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46

Aquaculture of red Tilapia (*Oreochromis sp.*) in marine environments : state of the art

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Abstract — *The Caribbean Marine Research Centre is conducting research on the development of methods for intensive culture of euryhaline red tilapias in marine environments for application to Caribbean islands and similar regions with limited freshwater resources.*

The effects of salinity on growth and reproductive performance of Florida red tilapa have been determined under controlled laboratory conditions. Salinity tolerance has been studied in relation to early salinity exposure and to ontogenetic development. The results provide a basis for the development of methods for seawater adaptation that minimize reliance on freshwater during the hatchery phase of production and that improve survival and growth in seawater.

A commercial-scale tilapia hatchery is in operation on Lee Stocking Island (Bahamas), supporting research on seed production and grow-out technology under saline conditions. Research has emphasized seed production methods that conserve freshwater through culture intensification, including use of high brood fish stocking densities and artificial egg incubation, and utilization of recirculated brackishwater. The feasibility for large-scale fry production using brackishwater (12 ppt) has been demonstrated.

Grow-out of Florida red Tilapia fingerlings in seawater (37-41 ppt) has been studied in 23-m^3 above ground pools and in 1 m^3 floating cages at densities of 25/m^3 and 300/m^3, respectively, using prepared diets containing 30-32 % protein. In pools, fish fed at satiation rates were reared from 1.3 to 467 g mean weight over 170 days with a survival of 89.7 % and a food conversion ratio of 1.6. In floating cages, fish fed at similar rates were reared from 9.1 to 150 g mean weight in 84 days, with a survival of 98.2 % and a feed conversion ratio of 2.0. The faisability of reducing cost by using diets containing protein levels as low as 20 % for grow-out has been demonstrated.

The results support an excellent potential for utilization of saline-tolerant red tilapias for intensive culture in tropical marine environments.

INTRODUCTION

The Caribbean Marine Research Centre (CMRC) is a private, non-profit research organization based in Riviera Beach, Florida, with principal research facilities on Lee Stocking Island, Exuma Cays, Bahamas. Since July 1984, CMRC has undertaken a programme of research aimed at developing methods for intensive saltwater culture of euryhaline tilapias for application to Caribbean Islands and similar regions where freshwater resources are often limiting (Watanabe *et al.*, in press-b).

Red hybrid tilapia are gaining popularity among culturists due to their resemblance to premium marine species such as sea bream (*Chrysophrys major*) and red snapper (*Lutjanus campechanus*) (Fitzgerald 1979; Liao and Chen 1983; Fassler 1984; Stickney 1986) and excellent growth and feed conversion rates in freshwater (Liao and Chen 1983). An excellent potential for market development exists for fresh product in Japan (Fassler 1984) and the U.S. West Coast (Trosclair 1988). In Caribbean Islands such as the Bahamas (J. Thompson), Curacao (H. Martina and R. Hoseth) and Martinique (J.-P. Marion), a domestic market for red tilapias has been created by the inability of marine catches to satisfy demand for fish (personal communications). Commercial tilapia farming in the Caribbean is successfully established in Jamaica, where red hydrid strains are preferred by consumers (Chakallal and Noriega-Curtis in press). Export of red tilapia fillets to Florida has recently begun. Production for 1987 is estimated at 2,600 mt from 720 ha of fresh and brackishwater (0-10 ppt) ponds. As water resources in Jamaica are scarce, water supply is considered as an important constraint to further expansion of aquaculture (Chakallal and Noriega-Curtis in press).

While the genetic heritages of the existing varieties of red tilapias are not well documented, their derivation is generally attributed to cross-breeding of mutant reddish-orange *Oreochromis mossambicus* (a normally black species) with other species including *O. aureus, O. niloticus* and *O. hornorum* (Fitzgerald 1979; Behrends *et al.*, 1982; Galman and Avtalion, 1983). The suitability of red hybrid tilapias for brackish - and seawater culture is suggested by the salinity tolerance exhibited by these parental species, which are known to be moderately (*O. niloticus* and *O. aureus*) to highly (*O.mossambicus* and *O. hornorum*) euryhaline (Philipart and Ruwet 1982; Stickney 1986).

