Potential for Saltwater *Tilapia* Culture in the Caribbean

WADE O. WATANABE, ROBERT I. WICKLUND, BORI L. OLLA[1], DOUGLAS H. ERNST AND LISA J. ELLINGSON
Caribbean Marine Research Center
Lee Stocking Island, Exuma Cays
Bahamas and
100 E. 17th St.
Riviera Beach, Florida 33404

[1]*Cooperative Institute for Marine Resources Studies*
National Marine Fisheries Service

ABSTRACT

El progreso en el área de la maricultura de los peces se ha visto obstaculizado por problemas técnicos relacionados con el control de la reproducción en cautiverio y con la producción de alimento vivo para las larvas. A pesar de que, hasta el presente, el cultivo de la tilapia (familia Cichlidae) se limita principalmente a sistemas de agua dulce o aquellos con agua salobre de baja salinidad, se ha sugerido que las tilapias eurihalinas pueden cultivarse en sistemas con agua salobre de alta salinidad o en agua de mar. A diferencia de las especies de peces marinos, la tilapia de agua dulce se reproduce libremente en cautiverio y su larva acepta alimento artificial a etapas muy tempranas (luego de la etapa con saco vitelino).

Las Bahamas, caracterizada por su abundancia en bahías naturales y áreas costeras protegidas con sus aguas claras, sin contaminación y con una tasa alta de flujo rápido de agua, es un lugar apto para el cultivo de peces en jaulas colocadas en el mar. Estudios previos llevados a cabo en Exuma Cays y Bahamas Central, han revelado que el híbrido rojo de la tilapia (hembra Oreochromis urolepis hornorum x macho Oreochromis mosambicus) tiene un alto grado de adaptabilidad al agua de mar, al igual que es resistente al manejo al cual se le someta y a las enfermedades. Este híbrido puede cultivarse a densidades altas con alimento artificial en jaulas flotantes en el mar con una tasa de mortalidad baja.

Su aceptabilidad como producto alimenticio ha aumentado por su atractiva coloración anaranjado-rojo, al igual que por su firmeza en la carne y por su buen sabor. Los métodos simples utilizados en la fase de vivero y en la etapa de producción, sugieren que el híbrido rojo de la tilapia es una especie apropiada para cultivarse en el mar, ya sea a nivel de subsistencia o con propósitos comerciales. Se necesitan, sin embargo, estudios dirigidos a determinar cuales son los métodos óptimos de aclimatación y como puede reducirse el uso del agua dulce durante el período de vivero y de crianza. Tomando en consideración la facilidad con que se puede criar y cultivar el híbrido de la tilapia roja y por su alta adaptabilidad al agua de mar, se considera que su cultivo en jaulas posee un gran potencial en la maricultura en áreas con recursos limitados de agua dulce o tierras cultivables, como lo son las Bahamas y otras regiones del Caribe.

INTRODUCTION

Scarcity of arable lands and limited freshwater resources in many areas of the Caribbean make traditional agriculture and livestock production impractical to increase food production. Temporal and spatial distribution of rainfall result in severe water shortages and surpluses in many areas (Leonce, 1980). In Haiti, demand for cultivable land created by an increasing population has led to deforestation of catchment areas where major rivers which provide water for agriculture originate, further reducing freshwater resources and causing erosion of valuable topsoil. In the Bahamas, water for agricultural development must be extracted from freshwater lenses, the only groundwater resource, which must be carefully managed to avoid saltwater intrusion and pollution (Cant, 1980). Islands lacking freshwater resources must rely on more costly methods of supply such as desalination or marine transport of groundwater from other islands.

Fisheries products, long recognized as a source of high quality protein, have traditionally formed an important component of the diet of the Caribbean people. The marine capture fisheries do not adequately meet the needs of the region which must therefore import much of the seafood consumed. Diminishing natural fish stocks due to heavy exploitation is an increasingly serious problem in lesser developed areas of the island chain where artisanal and subsistence fisheries operate. Although there exists a potential for increasing fishery production through proper development and management, it is unlikely that the protein needs of an expanding population can be adequately met by traditional capture fisheries. Mariculture has been suggested as a potentially important means of increasing animal protein production in the region, offering the important advantages of utilization of marginal lands and coastal areas, and minimizing reliance on freshwater.

