Tilapia culture in salt water: environmental requirements, nutritional implications and economic potentials

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Abstract

The shortage in freshwater in many countries, together with the competition for it with agriculture and other urban activities has increased the pressure to develop aquaculture in brackishwater and sea water. Tilapia are an excellent candidate for aquaculture in brackishwater and seawater is due to their ability to tolerate a wide range of water salinity. Salt tolerance depends on tilapia species, strains and size, adaptation time and method and environmental factors. *Oreochromis mossambicus*, *O. aureus* and *T. zillii* are the most salinity-tolerant tilapia species. *O. mossambicus* can tolerate up to 120‰ water salinity, but they can grow normally and reproduce at water salinity of 49‰, and their fry live and grow reasonably well at 69‰. Blue tilapia (*O. aureus*) and Nile tilapia (*O. niloticus*) are less salinity tolerant. Tilapia hybrids descended from salt-tolerant parents are highly salt-tolerant. Cold tolerance of tilapia reared under different salinities is species specific. The nutrient requirements of tilapia reared in seawater are not well-studied, and more research is needed in this regard. Published results indicated that tilapia reared in seawater and brackishwater environments may require lower protein levels for optimum growth than fish reared in fresh water. Feed consumption, digestion and utilization by these fishes are also affected by the changes in water salinity. In addition, the metabolic rate of tilapia increases with increasing water salinity. The economic potentials of tilapia culture in seawater have also not been well-investigated. However, the available information revealed that rearing these fishes in saltwater environments can be cost effective, if proper management measurements are adopted.

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1. Introduction

Tilapia fishes, despite being freshwater fishes, are believed to have been evolved from marine ancestors (Kirk, 1972). It is no surprise therefore that most of these fishes are able to tolerate a wide range of water salinity. They can grow and reproduce normally in brackishwater. Some species can even grow and reproduce at very high water salinity. However, limited data are available on tilapia culture in brackishwater and seawater, compared to the voluminous information available on their cultures in freshwater environments.

The shortage in freshwater in many countries, and the competition for it with agriculture and other urban activities has increased the pressure to develop aquaculture in brackishwater and sea water. Therefore, the first candidate that one may think of for aquaculture in brackishwater and seawater is tilapia. The present review throws some lights on tilapia culture in seawater/brackishwater, with emphasis on their environmental requirements, nutrient requirements and economic potential.

2. Environmental requirements

The environmental factors affecting tilapia in the wild or under aquaculture conditions include salinity, temperature, dissolved oxygen, ammonia and nitrites, pH, photoperiod and water turbidity. However, this review will focus on salinity and temperature as the two most important factors. For more details on the effects of other environmental factors on tilapia, the reader is kindly referred to the author's new book (Tilapia Culture) published by CABI in 2006.

2.1- Salinity tolerance

Extensive work has been published on the tolerance and adaptability of tilapia to water salinity and the suitability of salt water for tilapia culture (Table 1). Most of this work indicated that salt tolerance depends mainly on tilapia species, strains and size, adaptation time and method and environmental factors (Chervinski, 1982; Philippart and Ruwet, 1982; Suresh and Lin, 1992).

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Table 1. Salinity tolerance (‰) of tilapia (modified from El-Sayed, 2006).

Species	Upper limit		Optimum limit	Remarks	Reference
	Direct transfer	Gradual transfer			
O. niloticus	18[1]	36[1]	5-10[2], 15[3]	Reproduce at 13.5-29‰[4]	[1]Al-Amoudi (1987a), [2]Payne and Collinson (1983), [3]Alfredo and Hector (2002), [4]Balarin and Haller (1982)
O. mossambicus	27[5]	120[6]	17.5[7]	Spawn at up to 49‰[8]	[5]Al-Amoudi (1987b), [6]Whitefield and Blaber (1979), [7]Canagaratnam (1966), [8]Popper and Lichatowich (1975)
O. aureus	27[5]	54[4]	10-15[9]	Reproduce at 5-20‰, low growth and high mortality at 36‰[10]	[4]Balarin and Haller (1982), [9]Perry and Avault (1972), [10]McGeachin, Wicklund, Olla and Winton (1987)
O. spilurus	33[4]	40[11]	3-8[11]	Good growth and survival in seawater, but low fecundity[11]	[11]Al-Ahmed (2001)
S. galilaeus		29[4]	19[4]	Reproduce in the wild at 29‰[4]	
T. rendalli		13-19[4]	0[12]		[12]Likongwe (2002)
T. zillii		45[13]		Grow and reproduce naturally at 10->30‰[14]	[13]Chervinski (1982), [14]El-Sayed (pers. communication)
O. niloticus x *O. mossambicus*		35[15]	15[15]	At 35‰, the fish failed to adapt	[15]Alfredo and Hector (2002)
Florida red tilapia			17.8[16]	Grow normally up to 36.2‰	[16]El-Ebiary *et al.* (1997)

