An Evaluation of Three Cage Designs and Two Tilapias for Mariculture

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ABSTRACT

Growth and survival of *Oreochromis mossambicus* and Florida red tilapia were evaluated in 2-m^3 cages of three designs in a marine embayment (35 ppt) on St. Croix, U. S. Virgin Islands. The cage designs were:

1. rectangular-solid (REC), galvanized mesh treated with tributyltin antifouling paint, fixed position
2. cubic (CUB), knotless nylon mesh, rotating
3. cylindrical (CYL), knotless nylon mesh, rotating

Three replicate cages of each group of fish were stocked at 20/m^3 and fed a floating, 36% protein, pelleted diet for 112 days. Between the three cage designs, fish survival and growth was affected differentially by an episode of mortality. Combined survival of both tilapia groups in REC cages (88.7%) was greater ($P < 0.01$) than in CUB (26.7%) or CYL (22.5%) cages. Across tilapia groups, the combined daily growth rate of fish in REC cages was higher (2.32 g) than that of fish in CUB (0.93 g) or CYL (1.43 g) cages ($P < 0.05$). Across all cage designs, Florida red tilapia grew to a larger ($0.05 < P < 0.1$) final body weight (342 g) than *O. mossambicus* (306 g).

INTRODUCTION

The commercial cage rearing of tropical marine finfish is widespread in Southeast Asia, but as yet has not been developed in the Gulf and Caribbean region. Despite numerous sheltered embayments and abundant, high-quality seawater, and a year-round growing season, most aquaculture in the Caribbean has developed on islands with ample freshwater resources.

One of the most challenging problems affecting cage culture in tropical marine waters is the biofouling of cage mesh. Adhesion of plants (periphyton) and animals (primarily post-larval invertebrates) to cage netting decreases the size of the mesh opening. This reduces the velocity of water currents within the cage (Inoue, 1972), which are important for removing metabolite-laden water and supplying dissolved oxygen to caged fish. Biofouling of cage mesh and supporting structures also increases weight and drag, thereby reducing buoyancy

(Milne, 1970; Ansuini and Huguenin, 1978). Milne (1970) estimated that the force of water currents on a fouled net were 12.5 times that on a clean net. Independent of the culture environment, the degree and rate of biofouling depends largely on the selection of mesh material, whether the mesh is knotted or knotless, and on mesh size (Beveridge, 1987).

There have been attempts to control biofouling on fish cages by biological, chemical and mechanical methods. The latter two methods were considered in this study. Chemical methods utilize a biocide (metallic or organometallic) incorporated into mesh materials (*e.g.*, Cu-Ni expanded metal alloy) or coatings which slowly leach to form a toxic micro-layer adjacent to the cage mesh.

Mechanical methods for biofouling control include scrubbing cage mesh panels *in situ*, changing nets as they become fouled or employing a rotating cage design. Rotating cage designs control fouling by alternately exposing sections of fouled cage mesh to the dessicating effects of air and sunlight. Rotating cage designs have been successfully tested in the marine environment (Caillouet, 1972; Geffen, 1979; Blair and Burgess, 1979; Blair *et al.*, 1982; Dropsy, 1987).

Although tilapia is not a marine finfish *per se*, it has great potential for adaptation to marine cage culture. The salinity tolerance of tilapias has been known to aquaculturists for many years (see reviews by Wohlfarth and Hulata, 1983; Stickney, 1986). *Oreochromis mossambicus* grows well in seawater ponds of salinities ranging from 32 to 40 ppt (Popper and Lichatowich, 1975) and can adapt to salinities ranging from 0 to 120 ppt (Whitfield and Blaber, 1979). Red hybrid tilapia are also tolerant of a wide range of salinities; in fact, superior growth has been demonstrated in full-strength seawater as compared to brackish and freshwater (Liao and Chang, 1983; Meriwether *et al.*, 1984; Watanabe *et al.*, 1988).

The objective of this study was to measure the growth performance of *O. mossambicus* and Florida red tilapia in marine cages and to subjectively evaluate the effectiveness of three cage designs for biofouling control and tilapia culture suitability.

MATERIALS AND METHODS

This study was conducted in Salt River Bay, St. Croix, U.S. Virgin Islands (18°N, 65°W), a protected embayment open to the sea, which receives freshwater runoff only during periods of intense rainfall. During the study (29 June - 19 October 1988), salinity ranged from 35 to 38 ppt; surface water temperature ranged from 27 to 32°C as measured by a minimum-maximum thermometer. As fish stocking density was low and wind and currents were constant, dissolved oxygen was not measured.