SELECTION OF APPROPRIATE FINFISH SPECIES FOR MARICULTURE DEVELOPMENT

Characterized by clean, unpolluted seawater and a tropical climate, the Bahamas have been recognized to be eminently suitable for mariculture development (Roels, 1983). An abundance of natural embayments and sheltered coastal areas with high flushing rates due to ocean currents make the Bahamas well-suited for finfish culture in sea cages as well as in land-based tanks and ponds.

The Caribbean Marine Research Center (CMRC) is a private, non-profit research organization located on Lee Stocking Island, Exuma Cays, central Bahamas. In 1984, recognizing the potential importance of mariculture to the Caribbean region, CMRC initiated a search for suitable species for mariculture development. The primary criterion for species selection was to provide an inexpensive source of animal protein that could be farmed, not only by large-scale commercial ventures, but by small-scale farmers for local markets and self-sufficiency. It was also required that the selected species be suitable for farming in sea cages, thereby utilizing the natural topographical features of the region and minimizing land-based infrastructure requirements. These criteria limited the search to finfish species which are low on the food chain, and for which culture methods are technologically simple and readily transferable to lesser developed regions.

Many commercially attractive, but high trophic level species such as grouper, snapper, and dolphin (mahimahi) were considered inappropriate and/or profitable farming depends upon a product that would fetch a premium price on the export market. A potentially suitable candidate was the grey mullet (*Mugil cephalus*), a circumtropical species low on the trophic level and an important subsistence species in many areas of the world. Although farmed for centuries in southeast Asia, the industries remain dependent on capture of wild fry for stocking of ponds. Extensive research aimed at alleviating this dependency has led to the development of methods for controlled maturation and spawning in captivity; however, lack of reliable methods for rearing the early larvae to the juvenile stage remains a primary constraint, and mass propagation techniques which can supply adequate numbers of juveniles to farmers have not been developed (Nash and Shehadeh, 1980).

The economics of rearing larval marine finfish, in general, remains problematical. Knowledge of environmental and nutritional requirements for survival and growth of marine fish larvae during culture is incomplete. Lack of suitable artificial diets that can be used from first feeding requires that the larvae be provided with live, planktonic feeds upon completion of yolk-sac absorption. The logistics of mass production of live feeds are considerable, usually involving the intensive culture of several species of phytoplankton and zooplankton, the production cycles of which must be synchronized to the requirements of the larvae. In Japan, seedstock of the red sea bream (*Pagrus major*), one of the major net-pen mariculture species, is still largely dependent upon collection of wild fry. Hatchery-reared fry, used primarily for restocking the sea, are subsidized by governmental programs (Girin, 1982). The degree of technological sophistication required for larval rearing of marine finfish would appear, at present, to preclude the adaptation of these methods to lesser developed regions.

The species selected by CMRC for mariculture development were the tilapias (family Cichlidae), a group of freshwater origin. The tilapias possess many attributes which suit them for culture. Unlike many marine finfish species which do not reproduce in captivity, or require hormonal manipulation for gonadal maturation and spawning, freshwater tilapias attain sexual maturity and spawn freely in captivity, ensuring a relatively stable supply of seedstock. In mouthbrooding tilapias, including most commercially important species, a larval period (which begins with the transition to exogenous feeding and ends when the adult form is assumed at metamorphosis) is lacking, and the young are released at an advanced stage of development (Noakes and Balon, 1982). Live foods are not essential at first feeding, and the yolk-absorbed fry may be easily reared on prepared diets.

Under natural conditions, adult tilapias feed at the base of the food chain as herbivores and detritivores, making them an excellent source of inexpensive animal protein. Under intensive culture, tilapias readily take prepared feeds, and numerous organic domestic and agricultural wastes have been successfully used as supplemental feeds (Balarin and Hatton, 1979).

Tilapias can be grown at high densities in concrete tanks, ponds, and cages, an important culture characteristic relating to high yield potential (Balarin and Haller, 1982). The presently cultured varieties are widely accepted as food fish, having firm, good-tasting flesh and few intramuscular bones. The tilapias also tolerate a wide range of temperatures and salinities, tolerance ranges varying with species (Balarin and Hatton, 1979; Chervinski, 1982).