The feasibility of rearing red hybrid tilapia in brackish and seawater was first studied by Liao and Chang (1983) who reported good growth of Taiwanese red tilapia (*O. mossambicus* and *O. niloticus*) at salinities of 17 ppt and 37 ppt, although fish appeared susceptible to handling stress. Seawater-rearing studies of Taiwanese red tilapia in Kuwait (Hopkins *et al.*, 1985) showed that survival at 38-41 ppt was impaired at water temperatures below 24°C.

A red tilapia strain originating in Florida, USA was selected by CMRC for seawater culture trials in the Bahamas due to the high salinity tolerance of both its parental species (*O.hornorum and O. mossambicus*). Following a preliminary study which showed higher growth and feed conversion of juvenile, monosex males in brackish and seawater than in

freshwater (Watanabe *et al*,. 1988a), detailed studies on culture methodology were initiated. Experimental work at CMRC has sought to obtain basic information on the biology of the Florida red tilapia with respect to salinity tolerance as well as to assess production performance in seawater.

Origin of the « Florida red » tilapia strain

According to commercial culturists responsible for their development (C. Harris and R. De Wandel personal communication), red tilapia hybrids originating in the United States were first developed in the late 1970's by a commercial fish breeder (M. Sipe) in Florida. Inbredding of a population of *O. mossambicus* produced a mutant with reddish-yellow pigmentation, which was selectively bred to enhance the red and yellow coloration, resulting in a market decline in growth and body shape. In order to restore these qualities, mutant male *O. mossambicus* was crossbred with female *O. hornorum* (a black colored species) to produce a first generation (F1) red hybrid. F1 red hybrids were sold to producers for grow-out. In addition, black *O. hornorum* females and red *O. mossambicus* males were sold as broodstock to farmers, who could produce hybrids for grow-out, but could not generate additional pureline broodstock. In 1981, other commercial culturists began a selective breeding program with the F1 hybrids and, by the end of 1983, developed a relatively true breeding strain of red tilapia. Fish descended from F1 progeny became known to aquaculturists as the « Florida red » strain.

THE EFFECTS OF SALINITY ON GROWTH OF FLORIDA RED TILAPIA

Growth of juvenile, monosex males at different salinities

Little information is available on the influence of salinity on growth in tilapias. For most species, optimal ranges of salinities for growth have been inferred from data on natural distributions and/or fragmentary experimental evidence.

The effects of salinity on growth of juvenile, monosex-male Florida red tilapia were studied under controlled photoperiod (12 L : 12 D) and temperature (28°C). A high euryhaline capacity of the Florida red tilapia strain was evidenced by faster growth rates in brackish and seawater than in freshwater, although results appeared to be modified by stocking density (Watanabe *et al.* 1988.a). At a high density (20 fish/200 l tank), growth in freshwater was comparable to growth at 10 ppt and above. Growth under 36 ppt at a low density (10 fish/tank) was lower than that at a high density. At an intermediate density (15 fish/tank), however, there was a clear trend toward increased growth with salinity due to increased feed consumption and declining feed conversion ratios with salinity (Watanabe *et al.* 1988a). These results support previous reports of faster growth in brackish and seawater than in freshwater in certain tilapias including *O. mossambicus* (Canagaratnam, 1966; Jurss et al. 1984) and Taiwanese red tilapia hybrids (*O. mossambicus* and *O. niloticus*) (Liao and Chang 1983).