Three cross-shaped rafts (wooden walkways) were anchored in approximately 3 m of water at a distance of 10 m from a fringe of red mangrove

(*Rizophorae mangle*) in a small arm of the bay. A 3 x 2 factorial, randomized complete block design was used to evaluate the three cage types and two groups of tilapia. Treatments were blocked (as rafts) to minimize potential effects of cage position relative to currents and other cages. Each treatment was replicated three times. Each of two 2-m^3 cages of each design were randomly assigned and secured to one of the available positions on the raft and stocked with the two tilapia groups, one in each cage.

One cage type (REC) was constructed of galvanized, 1.9 cm mesh formed into a rectangular solid measuring 1.5 x 1.2 x 1.2 m (L x W x D). The cage was bolted onto two 5 x 5 cm lengths of wood along two of the top sides. The mesh was then treated with a blue antifouling paint containing tributyltin fluoride. The cage top was 1.9 cm plastic mesh. This cage was secured to the raft in a fixed position and not rotated during the experiment.

A second cage type (CUB) was constructed of knotless nylon, 1.9 cm (bar) mesh panels fabricated into a cube measuring 1.3 m on each side. A square flotation collar of 10 cm PVC pipe was placed inside the cage. After the cage was stocked with fish, the top panel was laced to the adjoining cage panels. A small concrete weight was suspended from each of the four lower corners. Submerged panels were alternately rotated to the surface as they became fouled by removing the two weights from the side adjacent to a fouled panel, and then reattaching them to the "new" lower corners. The surface panel was held out of the water by a feeding ring. Initially, cages were rotated weekly; later, it became necessary to rotate them twice per week.

The third cage type (CYL) was also constructed of knotless nylon, 1.9 cm mesh fabricated into a cylinder. Two 1.8 m diameter fiberglass hoops were placed inside the ends of the cylinder and were held apart by four 1.6 m lengths of 2.5 cm PVC pipe clamped to the hoops at equal intervals on the outside of the cage. The cages were 4 m^3 in volume and were positioned horizontally with half (2 m^3) the cage volume submerged. Flotation was attached to the PVC pipes. As the mesh became fouled, the cage was rotated to expose the submerged portion to the air. Cages were rotated weekly throughout the experiment.

A feeding ring of encapsulated polystyrene measuring 41 cm (ID) x 61 cm (OD) x 15 cm high was placed in each cage. Plastic, 3 mm mesh was tied to the outside of each ring and extended 31 cm into the water.

O. mossambicus were derived from stocks captured from the Salton Sea, California, USA. Florida red hybrid tilapia were derived after many generations from a cross of *O. urolepis honorum* (female) x *O. mossambicus* (male) made in Florida, USA. Fish were sex-reversed (males) as fry by dietary administration of 17a-methyltestosterone for 28 days and sorted as fingerlings by visual inspection of genital papilla. Fish were acclimated to seawater over a five-day period by direct transfer to water of a salinity 5 ppt greater than that of the previous day, beginning with a salinity of 15 ppt. Fish averaging 150 g (range = 137 – 156 g) were stocked at 40/cage (20/m^3) on 27 and 28 June 1988. Cages were stocked at a low rate to maximize fish growth potential by minimizing density dependent growth effects. Negligible mortality occurred during acclimation and stocking. Mortalities were replaced during the first week only.

Beginning on 29 June 1988, fish were fed an extruded (floating) diet (36% protein, Purina #5144) at 3.0% of body weight once per day in the morning. The feeding rate was adjusted weekly based on an assumed feed conversion ratio (dry wt. feed/wet wt. fish gain) of 2. Fish were not sampled during the experiment.

After 50 feeding days, many fish in the two rotating cage types (CUB and CYL) were observed with exopthalmia and disoriented swimming behavior; others were moribund. Gross histology revealed epidermal hyperplasia, exopthalmia, and pale livers. There was no evidence of internal or external parasites. After 64 feeding days and the onset of severe mortality (Figure 1), feed treated with oxytetracycline (Terramycin) was offered to fish at a rate of 80 mg/kg fish body weight for 14 days. Fish resumed active feeding following treatment with medicated feed, although feed quantity was decreased substantially to an amount which could be consumed within 30 minutes.