World aquaculture production of tilapias in 1983 was estimated at 200,000 tonnes with four south Asian countries (Taiwan, Thailand, the Philippines and Indonesia) accounting for 180,000 tonnes (Maclean, 1984). Culture methods range from cage culture in lakes and ponds, to a wide variety of land-based systems including rice-fish integration in paddies, integrated animal-fish farming systems in earthen ponds, and intensive farming systems in concrete tanks. In Taiwan, where intensive tilapia culture has reached its highest level of development, yields of 6—8 tonnes per year are reportedly attainable in 100 m^2 concrete ponds (Liao and Chen, 1983a).

Tilapia culture is not new to the Caribbean Basin where fish were first introduced into freshwater with the goal of increasing the availability of low-cost food fish in rural areas of the Dominican Republic, Guatemala, Jamaica, and Panama (Osborn, 1984).

In Jamaica, the mossambique tilapia, *Oreochromis mossambicus*, was first introduced into rivers and indigenous ponds in the 1950's for exploitation by the general population (Cooke and Mooyoung, 1983). In 1978, *O. mossambicus* was replaced by the more commercially attractive Nile tilapia, *O. niloticus*, and a locally manufactured feed was developed. By 1982, annual production of *O. niloticus* by the private sector was 69.6 tonnes (Cooke and Mooyoung, 1983).

HISTORY AND STATUS OF SALTWATER TILAPIA CULTURE

Although tilapia culture is limited primarily to freshwater and low-salinity brackishwater at present, a high degree of salt tolerance exhibited by some species has suggested the feasibility of extending their culture into higher salinity brackishwater and marine systems. Pioneering studies made in Hawaii in the late 1950's were associated with efforts to develop intensive tank culture methods for *O. mossambicus* as a baitfish for the skipjack tuna industry (Hida *et al.*, 1962; Uchida and King, 1962). Results of small-scale experiments indicated that reproduction and growth were enhanced at elevated salinities (10-15 ppt), suggesting that a commercial facility should be operated on a brackishwater system, thereby reducing freshwater costs (Uchida and King, 1962). In Israel, small-scale experiments in aquaria, concrete tanks, and ponds were concurrently being initiated to study the adaptability of some commercial tilapias (*e.g.*, *O. aureus* and *Tilapia zillii*) to various concentrations of seawater (see review by Chervinski, 1982). These preliminary studies indicated that these tilapias could be acclimated and grown in brackish or seawater, but suggested that additional studies were needed to accurately assess their culture potential.

Experiments on a larger scale employing man-made ponds (0.7—0.8 ha) were also conducted in south Israel near the Dead Sea to determine the feasibility of utilizing salt marshes and saline waters of desert areas for fish culture(Fishelson and Popper, 1968; Loya and Fishelson, 1969). Results of those studies showed that hybrids of *O. aureus* and *O. niloticus* could be cultured in low-salinity brackishwater (approximately 3.6—14.5 ppt). The possibility for using saline tolerant tilapias for culture in heated effluents of coastal power stations was later discussed (Kirk, 1972).

Following the early studies, little additional information on saltwater tilapia culture was available for a number of years. However, saltwater tilapia culture has recently regained considerable interest, perhaps due to the discovery of superior strains and species for culture and a greater awareness of their potential for widespread culture in arid and coastal areas (Kuo and Neal, 1982; Hopkins, 1983; Payne, 1983).

A recent review has compared the salinity tolerances of tilapias of aquaculture interest (Stickney, 1986). The species that have emerged as prime candidates for saltwater culture include *O. spilurus* (Osborne, 1979; in Payne, 1983; Hopkins *et al.*, 1986) and Taiwanese red tilapia hybrids (Liao and Chang, 1983b; Meriwether *et al.*, 1984). Basic studies on saltwater tilapia culture methodology have also appeared, including studies on salinity tolerance in tilapias in relation to ontogeny and early salinity exposure (Watanabe *et al.*, 1985a,b), reproductive performance at various salinities (Ridha *et al.*, 1985; Watanabe and Kuo, 1985) and the use of nitrogen-fixing marine blue-green algae as a food source for saltwater tilapia culture (Murray and Mitsui, 1982).

