feed (82.1% N and 90.2% P) were released into the cove as cage waste (Table 2). The total nutrient amounts released to the cove from the cages as wastes were 601.6 kg N and 151.9 kg P during the flooding season, which were equivalent to 0.76 kg N and 0.19 kg P ha^{-1} day^{-1} during the cage culture period, or 0.51 kg N and 0.13 kg P ha^{-1} day^{-1} during the culture period.

Water Quality and Plankton Abundance

Initial concentrations of all measured water quality parameters except TP were not significantly different among the six groups of sampling stations ($P > 0.05$; Table 3). Initial TP concentration was significantly lower at the main-reservoir station than at other sampling stations ($P < 0.05$). At the end of study period, final concentrations of all measured water quality parameters except NO_3-N were not significantly different among the six groups of sampling stations ($P > 0.05$). Final NO_3-N concentration at the main-reservoir stations was not significantly different from the near-shore stations ($P > 0.05$), but significantly higher than that at other stations ($P < 0.05$; Table 3). Overall mean values of all measured water quality parameters were not significantly different among the six groups of sampling stations ($P > 0.05$; Table 3). At the midpoint of the study period, TAN concentrations at the inside-cage station increased dramatically, while TAN concentrations in other sampling stations remained similar (Figure 3). Concentrations of TP and TKN increased starting from October and December, after the rainy season, while concentrations of other measured water quality parameters remained similar throughout the study period (Table 3, Figures 3 and 4).

Final concentrations of SRP were significantly lower than initial concentrations at all sampling stations except the main-reservoir stations ($P < 0.05$), where final and initial concentrations of SRP were not significantly different (Table 3). However, final concentrations of TP at the near-shore and inside-cage stations were significantly higher than initial concentrations ($P < 0.05$), while there were no significant differences between initial and final TP concentrations at other sampling stations ($P > 0.05$; Table 3). Final NO_2-N concentrations at all sampling stations were significantly lower than initial concentrations ($P < 0.05$). Final concentrations of TKN at the inside-cage station and two stations near cages (near-shore and near-fence stations) were significantly higher than initial concentrations ($P < 0.05$), while there were no significant differences between the final and initial TKN concentrations at the other stations far from cages, including near-shore, cage-fence and main-reservoir stations ($P > 0.05$). Final and initial concentrations of NO_3-N and TAN were not significantly different among all sampling stations ($P > 0.05$; Table 3).

Initial, final, and overall mean phytoplankton abundance was not significantly different among all sampling stations ($P > 0.05$), but the final phytoplankton abundance was about two times higher than initial values, and was significantly higher than initial abundance at all sampling stations (Table 4). There were no significant differences in initial or final zooplankton abundance among all sampling stations ($P > 0.05$), however, overall mean zooplankton abundance tended to be higher at the stations of farther from shore in the cove ($P < 0.05$; Table 4). The zooplankton abundance at the main-reservoir station was intermediate, significantly higher than at the near-shore station and lower than the near-fence station ($P < 0.05$), but it was not significantly different from abundances at other stations ($P > 0.05$; Table 4). Final zooplankton abundance was significantly lower than initial abundance at all sampling stations ($P < 0.05$; Table 4). In August, phytoplankton abundance was low, increased dramatically to the peak in September, maintained the peak level until December, decreased rapidly in January, then increased again during March–April. Zooplankton abundance decreased in the first month, increased gradually to a peak in January, and decreased rapidly in February towards the end of the study period in April.

Terrestrial Vegetation and Sediment

Terrestrial vegetation biomass harvested at the under-cage site was 334.0 and 641.6 g DM m^{-2} in July 2003 and July 2004, respectively, which were not significantly different from values measured (263.0 and 486.6 g DM m^{-2}, respectively) at the random site in July 2003 and July 2004, respectively ($P > 0.05$; Table 5). Changes in harvested terrestrial vegetation biomass were not significantly different between under-cage and random sites ($P > 0.05$). However, there were significant differences in harvested terrestrial vegetation biomass between July 2003 and July 2004 at the same sampling site ($P < 0.05$). The contents of nitrogen and phosphorus in the terrestrial vegetation were not significantly different between under-cage and random sites in the same year, or between the same site in two years ($P > 0.05$; Table 5).