The influence of behavior on growth at different salinities

The apparent density-dependent differences in growth response to salinity observed in these studies suggested that behavioral factors influenced these results. Further investigations revealed that agonistic encounters among fish as well as percentages of fish with damaged fins (due to agonistic encounters) declined with salinity, suggesting that growth response to salinity was influenced by inhibitory effects of territorial aggression, which was mitigated by increasing salinity (Watanabe *et al.*, 1988b). This suggested that agression impairs growth by lowering feed consumption (appetite) and increasing conversion ratios. Hence, as agression was mitigated by increasing salinity, growth was improved. That behavioral interaction may exert inhibitory effects on growth which vary with salinity. It was previously suggested for Taiwanese red tilapia (Liao and Chang 1983).

COMMERCIAL-SCALE HATCHERY FOR SALTWATER TILAPIA CULTURE

The general procedures developed by CMRC for culture of Florida red tilapia in seawater are relatively simple : Spawning occurs naturally in brood tanks maintained under low salinity (3-6 ppt groundwater). Periodically, free-swimming fry are collected from the pools while unhatched eggs and yolksac fry are removed from mouthbrooding females and incubated artificially. Yolksac-absorbed fry are fed a diet containing an androgenic hormone (17 alpha-ethynyltestosterone) for 28 days to transform genotypic females to phenotypic males (Guerrero 1975). Monosex culture prevents unwanted reproduction at an early age which results in overcrowding and stunting during grow-out and minimizes the possibility of reproduction outside of the hatchery and the likelihood of unwanted introductions. After sex-reversal, fry (approximately 0.8-0.9 g in weight) are acclimated to seawater over a period of 1 week, then transferred to nursery tanks where they are grown to large fingerling sizes (approximately 5-10 g) prior to stocking in tanks or sea cages for grow-out.

An experimental tilapia hatchery supporting research on seed production and grow-out technology under saline conditions, has been in operation since April 1987 on Lee Stocking Island, Bahamas. The design and operation of this commercial-scale facility, consisting of six 34 m2 broodfish tanks, sixteen 560 l rearing tanks for sex reversal of fry, and eight 4.9 m3 tanks for seawater acclimation of sex -reversed fry, is described in details by Ernst (In press). The hatchery incorporates a system for recirculation of water through biofilters, a critical design feature in the Bahamas where limited groundwater resources must be conserved. Multiple recirculation systems permit simultaneous testing of separate salinity regimes for broodstock holding and sex-reversal so that optimal salinities for maintaining broodstock and rates of acclimation of fry to seawater may be determined experimentally. Spawning, incubation of eggs and sex-reversal of fry may be conducted at any salinity up to that of full seawater (36-37 ppt).

DEVELOPMENT OF METHODS FOR ADAPTATION TO SEAWATER

While the suitability of the Florida red tilapia strain for seawater grow-out has been demonstrated by high growth rates and feed conversion efficiencies, the hatchery phase of production remains restricted to water of lower salinities. The requirements for low-salinity water for maintaining broodstock and for early fry rearing restricts the siting of future hatcheries to areas where low-salinity water is available, ultimately affecting the ability of farmers to obtain fingerlings. Methods for seawater adaptation have been developed that minimize reliance on low-salinity water during the hatchery phase of production and that maximize survival and growth following transfer to seawater.

Selection of optimal life stage for seawater transfer

Low-salinity water requirements during the hatchery phase of production may be reduced by acclimating stocks to seawater at early stages of development (Watanabe *et al.*, 1985a-b). However, as salinity tolerance in tilapias varies ontogenetically, survival and growth in seawater may be affected by the life stage at which acclimation to seawater is initiated (Watanabe *et al*,. 1985b).

Salinity tolerance was determined in Florida red tilapia, spawned under 5 ppt, at 10, 25, 40, 55 and 70 days post-hatching, using the 96 hours median lethal salinity (MLS- 96) index. A trend toward increased tolerance with age was observed, with tolerance improving markedly from 40 days post-hatching (Watanabe *et al*,. unpublished date). To assess the influence on culture performance of age at which transfer to seawater (37 ppt) is initiated, survival of progeny acclimated to seawater beginning at 10, 25 and 39 days-hatching was compared. Survival to 48 days post-hatching improved as transfer was delayed, from 20.0 % in progeny beginning acclimation at 10 days post-hatching, to 55.9 % in progeny beginning acclimation at 39 days post-hatching. The results demonstrate that premature transfer to seawater can impair survival and that, selection of proper transfer time, based on knowledge of ontogenetic variation in salinity tolerance, can improve survival.