After 112 feeding days fish from each cage were weighed *en masse* and counted.

The effects of cage design, tilapia group and cage design x tilapia group (interaction), and raft (block) on mean values for final body weight, cage biomass, survival rate, specific growth rate, and daily weight gain were compared by analysis of variance. Least significant difference tests were performed for all main effect means. Comparisons were considered significant at a confidence level exceeding 95%.

RESULTS

The final mean body weight of the two groups of tilapia combined across cage designs were not significantly different ($0.05 < P < 0.1$) although Florida red tilapia grew to a larger final body weight (342 g) than that of *O. mossambicus* (306 g) (Table 1). Final body weight was highest for Florida red tilapia cultured in REC cages (439 g) and lowest for Florida red tilapia cultured in CUB cages (247 g). Among cage designs, the combined final body weight of both groups of tilapia cultured in REC cages (410 g) was greater ($P < 0.05$) than that of fish in CYL (307 g) and CUB (256 g) cages.

Growth rates (specific growth rate and daily weight gain) of the two groups of tilapia combined across cage designs were not significantly different ($P > 0.05$) although Florida red tilapia grew faster (0.65%/day or 1.71 g/day) than *O. mossambicus* (0.63%/day or 1.41 g/day). Across cage designs, specific growth rate of both groups of tilapia in REC cages (0.89%/day) was not different (P >

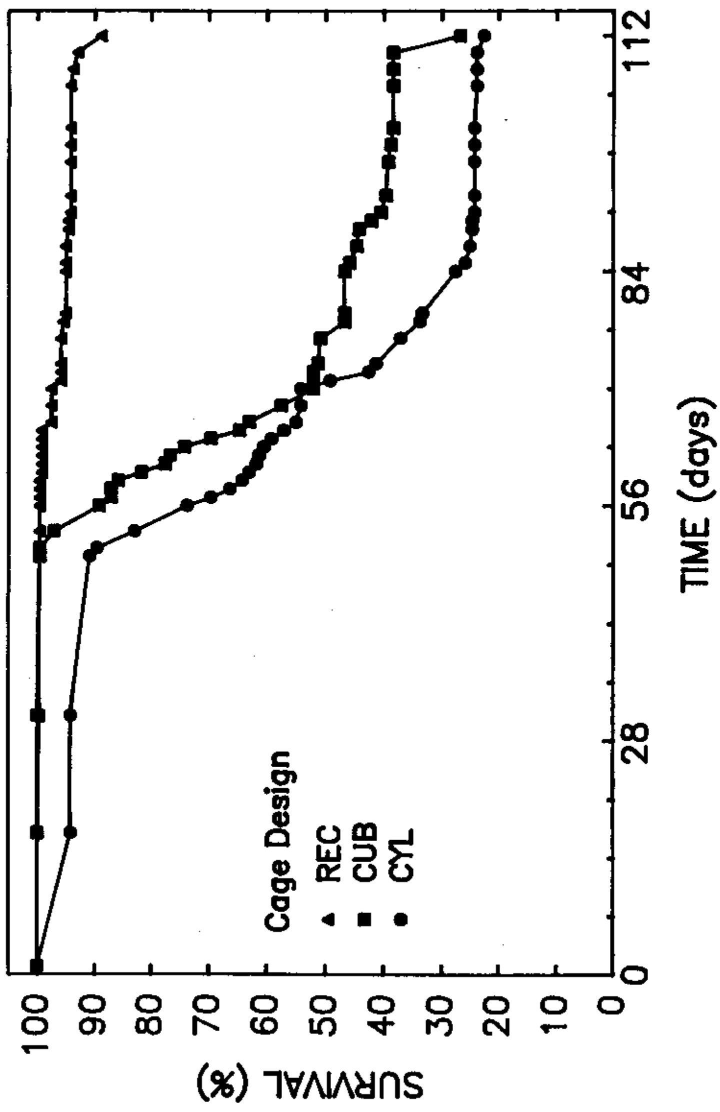

Figure 1. Survival of *Oreochromis mossambicus* and Florida red tilapia in seawater cages of REC, CUB, or CYL design. Plotted points represent means (N = 6).