Nitrogen content in sediments in July 2004 after cage culture were not significantly different between under-cage and random sites, while phosphorus contents were significantly lower at the under-cage site than at the random site ($P < 0.05$; Table 5). Change in nitrogen or phosphorus was not significantly different between random and under-cage sites ($P > 0.05$). Organic matter content in sediments was significantly higher at the under-cage site than the random site before and after cage culture ($P < 0.05$), but there were no significant differences in change of organic matter content in sediments ($P > 0.05$; Table 5).

Discussion

Red tilapia grew well in cages suspended in the cove, but the feed utilization efficiency was very poor, giving high FCRs of 3.2–3.6. The poor FCRs, which were much lower than those achieved in the tilapia-tilapia cage-cum-pond integrated culture (Yi et al., 1996; Yi, 1997; Yi and Lin, 2001), might be due mainly to the *ad-libitum* feeding method used in this study, which might lead to more feed consumption than a fixed-percentage feeding method.

Fish culture in coves depends solely on natural foods, thus cultured fish species are mainly herbivorous and omnivorous. The species composition and biomass of fauna and flora in coves influence fish productivity and also influence the efficiency of using cage wastes and the derived natural foods in integrated cage-cum-cove culture. In this study, the resident farmer owning the cove did not stock fingerlings in the cove, but he left the cove net open early in the culture season to allow fish to naturally enter the cove. Production in the same cove in 2002–2003 was 3,402 kg, with about 44% of the yield in carnivorous marble goby feeding mainly on small prawns and 46% (1,918 kg) of the yield in non-carnivorous fish species including common carp, grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), and bighead carp (*Aristichthys nobilis*) (Luong and Yi, in press). Production of the non-carnivorous fish was 2,328 kg in 2002–2003. The production of non-carnivorous fish species was higher in 2003–2004 (with cage culture) than in 2002–2003 (without cage culture). The relatively high nutrient inputs from cage wastes, which were equivalent to 0.51 kg N and 0.13 kg P ha^{-1} day^{-1}, are likely to have enhanced natural food production and contributed to the increased production of the non-carnivorous species.

Final values of all water quality parameters except nitrate-N were not significantly different between the main reservoir and other locations in the cove, and the final values of all water quality parameters were not significantly worse than their initial values. These results indicate that nutrients released from cages to the cove did not cause significant deterioration of water quality in the main reservoir. There was also no significant accumulation of cage wastes on the cove bottom. All these results imply that fish in the open water of the cove utilized the nutrients derived from cage culture. Compared to the cove before cage culture, terrestrial vegetation biomass at both under-cage and random sites was significantly higher after cage culture, implying that cage wastes enhanced terrestrial vegetation growth, and that terrestrial vegetation biomass after cage culture harvested more nutrients from the cove sediment. Common carp accounted for a large portion of harvested fish biomass, and may have consumed wastes in sediments. However, the low density of phytoplankton feeders may be a reason for the significantly higher abundance of phytoplankton, compared to initial levels. Thus, maintenance of appropriate fish species composition in the cove is important to utilize cage wastes and derived natural foods.

The integrated cage-cum-cove culture system can enhance fish production in coves by cage-cultured fish and increased production of open-water fish by releasing wastes from cage culture. The integrated cage-cum-cove system can use appropriate stocking composition in open water to efficiently use cage wastes, use terrestrial vegetation to absorb cage wastes in cove sediments, and also use the dry period of the cove to decompose organic cage wastes. However, cage culture in coves is a new practice, and needs more research to develop an environmentally sound and balanced cage-cum-cove culture system.