Production of seedstock in brackishwater

Another approach to reducing low-salinity water requirements during the hatchery phase of production is to maintain and spawn broodstock at elevated salinities. This approach is generally limited by the fact that, in tilapias, normal reproduction is inhibited by increasing salinity (Ridha *et al*,. 1985; Watanabe and Kuo, 1985).

The reproductive performance of yearling Florida red tilapia broodstock was studied in laboratory aquaria at salinities of 1 (freshwater), 9, 18, 27 and 36 ppt under controlled photoperiod (14 L : 10 D) and temperature (28 °C) (Watanabe *et al.*, in press-a). Spawning was observed at all salinities, although an inhibitory effect of salinity on reproductive perfor-

mance was manifested by a trend toward lower fertilization, hatching, and survival of prejuveniles with increasing salinity. Fry production per unit female weight declined at salinities above 18 ppt. The results suggest that Florida red tilapia broodstock may be maintained under salinities as high as 18 ppt without impairing fry production, further suggesting that hatchery production in brackishwater would be practical in areas where freshwater resources are limiting.

Influence of spawning salinity on survival and growth in brackish and seawater

To assess the influence of spawning salinity on survival and growth in brackish or seawater, growth of juveniles, spawned at salinities of 4 and 18 ppt, were compared at rearing salinities of 18 ppt and 36 ppt, in 200 l aquaria under controlled photoperiod (12 L : 12 D) and temperature (28° C). Under both rearing salinities, growth was significantly higher for progeny spawned at 18 ppt than those spawned at 4 ppt, suggesting that progeny spawned under elevated salinities are better adapted for growth in brackish and seawater (Watanabe *et al.*, 1989).

In another experiment, growth of juvenile progeny spawned and sex reversed at salinities of 2 ppt and 1.8 ppt was compared in 24 m3 outdoor pools at 36 ppt. When water temperatures exceeded 27° C, growth and survival were not significantly different between these groups. However, when temperatures abruptly fell below 25° C, growth and survival remained significantly higher among progeny spawned at 18 ppt (Watanabe *et al.*, 1989). This suggests that brackishwater-spawned progeny possesses a higher resistance to cold-stress in seawater than freshwater-spawned progeny. As Florida red tilapia have been overwintered in seawater tanks (37 ppt) in the Bahamas under water temperatures as low as 16° C without adverse effects (Watanabe et al., unpublished data), low-temperature tolerance may be related to the rate of temperature decline, rather than to a critical lower limit.

Large scale seed production in brackishwater

At the CMRC tilapia hatchery, broodstock are maintained in 34 m^3 broodtanks at a ratio of 180 females to 60 males. Based on the results of laboratory studies in which successful reproduction in brackishwater and improved seawater survival and growth of brackishwater-spawned progeny were observed, brood tank salinities were increased in 1988 to 12 ppt by mixing groundwater with seawater. Rates of seed (eggs, yolksac fry and free-swimming fry) production in broodtanks were monitored under the egg removal method of broodstock management, in which eggs as well as yolksac fry are removed every 16 days for artificial incubation. Data for an 84 days period during March-May 1988 showed that each broodtank produced a mean of 188,000 eggs and yolksac fry and 79,808 free swimmming fry (3188 seed/day or 93.8 seed/m^3/day) (Watanabe *et al.*, unpublished data), a higher production rate than reported for intensive seed production of *O. niloticus* (73 seed/m^3/day) (Hughes and Behrends, 1983). Average survival of eggs and yolksac fry through artificial incuba-

tion was 66.5 %, while survival through the 28 days sex-reversal period was 73.9 % for artificially incubated fry and 49.7 % for naturally incubated fry, yielding 1572 sex-reversed fry/day, or 46.2/m^2/day. The feasibility for large-scale production of Florida red tilapia fry in brackishwater (12 ppt) was demonstrated.