Table 1. Mean ± S.E. (N=3) initial and final body weight, daily specific growth rate and weight gain, final cage biomass and survival rate of Florida red tilapia and Oreochromis mossambicus cultured in 2-m3 REC, CUB or CYL cages for 112 days in seawater. (REC = rectangular solid, galvanized mesh coated with tributlytin antifouling paint, fixed positi; CUB = cubic, knotless nylon mesh, rotating; CYL = cylindrical, knotless nylon mesh, rotating)

Tilapia Group	Cage Type	Initial body weight (g)	Final body weight (g)	Daily specific growth (%)	Daily weight gain (g)	Final cage biomass (kg/m3)	Survival rate (%)
Florida red	REC	152 ± 3	439 ± 2	0.95 ± 0.01	2.56 ± 0.01	8.3 ± 0.3	94.2 ± 3.0
tilapia	CUB	152 ± 2	247 ± 74	0.32 ± 0.36	0.85 ± 0.68	0.9 ± 0.5	14.2 ± 6.5
CYL		148 ± 3	342 ± 73	0.70 ± 0.21	1.73 ± 0.64	1.7 ± 0.8	20.8 ± 10.1
Oreochromis	REC	148 ± 4	381 ± 21	0.84 ± 0.04	2.08 ± 0.17	6.5 ± 1.5	83.3 ± 16.7
mossambicus	CUB	150 ± 1	264 ± 3	0.50 ± 0.00	1.02 ± 0.01	2.1 ± 0.5	39.2 ± 9.6
CYL		145 ± 4	273 ± 28	0.55 ± 0.11	1.14 ± 0.28	1.4 ± 0.7	24.2 ± 10.6
Mean	REC	150 ± 2 x[1]	410 ± 16 x	0.89 ± 0.03 x	2.32 ± 0.13 x	7.4 ± 0.8 x	88.7 ± 8.0 x
CUB		151 ± 1 x	256 ± 33 y	0.41 ± 0.17 xy	0.93 ± 0.31 y	1.5 ± 0.4 y	26.7 ± 7.6 y
	CYL	147 ± 2 x	307 ± 38 y	0.63 ± 0.11 y	1.43 ± 0.34 y	1.5 ± 0.5 y	22.5 ± 6.6 y
LSD[2]		6	83	0.34	0.74	1.7	21.9

1 Means within a column followed by the same letter are not signficantly different (P > 0.05).

2 Least Signficant Difference value for comparisons across cage designs.

0.05) from that of fish in CYL cages (0.63%/day) but was significantly greater than that of fish in CUB cages (0.41%/day). Expressed as daily weight gain, growth of fish in REC cages (2.32 g/day) was significantly greater than that of fish in CYL (1.43 g/day) and CUB (0.93 g/day) cages.

Final cage biomass of both groups of fish in all cages was low due to low stocking density and high mortality. Final cage biomass was highest for Florida red tilapia cultured in REC cages (8.3 kg/m^3) and lowest for Florida red tilapia cultured in CUB cages (0.9 kg/m^3) (Table 1). Final biomass of both groups of tilapia cultured in REC cages (7.4 kg/m^3) was greater than that of either CUB (1.5 kg/m^3) or CYL (1.5 kg/m^3) cages.

Survival rate of both groups of fish in REC cages (88.7%) was greater than that of fish in CUB (26.7%) or CYL (22.5%) cages (Figure 1). Combined across cage designs, overall mean survival of Florida red tilapia (43.1%) was not significantly different from that of *O. mossambicus* (48.9%) (Table 1). Survival rate was highest for Florida red tilapia cultured in REC cages (94.2%) and lowest for Florida red tilapia cultured in CUB cages (14.2%). As survival rate of fish was low in both CUB and CYL cages, feed conversion ratios of fish in these cages was exceedingly high. Mean feed conversion ratio of Florida red tilapia in REC cages (2.52) was lower than that of *O. mossambicus* (9.50).

Interaction (cage design x tilapia group) effects for the model parameters listed above were not significant ($P > 0.05$). The effect of raft (block) was small ($0.05 < P < 0.1$), indicating that the blocks were relatively homogeneous.

DISCUSSION

The culture performance of both species of tilapia was far superior in REC cages, although the reasons for this are not clear. Fish cultured in REC cages were not as affected by the disease episode which severely afflicted both groups of fish in CUB and CYL cages. Prior to the onset of the disease episode, in an effort to obtain maximum growth rates, fish were fed at a rate beyond satiation. Feed remained on the surface for several hours and became saturated with seawater, possibly leaching water-soluble nutrients. Ingestion of this seawater-soaked feed of reduced nutrient quality may have subjected the tilapia to additional osmotic stress to the extent that resistance to ubiquitous marine pathogens was weakened. Treatment of fish feed with oxytetracycline effectively reduced the rate of mortality of fish in CUB and CYL cages. Reduction of the feeding rate following onset of the mortality episode to levels that could be consumed rapidly by the fish may have also contributed to recovery and resumption of growth.