Anticipated Benefits

The results of this study could be used to enhance fish production with greater economic return from cove culture. The study also provides an environmentally friendly strategy for the sustainable development of reservoir aquaculture. This integrated system will benefit the fish farmers throughout the region

Acknowledgements

The authors wish to acknowledge Nong Nam University (NNU) of Vietnam for providing the research, field, and laboratory facilities. P.N. Tam, P.V. Minh, and N.T. Vy of NNU are greatly appreciated for their field and lab assistance. The authors also wish to thank Aye Aye Mon of AIT for data analyses.

Literature Cited

Ackefors, H., 1986. The impact on the environment by cage farming in open water. J. Aquacult. Trop., 1: 25–33.

APHA, AWWA, and WPCF, 1985. Standard Methods for the Examination of Water and Wastewater, 16th Editon. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, D.C. 1,268 pp.

Beveridge, M.C.M., 1984. Cage and Pen Fish Farming: Carrying Capacity Models and Environmental Impacts. FAO Fisheries Technical Paper No. 255, FIRI/222. Food and Agriculture Organization of the United Nations, Rome, Italy, 131 pp.

Beveridge, M.C.M., 1996. Cage Aquaculture, 2nd Edition. Fishing News Books Ltd., Oxford, UK, 346 pp.

Boyd, C.E., 1995. Bottom Soils, Sediment and Pond Aquaculture. Chapman & Hall, USA, 350 pp.

Li, S.F., and S. Xu. 1995. Culture and Capture of Fish in Chinese Reservoirs. Southbound, Penang, Malaysia, and IDRC, Ottawa, Canada, 128 pp.

Lin, C.K., and J.S. Diana 1995. Co-culture of catfish (*Clarias macrocephalus x C. gariepinus*) and tilapia (*Oreochromis niloticus*) in ponds. Aquat. Living Resour., 8:449–454.

Lin, C.K., K. Jaiyen, and V. Muthuwan, 1990. Integration of intensive and semi-intensive aquaculture: concept and example. Thai Fish. Gaz., 43: 425–430.

Ling, S.W., 1977. Aquaculture in Southeast Asia. University of Washington, Seattle, Washington, USA.

Luu, T. T., 1998. The Survey of Pollution of Cage Aquaculture in Tri An Reservoir in 1997-1998. Department of Technology and Environment of Dong Nai Province, 42 pp (in Vietnamese).

Luong, V.C., and Y. Yi., in press. Cove culture of marble goby (*Oxyeleotris marmorata* Bleeker) and carps in Tri An Reservoir of Vietnam. Aquaculture.

McGinty, A.S., 1991. Tilapia production in cages: effects of cage size and number of noncaged fish. Prog. Fish-Cult., 53:246–249.

People Committee, 2000. Present Status and Planning for the Development of Aquaculture and Fisheries of Dong Nai Province in Period 2000–2010. Bien Hoa, 65 pp (in Vietnamese).

Pillay, T.V.R., 1990. Aquaculture Principles and Practices. Fishing Book News, London, UK.

Steele, R.G.D., and J.H. Torrie, 1980. Principles and Procedures of Statistics, 2nd Edition. McGraw-Hill, New York, 633 pp.

Yi, Y., 1997. An integration rotation culture system for fattening large Nile tilapia (*Oreochromis niloticus*) in cages and nursing small Nile tilapia in open ponds. Ph.D. Dissertation, Asian Institute of Technology, Bangkok, Thailand.

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

Yoshida, S., D.A Forno, J.H. Cock, and K.A. Gomez, 1976. Laboratory Manual for Physiological Studies in Rice, 3rd Edition. International Rice Research Institute, Philippines, 83 pp.

Table 1. Performance of red tilapia stocked at different densities in cages.