Tab. 1. — Summarized data on seawater rearing experience with monosex-male Florida red Tilapia hybrids in 23.2 m^3 aboveground pools and in 1.0 m^3 floating cages[a] (Data are based on 4 replicate culture units)

	Culture system	
	Floating cages	Aboveground pools
Stocking data		
Initial wt. (g)	9.1	1.3
Density (number/m^3)	300	25
Initial biomass (kg/m^3)	2.73	0.03
Growth data		
Culture duration (days)	84	170
Feeding rate (% body wt./day)[a]	9.9 declining to 3.3	>30 declining to 1.5
Daily weight gain (g/day)[b]	1.68	2.74
Specific growth rate (%/day)[c]	3.34	3.46
Harvesting data		
Survival (%)	98.2	89.7
Final wt. (g)	150	467
Final biomass (kg/m^3)	35.2	10.5
Feed conversion ratio (dry wt./wet wt.)	2.0	1.6
Culture conditions		
Salinity (ppt)	34 - 41	36 - 39
Temperature (°C)	26 - 33	22 - 30
Dissolved oxygen (ppm)	3.0 - 5.2	4.3 - 6.7

[a] Fish were fed commercially prepared diets containing 32 % (floating cages) or 30 % (aboveground pools) protein.
[b] (final wt - initial wt.)/number of days.
[c] 100 (Ln final wt - Ln initial wt.)/number of days.

REARING EXPERIMENTS IN MARINE CAGES

An experiment was conducted to assess the feasibility of rearing Florida red tilapia in floating cages at a marine site on Great Exuma, Bahamas. Survival and growth of monosex males (9.1 g mean weight) were studied in cages (1 m^3, 12.7 mm mesh) stocked at density of 300/m^3. Fish were fed three times daily a commercially prepared diet containing 32 % protein at a satiation rate. Over 84 days, feeding rate declined with increasing fish size from 10.5 % to 3.3 % body weight/day. After 84 days, mean fish weight was 150 g and average daily weight gain was 1.82 g (J. Clark *et al*,. unpublished data) (Table 1), a growth rate comparable to that observed in seawater pools (Ernst *et al.*, in press) when data on growth over a similar size interval were compared. Feed conversion ratio for the 84 days period was 2.04.

Temperatures remained above 28° C during the first 62 days but showed relatively abrupt declines during the final 22 days, with minimum temperatures falling to 26° C during this period. Salinity fluctuated over a relatively wide range (34-41 ppt) and was affected by tides and rainfall. Ambient dissolved oxygen levels ranged from 4.0 to 5.8 ppm, while in-cage levels were below ambient and decreased over time as cage biomass increased, falling to a low of 3.0 ppm and indicating that cage carrying capacities were approached. While no information is available in critical dissolved oxygen levels for tilapias reared in seawater cages, a dissolved oxygen of 3.0 ppm is considered a minimum below which adverse effects appear during freswater cage culture (Coche 1982). When the experiment was terminated after 84 days, survival was 98.2 % and final biomass was 35.2 kg/m^3. Evidence of disease (i.e., clouded eyes, external hemorrhagic areas, and reduced feeding) observed during the final 14 days of the study were likely related to stress induced by the combined effects of declining in cage dissolved oxygen and declining temperature.

Although the feasibility for culture of Florida red tilapia in floating marine cages was demonstrated by high growth and feed conversion rates, further studies are required to assess long-term growth under conditions in which dissolved oxygen is not limiting. In cage dissolved oxygen can likely be improved by utilization of lower stocking densities and increasing cage mesh size with fish growth, to improve circulation.