As immersion of REC cages did not occur for more than a year following application of the antifouling paint, some fouling of the cage mesh occurred, particularly on panels facing to windward. Although tilapia will consume periphytic algae on freshwater cages (Coche, 1982), they are unable to control biofouling on marine cages. Nevertheless, fish may have ingested some of this fouling community and derived nutritional benefit. Fish in CUB and CYL cages did not obtain this benefit as biofouling was effectively controlled by rotation.

Although *O. mossambicus* have been infected with the marine monogenean parasite, *Neobenedenia melleni*, in seawater cages (Kaneko *et al.*, 1988), no external parasites were observed directly. In REC cages, it is possible that sufficient residual concentrations of tin remained and were ingested, thereby inhibiting development of pathogenic organisms.

The environmental toxicity of tributyltin and other biocidal antifouling paints has been widely reported (Alzieu, 1986; Paul and Davies, 1986; Ward, 1988). Despite the promising results in the TBT-treated cages, evidence now suggests that these compounds may pose a public health risk by accumulating in the muscle tissue of cultured species, such as chinook salmon (Short and Thrower, 1986) and scallops and oysters (Davies *et al.*, 1986). With legislation pending before the U.S. Congress, the use of TBT-based antifouling paints may be banned shortly.

Although final mean body weight, caged fish biomass, and survival rate of both groups of fish were higher in REC cages, and REC cages were less susceptible to damage by piscivorous fish (*e.g.* juvenile barracuda, *Sphyraena barracuda*), better control of biofouling was observed with rotating cage designs. Biofouling control by rotating CYL cages, which were rotated once weekly, allowing for complete dessication of half the cage mesh surface, was more effective than rotating CUB cages.

A disadvantage of cylindrical rotating cage designs is the relatively high materials cost as only half the cage volume is submerged at any one time. In addition, cage mesh exposed to intense sunlight will degrade from ultraviolet radiation (Porter, 1981). The CYL cages in this study were subject to distortion from wind and waves striking at oblique angles. As CYL cages were completely enclosed, access to cages was difficult.

CUB cages were rotated twice weekly and thus required more labor than CYL cages to achieve biofouling control. As the cage consisted of six panels, each panel was dessicated after three weeks of immersion. Apparently, the action of cage rotation was observed not to affect fish swimming behavior or feed consumption.

Culture performance of Florida red tilapia was superior to *O. mossambicus* in REC and CYL cages. Florida red tilapia have been subjected to selective breeding for improved growth and color characteristics for more than 10 years, whereas *O. mossambicus* originated from an unselected (wild) population.

Control of biofouling on the mesh of marine fish cages in tropical waters can be achieved with both chemical and mechanical methods. Although biofouling control was observed to be superior with rotating cages, culture performance of fish stocked in cages treated with a biocidal antifouling paint was superior to that of fish stocked in rotating cages due to reduced susceptibility to parasitism and disease. Considering the potential environmental and public health consequences of using biocidal antifouling paints and the low survival of fish cultured in rotating cages, it is clear that other cage designs are required to achieve both biofouling control and acceptable tilapia culture performance. However, the growth characteristics of both groups of tilapia in this study indicate that Florida red tilapia may be more suitable for culture in marine cages than *O. mossambicus.*

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LITERATURE CITED

Alzieu, C. 1986. TBT detrimental effects on oyster culture in France - evolution since antifouling paint regulation. *In Oceans '86 Conference Record: Science-Engineering-Adventure.* Vol. **4**. IEEE, New York.

Ansuini, F.J. and J.E. Huguenin. 1978. The design and development of a fouling-resistant marine fish-cage system. *Proceedings of the Ninth Annual Meeting World Mariculture Society* pp. 737-745.

Beveridge, M.C.M. 1987. *Cage aquaculture.* Fishing News Books, Ltd. Farnham, Surrey, England.

Blair, A. and W.H. Burgess. 1979. Rotating, floating cage for fish culture simplifies cleaning and replacement of panels. *Prog. Fish. Cult.* **41**:74-76.