Parameter	Stocking Density (fish m^{-3})				
	50	75	100	125	150
STOCKING					
Total Number of Fish	1,600	2,400	3,200	4,000	4,800
Mean Weight (g $fish^{-1}$)	20.0	20.0	20.0	20.0	20.0
Total Weight (kg $cage^{-1}$)	32.0	48.0	64.0	80.0	96.0
HARVEST					
Total Number	1,436	1,951	2,344	3,241	3,755
Survival Rate (%)	89.8	81.3	73.3	81.0	78.2
Mean Weight (g $fish^{-1}$)	538.3	502.3	481.2	433.5	400.0
DWG (g $fish^{-1}$ day^{-1})	3.4	3.2	3.1	2.7	2.5
Net Fish Yield (kg $cage^{-1}$)	741.0	932.0	1,064.0	1,325.0	1,406.0
Net Fish Yield (kg m^{-3} year)	56.0	70.4	80.4	100.1	106.2
Gross Fish Yield (kg $cage^{-1}$)	773.0	980.0	1,128.0	1,405.0	1,502.0
Gross Fish Yield (kg m^{-3} year)	58.4	74.0	85.2	106.1	113.5
FCR	3.6	3.5	3.4	3.2	3.5

Table 2. Input, output, and waste loading of nutrients (nitrogen and phosphorus) in cages stocke with red tilapia at different stocking densities. The values in parentheses are percentages.

Parameter (kg $cage^{-1}$)	Stocking Density					Overall
	50 m^{-3}	75 m^{-3}	100 m^{-3}	125 m^{-3}	150 m^{-3}	
NITROGEN						
Input From Feed	103.7 (100)	128.2 (100)	139.5 (100)	162.8 (100)	189.7 (100)	723.9 (100)
Harvested by Tilapia	17.6 (17.0)	22.1 (17.2)	25.3 (18.1)	31.5 (19.3)	33.4 (17.6)	129.9 (17.9)
Waste	86.9 (83.0)	107.2 (82.8)	115.7 (81.9)	133.2 (80.7)	158.6 (82.4)	601.6 (82.1)
PHOSPHORUS						
Input From Feed	24.0 (100)	29.7 (100)	32.3 (100)	37.5 (100)	43.9 (100)	167.4 (100)
Harvested by Tilapia	2.2 (9.2)	2.8 (9.4)	3.2 (9.9)	4.0 (10.7)	4.2 (9.6)	16.4 (9.8)
Waste	21.9 (90.8)	27.0 (90.6)	29.3 (90.1)	33.7 (89.3)	40.0 (90.4)	151.9 (90.2)

Table 3. Initial, final, and overall mean values of water quality parameters measured at different sampling stations in Truong Dang Cove of Tri An Reservoir during August 2003–April 2004.