Commercial saltwater tilapia culture is still in its early stages of development. In the Philippines, *O. mossambicus* invades brackishwater milkfish ponds and is harvested along with the main crop. A few farmers have begun to stock *O. niloticus* in fertilized brackishwater ponds (Guerrero, 1985). In the Middle East, pilot (albeit experimental) projects have been initiated recently in Kuwait (Kevin Hopkins, pers. comm.) and in Saudi Arabia (Smart, 1984) aimed at demonstrating the commercial feasibility of integrating agriculture with fish farming in arid regions utilizing low-salinity groundwater. In Kenya, a 50 t production model tilapia farm has been established using brackishwater (15 ppt) to make use of coral scrub land (Balarin, 1982). In China, tilapia have been stocked into Dayawan Bay (Guandong Province), a coastal mangrove area with salinities ranging from 15-33 ppt (Xu, 1985).

Little information is available on cage culture of tilapias in saltwater. Experimental brackishwater cage culture of *O. niloticus* and *S. melanotheron* in the Ivory Coast has been reported (see review by Coche, 1982), although details were not available. Good growth of Taiwanese red tilapia hybrids (*O. mossambicus* x *O. niloticus*) under intensive cage culture in brackishwater (11—17 ppt) shrimp ponds was recently reported (Meriwether *et al.*, 1984). A pilot-scale hatchery for production of Florida red tilapia fingerlings for experimental sea cage culture is presently under construction at CMRC, central Bahamas (Ernst, 1989).

PRELIMINARY STUDIES ON SALTWATER TILAPIA CULTURE IN THE BAHAMAS

Based on its reputed high salinity tolerance, *O. aureus* was initially selected by the CMRC for saltwater culture in the Bahamas. In a preliminary study conducted in October 1984, growth of *O. aureus* fingerlings (21.2 g) was monitored for 90 days in floating cages (1.0 m^3) located in concrete seawater (36 ppt) ponds (McGeachin *et al.*, 1986). Disease, high mortalities, and poor growth (1.08 %/day specific growth rate), indicated that *O. aureus* may be unsuitable for cage culture in full seawater.

Research was subsequently focused on a red tilapia from Florida, a hybrid strain originally derived by crossing *O. urolepis hornorum* (female) with *O. mossambicus* (male) (Sipe, 1979). Both parental species are known to be saline tolerant (Phillipart and Ruwet, 1982). An attractive, orange-red body coloration was also considered an attribute that would enhance acceptability as a food fish. Preliminary studies at CMRC have shown Florida red tilapia hybrids to be highly adaptable to seawater and studies are presently underway to develop hatchery, nursery, and growout methods. Culture methods are relatively simple: spawning occurs naturally in freshwater brood tanks, and yolksac-absorbed fry are collected following release by mouthbrooding females. The fry are then sex-reversed by hormone (17AC-ethynyltestosterone) treatment to transform genotypic females to phenotypic males (Guerrero, 1975). Monosex culture prevents unwanted reproduction at an early age which results in large numbers of small, unmarketable fish. It also minimizes the possibility of reproduction in seawater and the likelihood of unwanted introductions. After sex-reversal, fry are acclimated to seawater, then stocked in nursery tanks for a period of rapid growth prior to stocking in production tanks or sea cages. The hatchery system developed at CMRC is described in detail by Ernst (1989) elsewhere in this volume.

In May 1986, a preliminary study on growth of Florida red tilapia hybrids in seawater cages was conducted (Table 1). Fingerlings were stocked in floating cages (1.0 m^3) located in a sheltered intra-island watercourse near Barraterre, Exuma Cays, Bahamas, and reared for 51 days. They were fed a commercial tilapia diet (Insta-Pro, 30% protein) at a daily rate of approximately 4—5% biomass, by Barreterre residents. Evaluation of the results with respect to those of previous freshwater cage culture studies is difficult due to the many differences in culture conditions employed. However, growth rates of Florida red tilapia in sea cages were comparable to highest published values for intensive cage culture of *O. niloticus* in freshwater, when studies utilizing similar initial fingerling sizes, stocking densities, feed protein content, and culture periods were considered (see review by Coche, 1982). The real potential of Florida red tilapia hybrids for seawater cage culture remains to be established; growth rates and food conversion efficiencies can presumably be improved by optimizing stocking densities and feed rates and by simple cage modifications to prevent food loss.