Blair, A., R. Campbell, and P. T. Grant. 1982. A submersible fish cage that can be rotated on the surface to remove biofouling and for other purposes. *Aquaculture* **29**:177-184.

Caillouet, C.W. 1972. Rotatable cage for high density aquaculture. *Prog. Fish Cult.* **34**(1):8.

Coche, A.G. 1982. Cage culture of tilapias. Pages 205-246 *in* R.S.V. Pullin and R.H. Lowe-McConnell, eds. The biology and culture of tilapias. *ICLARM Conference Proceedings* 7. International Center for Living Aquatic Resources Management, Manila, Philippines.

Davies, I.M., J.C. McKie, and J.D. Paul. 1986. Accumulation of tin and tributyltin from anti-fouling paint by cultivated scallops (*Pecten maximus*) and Pacific oysters (*Crassostrea gigas*). *Aquaculture* **55** (2):103-114.

Dropsy, B. 1987. Bilan biotechnique d'elevage en cage sur quelques especes de poissons tropicaux a l'ADAM. *Proc. Gulf Carib. Fish. Inst.* **38**:45-63.

Geffen, A. 1979. Rotating fish cages to prevent fouling. *Aquaculture* **16**:83-85.

Inoue, H. 1972. On water exchange in a net cage stocked with the fish, Hamachi. *Bull. Japanese Soc. Sci. Fish.* **38**:167-76.

Kaneko II, J. J., R. Yamada, J.A. Brock, and R.M. Nakamura. 1988. Infection of tilapia, *Oreochromis mossambicus* (Trewavas), by a marine monogenean, *Neobenedenia melleni* (MacCallum, 1927) Yamaguti, 1963 in Kaneohe Bay, Hawaii, USA, and its treatment. *J. Fish Disease* 11(4):295-300.

Liao, I. C. and S.L. Chang. 1983. Studies on the feasibility of red tilapia culture in saline water. Pages 524-533 *in* L. Fishelson and Z. Yaron, compilers. *Proc. Int. Symp. on Tilapia in Aquaculture.* Tel Aviv University, Tel Aviv, Israel.

Meriwether, F.H., E.D. Scura, and W.Y. Okamura. 1984. Cage culture of red tilapia in prawn and shrimp ponds. *J. World Maric. Soc.* **15**:254-265.

Milne, P. H. 1970. Fish farming: a guide to the design and construction of net enclosures. *Mar. Res.* **1**:1-31.

Paul, J. D. and I. M. Davies. 1986. Effects of copper- and tin- based anti-fouling compounds on the growth of scallops (*Pecten maximus*) and oysters (*Crassostrea gigas*). *Aquaculture* **54**(3):191-203.

Popper, D. and T. Lichatowich. 1975. Preliminary success in predator control of *Tilapia mossambica. Aquaculture* **5**:213-214.

Porter, C. 1981. Cage culture of gilthead bream (*Sparus aurata*) at an exposed site on the Red Sea. *Special Publication of the European Mariculture Society* **6**:15-24.

Short, J. W. and F.P. Thrower. 1986. Accumulation of butyltins in muscle tissue of chinook salmon reared in sea pens treated with tri-n-butyltin. *Mar. Poll. Bull.* 17(12):542-545.

Stickney, R. R. 1986. Tilapia tolerance of saline waters: a review. *Prog. Fish Cult.* **48**:161-167.

Ward, J. 1988. Antifouling paints threaten fisheries resources. *NAGA - The ICLARM Quarterly* **11**(2):15.

Watanabe, W.O., L.J. Ellingson, R.I. Wicklund, and B.L. Olla. 1988. The effects of salinity on growth, food consumption and conversion in juvenile, monosex male Florida red tilapia. *In* R. S. V. Pullin, T. Bhukasawan, K. Tonguthai, and J. L. Maclean, eds. The Second International Symposium on Tilapia in Aquaculture. *ICLARM Conference Proceedings* 15. Department of Fisheries, Bangkok, Thailand and International Center for Living Aquatic Resources Management, Manila, Philippines.

Whitfield, A.K. and S.J.M. Blaber. 1979. The distribution of the freshwater cichlid *Sarotherodon mossambicus* in estuarine systems. *Enviro. Bio. Fish.* **4**(1):77-81.

Wohlfarth, G. W. and G. Hulata. 1983. Applied genetics of tilapias. *ICLARM Studies and Reviews* 6. International Center for Living Aquatic Resources Management, Manila, Philippines.