Parameter	Sampling Stations					
	Near Shore	*Cage Shore*	*Inside Cage*	*Cage Fence*	*Near Fence*	*Main Reservoir*
INITIAL						
TAN (mg L^{-1})	0.10 ± 0.02	0.10 ± 0.01	0.10 ± 0.01	0.09 ± 0.00	0.12 ± 0.01	0.11 ± 0.01
NO_2-N (mg L^{-1})	$0.01\pm0.00_x$	$0.01\pm0.00_x$	$0.01\pm0.00_x$	$0.01\pm0.00_x$	$0.01\pm0.00_x$	$0.01\pm0.00_x$
NO_3-N (mg L^{-1})	0.21 ± 0.01	0.41 ± 0.10	0.38 ± 0.15	0.25 ± 0.05	0.30 ± 0.05	0.26 ± 0.06
TKN (mg L^{-1})	0.16 ± 0.09	$0.23\pm0.06_x$	$0.32\pm0.06_x$	$0.09\pm0.06_x$	0.23 ± 0.06	0.35 ± 0.08
SRP(mg L^{-1})	$0.02\pm0.00_x$	$0.02\pm0.00_x$	$0.05\pm0.00_x$	$0.02\pm0.00_x$	$0.02\pm0.00_x$	0.01 ± 0.00
TP(mg L^{-1})	$0.04\pm0.00^{b}{}_{x}$	0.04 ± 0.00^{b}	$0.04\pm0.00^{b}{}_{x}$	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.03 ± 0.00^{a}
FINAL						
TAN (mg L^{-1})	0.11 ± 0.01	0.09 ± 0.01	0.12 ± 0.01	0.10 ± 0.01	0.10 ± 0.02	0.08 ± 0.02
NO_2-N (mg L^{-1})	$0.00\pm0.00_y$	$0.00\pm0.00_y$	$0.00\pm0.00_y$	$0.00\pm0.00_y$	$0.00\pm0.00_y$	$0.00\pm0.00_y$
NO_3-N (mg L^{-1})	0.22 ± 0.02^{ab}	0.20 ± 0.01^{b}	0.18 ± 0.00^{b}	0.20 ± 0.01^{b}	0.17 ± 0.04^{b}	0.27 ± 0.03^{a}
TKN (mg L^{-1})	0.51 ± 0.06	$0.51\pm0.05_y$	$0.54\pm0.05_y$	$0.49\pm0.00_y$	0.84 ± 0.30	0.56 ± 0.04
SRP(mg L^{-1})	$0.01\pm0.00_y$	$0.01\pm0.00_y$	$0.01\pm0.00_y$	$0.01\pm0.00_y$	$0.01\pm0.00_y$	0.01 ± 0.00
TP(mg L^{-1})	$0.07\pm0.01_y$	0.06 ± 0.01	$0.06\pm0.00_y$	0.05 ± 0.01	0.05 ± 0.00	0.05 ± 0.00
MEAN (mg L^{-1})						
TAN (mg L^{-1})	0.05 ± 0.00	0.06 ± 0.00	0.10 ± 0.02	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00
NO_2-N (mg L^{-1})	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
NO_3-N (mg L^{-1})	0.17 ± 0.01	0.19 ± 0.01	0.19 ± 0.02	0.17 ± 0.00	0.18 ± 0.01	0.20 ± 0.01
TKN (mg L^{-1})	0.33 ± 0.00	0.32 ± 0.04	0.32 ± 0.01	0.27 ± 0.02	0.30 ± 0.04	0.30 ± 0.16
SRP(mg L^{-1})	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
TP(mg L^{-1})	0.05 ± 0.00	0.04 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.04 ± 0.00	0.05 ± 0.00

^{abcd} The values with different superscripts in each row were significantly different ($P < 0.05$).
^{xy} Parameters with different subscripts for initial and final concentrations were significantly different ($P < 0.05$).

Table 4. Initial, final and overall mean values of plankton biomass measured at different sampling stations in Truong Dang Cove of Tri An Reservoir during August 2003–April 2004.

Parameter	Sampling Stations					
	Near Shore	*Cage Shore*	*Inside Cage*	*Cage Fence*	*Near Fence*	*Main Reservoir*
PHYTOPLANKTON (cells L^{-1})						
Initial Value	$11{,}541 \pm 549_x$	$13{,}165 \pm 596_x$	$13{,}116 \pm 1{,}490_x$	$10{,}665 \pm 590_x$	$12{,}190 \pm 1{,}337_x$	$12{,}931 \pm 126_x$
Final Value	$26{,}237 \pm 1{,}259_y$	$23{,}123 \pm 968_y$	$22{,}229 \pm 1{,}912_y$	$25{,}688 \pm 494_y$	$25{,}091 \pm 2{,}203_y$	$22{,}066 \pm 1{,}697_y$
Overall Mean Value	24,798±1,007	23,910±725	25,665±544	25,486±496	25,971±610	24,411±539
ZOOPLANKTON (cells L^{-1})						
Initial Value	$254 \pm 11_x$	$221 \pm 40_x$	$210 \pm 20_x$	$184 \pm 21_x$	$223 \pm 5_x$	$235 \pm 18_x$
Final Value	$94 \pm 10_y$	$79 \pm 2_y$	$94 \pm 5_y$	$96 \pm 5_y$	$97 \pm 11_y$	$90 \pm 11_y$
Overall Mean Value	180 ± 8^a	184 ± 6^{ab}	200 ± 7^{abc}	220 ± 14^{cd}	235 ± 1^d	208 ± 1^{bc}

^{abcd} The values with different superscripts in each row were significantly different ($P < 0.05$).
^{xy} Parameters with different subscripts for initial and final concentrations were significantly different ($P < 0.05$).