REARING EXPERIMENTS IN SEAWATER POOLS

Survival and growth of monosex male Florida red tilapia (1.3 g mean weight) was studied in 23 m^3 above ground pools stocked at a density of 25 fish/m^3 (Ernst *et al.*, in press) (Table 1). Pools were provided with aeration and with flow-through seawater (37 ppt) at 2.5 - 5.0 exchanges per day. Temperatures ranged from 22.0 to 29.5°C during the experiment, while dissolved oxygen averaged 5.6 ppm.

Fish were fed daily a commercially prepared diet containing 30 % protein at a satiation rate, defined as the percentage of body weight consumed in three 30 minutes feeding periods. Over 170 days, feeding rate declined with increasing fish size from > 30 % to 1.5 % body weight/day. After 170 days, mean fish weight was 467 g at a survival rate of 89.7 %. Average daily weight gain was 2.74 g, a growth rate superior to those reported for Taiwanese red tilapia reared brackish and seawater (0.43-1.21 g/day) (Liao and Chang, 1983; Neriwether *et al*,. 1984; Hopkins *et al.* 1985) and comparable to that achieved with Taiwanese red tilapia under intensive freshwater culture, where fish are grown from 1 to 500 g in 150 to 180 days (2.77 - 3.33 g/day) (Liao and Chen, 1983). Feed conversion ratios for the 170 days period was 1.6. A high growth capacity and excellent feed conversion ratios in seawater from fingerling through market stages were demonstrated.

GROWTH, FEED AND PROTEIN UTILIZATION ON DIETS WITH DIFFERENT PROTEIN LEVELS IN SEAWATER POOLS

Growth, feed and protein utilization of monosex male Florida red tilapia fingerlings (10.6 g mean wt.) fed isocaloric diets with different protein levels (20 %, 25 % and 30 % protein) were studied through adult, marketable sizes in seawater pools (10 m^3) stocked at a density of 25 fish/m^3 (A. Clark *et al.*, unpublished data). Pools were provided with aeration and with flow-through seawater (37 ppt) at 7 exchanges per day. Average maximum/minimum temperatures were 32 ± 1°C / 28 ± 1°C during the experiment, while dissolved oxygen averaged 5.1 ppm.

Growth rates were high for all diets, with mean weights ranging from 440 to 464 g after 120 days, and survival ranging from 97.0 - 97.5 %. Feed consumption decreased with increasing body weight, with average consumption declining from 11.3 to 2.57 % body weight/day during the experiment. While there were no significant differences among diets in mean daily weight gain (3.60 - 3.75 g/day) or feed conversion ratios (2.01 -2.20), protein efficiency ratio was significantly higher in the 20 % protein diet (2.41) than at higher protein levels (1.74 - 2.04). The results demonstrate that Florida red tilapia can be reared in seawater from fingerling through marketable sizes more economically levels and suggest that reasonable growth rates may be maintained at protein levels lower than 20 %.

FUTURE RESEARCH REQUIREMENTS

Available evidence suggests that in tilapias, resistance to cold-stress is lowered under high salinities due to the interactive effects of temperature and salinity on osmoregulation (Allanson *et al*,. 1971; Tilney and Hocutt, 1987). Whereas *O. aureus, O. niloticus* and Taiwanese red tilapia hybrids *(O. mossambicus* x *O. niloticus*) exhibited heavy mortalities in seawater cages (30 ppt) under seasonally declining temperatures, considerably fewer mortalities were observed among fish reared at salinities of 8 ppt (Ting *et al*,. 1984). Furthermore, red tilapia growth rates were higher at 16 ppt than at 8 ppt or 30 ppt under these conditions. Increased incidence of disease under seasonally declining temperatures was previously observed in Florida red tilapia reared in seawater pools (Ernst *et al*,. in press).

Studies are required to assess the effects of salinity on low-temperature tolerance in Florida red tilapia, to identify causative agents of overwintering diseases, and to develop methods for prevention or treatment. Introgressive breeding may be a potentially important technique for developing cold-tolerant strains (Behrends and Smitherman, 1984).