Taiwanese red tilapia hybrids are easily bruised when reared in seawater (Liao and Chang, 1983b). Lack of similar observations for Florida red tilapia hybrids is perhaps indicative of a relatively high adaptability to seawater.

FUTURE RESEARCH REQUIREMENTS

Three important constraints to the development of sea cage culture of Florida red tilapia hybrids are:

1. The requirement for low-salinity water during the hatchery phase of production.
2. Poor low-temperature tolerance which may preclude production during the cold season.
3. The requirement for complete diets for cage culture.

At present, low-salinity groundwater (2 ppt) is required for maintaining broodstock for spawning, and for rearing young fry until completion of sex reversal, approximately 6 weeks from spawning. Restriction of the hatchery phase to low-salinity water will likely impose limitations on the selection of suitable hatchery sites and increase infrastructure costs with respect to recirculation of water, ultimately affecting the ability of farmers to obtain male fingerlings. The possibility of minimizing low-salinity water requirements during the hatchery phase through early seawater acclimation requires study. Early acclimation may be accomplished by initiating seawater transfer during the early fry stages or by incubating and hatching eggs at elevated salinities

Table 1. Summary of data on culture of monosex male Florida red tilapia hybrids for 51 days in 1.0 m^3 floating sea cages, Exuma Cays, Bahamas.

Cage No.	Stocking Data W_i (g)	Stocking Data N/m^3	Stocking Data B_i (kg/m^3)	Growth Data G (g/day)	Growth Data SGR (%/day)	Harvesting Data W_f (g)	Harvesting Data B_f (kg/m^3)	Harvesting Data MP (kg/m^3)	FCR	Remarks
1	51.6	305	15.7	1.4	1.70	122.8	36.8	12.4	2.62	temp. 24-27°C,
2	37.7	306	11.5	1.4	2.09	109.2	32.8	12.5	2.15	dissolved oxygen 5-6mg/L, salinity 37-55 ppt.

W_i = mean initial weight
N = number of fish
B_i = initial biomass
G = mean daily weight gain
SFR = specific growth rate: $(\log_n W_i - \log_n W_i)$/number of days
W_f = mean final weight
B_f = final biomass
MP = monthly production
FCR = feed conversion ratio: total feed/$(B_f - B_i)$

(Watanabe *et al.*, 1985a,b). Alternatively, broodstock may be maintained and spawned at elevated salinities. As normal reproduction in tilapias is inhibited by increasing salinity (Watanabe and Kuo, 1985; Ridha *et al.*, 1985), the range of salinities over which successful reproduction occurs in Florida red tilapia hybrids must be determined.

In areas where water temperatures approach lower lethal tolerance limits, production must be curtailed, and stocks overwintered in covered ponds or heated tanks (Balarin and Haller, 1982). Recent studies in Kuwait (Hopkins *et al.*, 1986) have shown that although Taiwanese red tilapia hybrids grew faster than either *O. spilurus* or *O. spilurus* x *O. aureus* hybrids, survival was relatively lower in red tilapias during the winter. Similarly, high mortalities associated with low temperatures (approximately 21—24° C) in Florida red tilapia hybrids maintained in seawater have been observed. Cage culture overwintering experiments in Taiwan have shown that mortalities are considerably lower for tilapias maintained in brackishwater (8 ppt and 16 ppt) than in seawater (30 ppt) at environmental temperatures ranging from 14.5 to 19.4° C (Ting *et al.*, 1984). Furthermore, red tilapia growth rates were higher at 16 ppt than at either 8 ppt or 30 ppt under these conditions. Studies are required to assess the effect of salinity on low-temperature tolerance in Florida red tilapia hybrids, to identify causative agents of overwintering diseases, and to develop methods for treatment. Introgressive breeding may also be a potentially important technique for developing cold-tolerant strains (Behrends and Smitherman, 1984).

Culture of tilapias in ocean cages requires intensive feeding of complete diets, as natural foods are extremely limited. As feed costs represent a major portion of total production costs under these conditions, the development of cost-effective artisanal feeds using a combination of inexpensive, locally-available ingredients, which minimize protein levels, is an important area for research. The utility of organic fertilizers (*i.e.*, chicken manure) in lieu of artificial feeds for fingerling production in seawater tanks is presently under investigation at CMRC. The feasibility of intensive fingerling production in sea cages, which obviates land-based nursery systems, must also be assessed.

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