Table 5. Values for nitrogen, phosphorus, and organic matter in sediment and terrestrial vegetation biomass in July 2003 and July 2004, as well as values for change in each parameter over the time period.

Parameter	Sample Site	
	Under Cage	*Random*
TERRESTRIAL VEGETATION		
Biomass (g DM m^{-2})		
Before Flooding 2003	$334.0 \pm 10.6_x$	$263.0 \pm 67._x$
Before Flooding 2004	$641.6 \pm 133.4_y$	$486.6 \pm 96.2_y$
Change	307.6±135.5	223.6±76.8
Nitrogen (%)		
Before Flooding 2003	0.95±0.08	1.04±0.10
Before Flooding 2004	1.68±0.21	2.07±0.33
Change	0.74±0.26	1.04±0.42
Phosphorus (%)		
Before Flooding 2003	0.27±0.04	0.20±0.02
Before Flooding 2004	0.42±0.06	0.35±0.04
Change	0.14±0.06	0.15±0.05
SEDIMENT		
Nitrogen (%)		
Before Flooding 2003	0.22±0.03	0.24±0.03
Before Flooding 2004	0.23±0.04	0.23±0.03
Change	0.01±0.05	-0.01±0.04
Phosphorus (%)		
Before Flooding 2003	0.11±0.01	0.10±0.01
Before Flooding 2004	0.09 ± 0.01^a	0.12 ± 0.01^b
Change	-0.02±0.01	0.02±0.02
Organic Matter (%)		
Before Flooding 2003	5.84 ± 0.25^a	4.50 ± 0.40^b
Before Flooding 2004	5.88 ± 0.20^a	4.96 ± 0.20^b
Change	0.04±0.15	0.46±0.43

^{ab} The values with different superscripts in the same row were significantly different ($P < 0.05$).
^{xy} Parameters with different subscripts for initial and final concentrations were significantly different ($P < 0.05$).

Figure 1. Schematic of 20 sampling stations in Truong Dang cove.

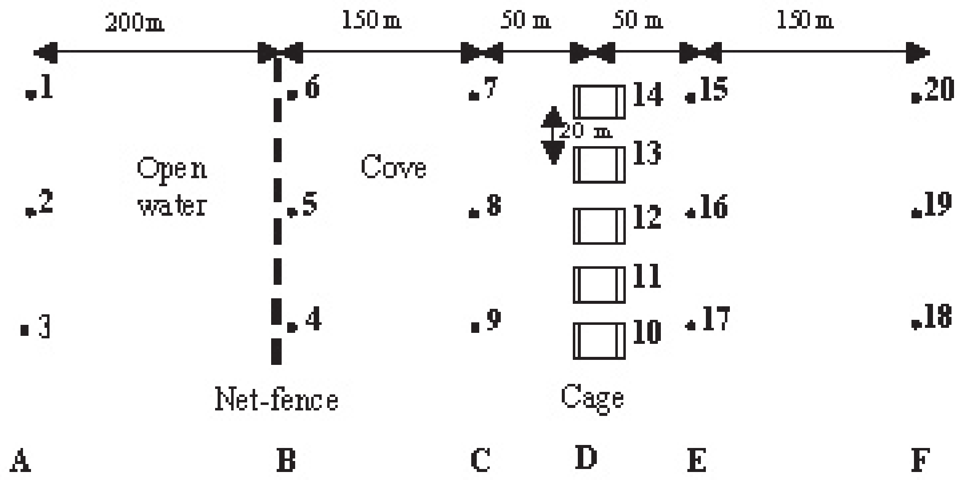

Figure 2. Relationships between stocking density and mean weight, daily weight gain or net yield of red tilapia cultured in cages.