Studies are also needed to determine the combined effects of dissolved oxygen, salinity, temperature and photoperiod on survival and growth of Florida red tilapia in order to define environmental conditions suitable for saltwater culture of this strain and to develop methods for maximizing survival and growth by environmental control.

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Allanson B.R., A. Bok and N.I. van Wyk, 1971. The influences of exposure to low temperature on *Tilapia mossambica* Peters (Cichlidae). II. Changes in serum osmolarity, sodium and chloride concentrations. *Journal of Fish Biology*, **3** : 181 - 185.

Behrends L.L., R.G. Nelson, R.O. Smitherman and N.M. Stone, 1982. Breeding and culture of the red-gold color phase of tilapia. *Journal of the world Mariculture Society*, **13** : 210 - 220.

Behrends L.L and R.O. Smitherman, 1984. Development of a cold-tolerant population of red tilapia through introgressive hybridization. *Journal of the world Mariculture Society*, **15** : 172 - 178.

Canagaratnam P., 1966. Growth of *Tilapia mossambica* (Peters) in different salinities. *Bulletin of the Fisheries Research Station Ceylon*, **19** : 47 - 50.

Chakallal B. and P. Noriega-Curtis, (in press). Tilapia farming in Jamaica. Proceedings 41 st Annual Gulf and Caribbean Fisheries Institute, 6- 11 November 1988, St. Thomas, U.S. Virgin Islands.

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

Ernst D.H., (in press). Design and operation of a hatchery for seawater production of tilapia in the Caribbean. Proceedings of the Thirty-Ninth Annual Gulf and Caribbean Fisheries Institute, November 1986, Bermuda.

Ernst D.H., L.J. Ellingson, B.L. Olla, R.I. Wicklund, W.O. Watanable and J.J. Grover, (in press). Production of Florida red hybrid tilapia in fed and nanured seawater pools. *Aquaculture*.

Fassler R., 1984. Golden Tilapia The catch of tommorow. *Hawaii Fishing News*, **9** (3) : 24 - 25.

Fitzgerald W.J., 1979. The red orange tilapia : a hybrid that could become a world favourite. *Fish Farming International*, **6** (1) : 26 - 27.

Galman O.R. and R.R. Avtalion, 1983. A preliminary investigation of the characteritics of red tilapias from the Philippines and Taiwan. Pages 291 - 301 *in* L. Fishelson and Z. Yaron, compilers. Proceedings of the International Symposium on Tilapia in Aquaculture, Nazareth, Israel, 8 - 13 May 1983. Tel Aviv University, Tel Aviv.

Guerrero R.D. III,. 1975. Use of androgens for the production of all male *Tilapia aurea* (Steindachner). *Transactions of the American Fisheries Society*, **104** : 342 - 348.

Hopkins K., M. Ridha, D. Leclercq and T. Al-Ahmad, 1985. Screening tilapias for sea water culture in Kuwait. Interim Report, 15 pp. Mariculture and Fisheries Department, Kuwait Institute for Scientific Research and International Center for living Aquatic Resources Management.

Hughes D.G. and L.L. Behrends, 1983. Mass production of *Tilapia nilotica* seed in suspended net enclosures. Pages 394 - 401 *in* L. Fishelson and Z. Yaron, compilers. Proceedings of the International Symposium on Tilapia in Aquaculture, Nazareth, Israel, 8- 13 May 1983. Tel Aviv University, Tel Aviv.

Jurss K., Th. Bittorf, Th. Vokler and R. Wacke, 1984. Biochemical investigations into the influence of environmental salinity on starvation of the tilapia, *Oreochromis mossambicus. Aquaculture*, **40** : 171 - 182.

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. Proceedings of the International Symposium on Tilapia in Aquaculture, Nazareth, Israel, 8 - 13 May 1983. Tel Aviv University. Tel Aviv.

Liao I.C. and T.P. Chen, 1983. Status and prospects of tilapia culture in Taiwan. Pages 588 - 598 *in* L. Fishelson and Z. Yaron, compilers. Proceedings of the International Symposium on Tilapia in Aquaculture, Nazareth, Israel, 8- 13 May 1983. Tel Aviv University, Tel Aviv.