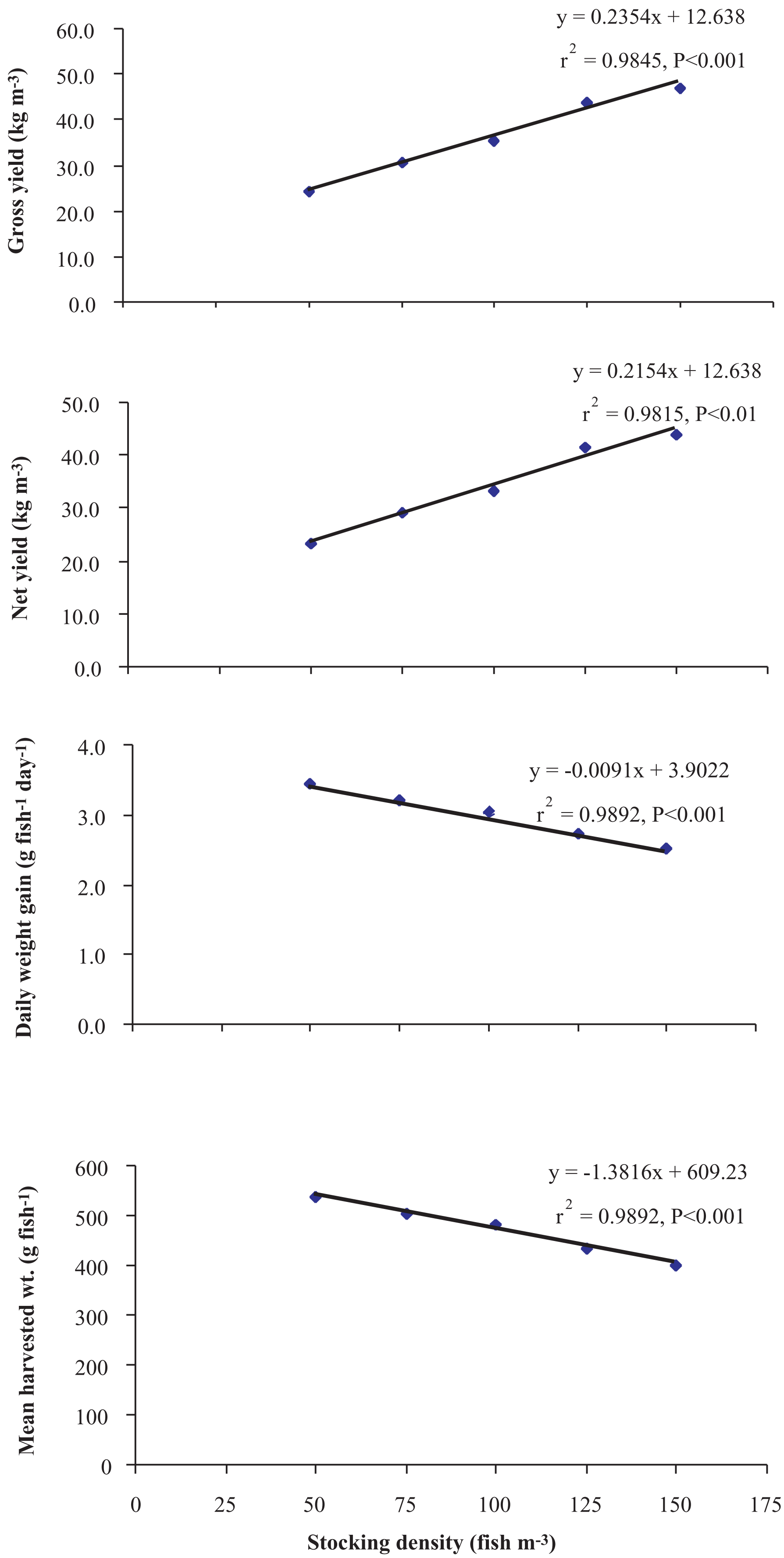

Figure 3. Monthly values for TAN, NO_2-N, NO_3-N, and TKN concentrations measured at 0900–1000 h.