Meriwether F.H. II., E.D. Scura and W.Y. Okamura, 1984. Cage culture of red tilapia in prawn and shrimp ponds. *Journal of the world Mariculture Society*, **15** : 254-265.

Philippart J.C. and J.C. Ruwet, 1982. Ecology and distribution of tilapias. Pages 15 - 59 *in* R.S.V. Pullin and R.H. Lowe-McConnell, editors. The Biology and Culture of Tilapias. ICLARM Conference Proceedings 7, International Center for Living Aquatic Resources Management, Manila, Philippines.

Ridha M., T.A. AL-Ahmad and A.A. Al-Ahmad, 1985. Tilapia culture in Kuwait : spawning experiments, 1984. KIBR technical report 1875, 19 pp. Kuwait Institute for Scientific Research.

Stickney R.R., 1986. A review of tilapia salinity tolerance. *Progressive Fish-Culturist*, **48** : 161-167.

Tilney R.L. and C.H. Hocutt, 1987. Changes in gill epithelia of *Oreochromis mossambicus* subjected to cold shock. *Environmental Biology of Fishes*, **19 (1)** : 35-44.

Ting Y.Y., M.H. Chang, S.H. Chen, Y.S. Wang and W.H. Cherng, 1984. Three kinds of Tilapia spp. reared in three different salinities water for cage cultural wintering experiment. *Bulletin of the Taiwan Fisheries Research Institute*, **37** : 101 - 115.

Trosclair C., 1988. Arizona desert targeted for $10 million investments. *Water Farming Journal*, **3 (4)** : **1**.

Watanabe W.O. and C.M. Kuo, 1985. Observations on the reproductive performance of Nile tilapia (*Oreochromis niloticus*) in laboratory aquaria at various salinities. *Aquaculture*, **49** : 315 - 323.

Watanabe W.O., C.M. Kuo and M.C. Huang, 1985a. Salinity tolerance of Nile tilapia fry (*Oreochromis niloticus)*, spawned and hatched at various salinities. *Aquaculture*, **48** : 159 - 176.

Watanabe W.O., C.M. Kuo and M.C. Huang, 1985b. The ontogeny of salinity tolerance in the tilapias *oreochromis aureus, O. niloticus,* and an *O. mossambicus x O. niloticus* hybrid, spawned and reared in freshwater. *Aquaculture*, **47** : 353 - 367.

Watanabe W.O., K.M. Burnett, B.L. Olla and R.I. Wicklund, in press-a. The effects of salinity on reproductive performance of Florida red tilapia. *Journal of the World Aquaculture Society.*

Watanabe W.O., L.J. Ellingson, R.I. Wicklund and B.L. Olla, 1988a. The effects of salinity on growth, food consuption and conversion in juvenile, monosex male Florida red tilapia. *In* R.S.V. Pullin, T. Bhukasavan, K. Tonguthai and J.L. Maclean, editors. 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.

Watanabe W.O., K.E. French, L.J. Ellingson, R.I. Wicklund and B.L. Olla, 1988b. Further investigations on the effects of salinity on growth of Florida red tilapia : evidence for the influence of behavior. *In* R.S.V. Pullin, T. Bhukasawan, K. Tonguthai and J.L. Maclean, editors. 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.

Watanabe W.O., K.E. French, B.L. Olla, D.H. Ernst and R.I. Wicklund, 1989. Salinity during early development influences survival and growth of Florida red tilapia in brackish and seawater. *Journal of the world Aquaculture Society* **20** (1).

Watanabe W.O., R.I. Wicklund, B.L. Olla, D.H. Ernst and L.J. Ellingson, *in* press. Potential for saltwater tilapia culture in the Caribbean. Proceedings 39th Annual Gulf and Caribbean Fisheries Institute, 10-14 November 1986, Bermuda.