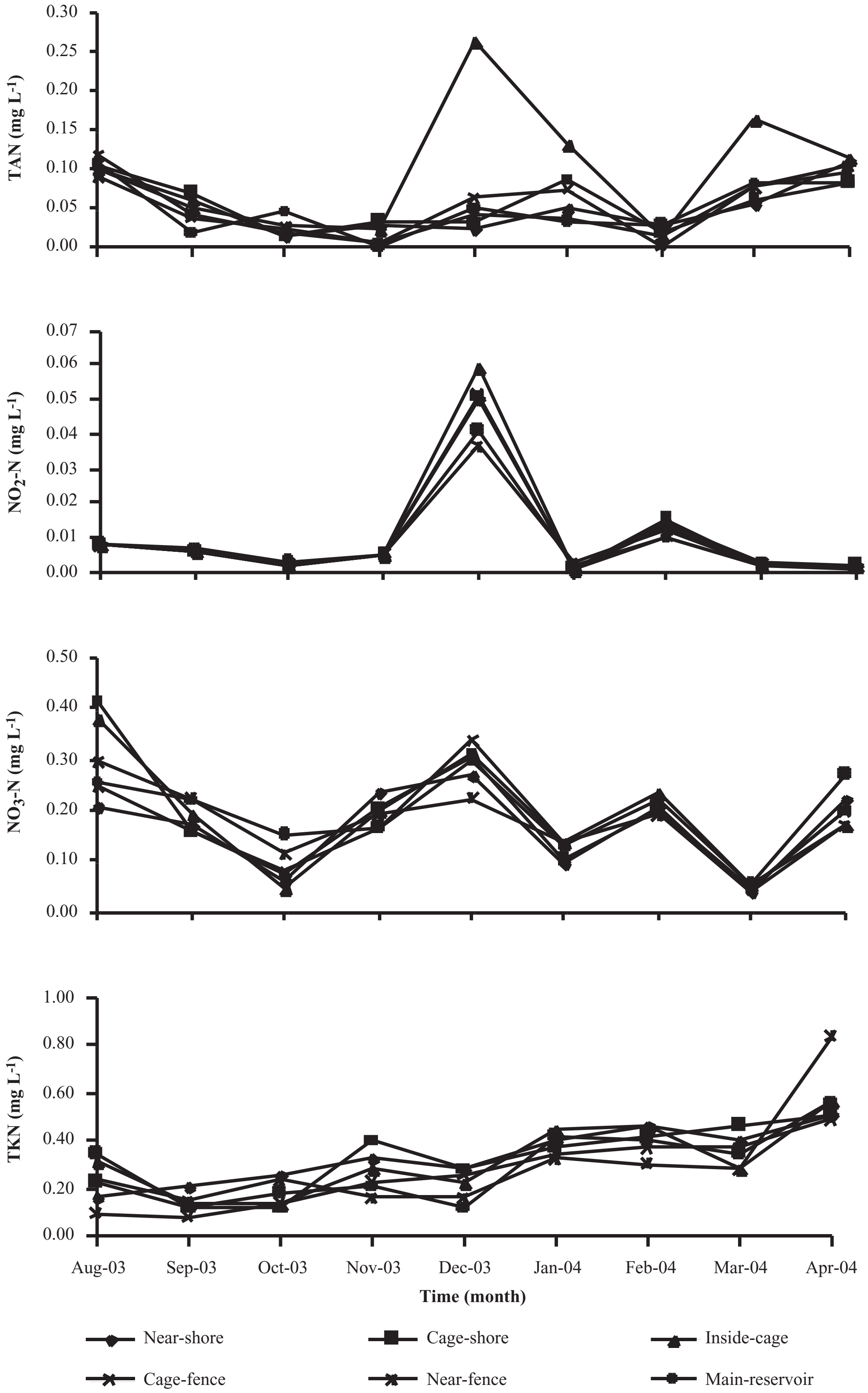

Figure 4. Monthly values for SRP and TP concentrations measured at 0900-1000 h.