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Species, strain and size

It has been reported that *O. mossambicus*, *O. aureus* and *T. zillii* are the most salinity-tolerant tilapia species. *O. mossambicus* can tolerate up to 120‰ water salinity (Whitefield and Blaber, 1979). Moreover, they can grow normally and reproduce at water salinity of 49‰, and their fry live and grow reasonably well at 69‰ (Whitefield and Blaber, 1979). *O. aureus* are less salinity-tolerant, but can grow well at a salinity of up to 36 to 44‰, while reproduction occurs at 19‰. With gradual acclimation, they can tolerate a salinity of up to 54‰ (Balarin and Haller, 1982). However, *O. aureus* reared at a salinity of 30‰ developed a toxic algae bloom and suffered from epithelia erosion caused by the dinoflagellate *Pfiesteria piscicida*, and brighter flashing on the dorsal and pectoral fins and tail (McMahon and Baca, 1999). Higher salinity also severely restricted fish reproduction despite increasing somatic growth. Similarly, McGeachin *et al.* (1987) found that *O. aureus* reared in seawater cages (36‰) showed a sharp reduction in growth rates and were infected with *Bacillus* sp. which has lead to severe mortality.

T. zillii are also among the most salinity-tolerant tilapia species. They are found in highly saline water (36-45‰) in many tropical and subtropical regions (Balarin and Hatton, 1979; A.-F.M. El-Sayed, Alexandria, Egypt, 1996, pers. com.). *T. zillii* can also reproduce at 29->30‰. However, this species is not suitable for aquaculture due to it low growth and overreproduction. On the contrary, *O. spilurus* has also been successfully cultured in full sea water and trails are going on in a number of countries for their commercial culture in seawater cages and tanks, with promising results (Carmelo, 2002).

Other tilapias are generally less euryhaline and can tolerate water salinities ranging from about 20 to 35‰ (see details in Table 1). Most of these tilapia grow, survive and reproduce at 0-29‰, depending on the species and acclimation period.

Salinity tolerance of tilapia is also affected by fish sex and size. Perschbacher and McGeachin (1988) evaluated the salinity tolerance of red tilapia (*O. mossambicus* x *O. urolepis hornorum*) fry, juveniles and adults. Adult fish were more salt-tolerant than fry and juveniles. Fry and juveniles tolerated direct transfer to 19‰, without apparent stress and mortality, but 100% mortality occurred at 27‰. On the other hand, adult fish tolerated a direct transfer to 27‰, with a100% mortality at 37‰. Similarly, Watanabe, Kuo, & Huang (1985) studied the ontogeny of salinity tolerance in Nile tilapia, blue tilapia and hybrids tilapia *O. mossambicus* female x *O. niloticus* male. The median lethal salinity-96 h (MLS-96) for Nile tilapia and blue tilapia over an age of 7-120 days post-hatching (dph) was 18.9 and 19.2‰. In contrast, MLS-96 of tilapia hybrids changed with age and increased from 17.2‰ at 30 dph to 26.7‰ at 60 dph. The authors referred these ontogenitic changes in salinity tolerance to body size than to chronological age. Watanabe *et al.* (1985) reported also that male tilapia tend to be more salt tolerant than females.

Water salinity has also been reported to affect the reproduction of tilapia. Gonadal development and spawning of Nile tilapia occurred at salinities of 17-29‰, while the onset of reproduction was delayed with increasing water salinity from 25 to 50‰, and reproduction stopped completely at salinity above 30‰ (Fineman-Kalio, 1988). On the other hand, Watanabe and Kuo (1985) found that the total number of spawnings of Nile tilapia females was greater in brackishwater (5-15‰) than in either full strength seawater (32‰) or freshwater.

It has also been reported that tilapia hybrids descended from salt-tolerant parents (such as *O. mossambicus* and *O. aureus*) are highly salt-tolerant (Suresh and Lin, 1992a; Romana-Eguia and Eguia, 1999). This may explain why Taiwanese red tilapia (Liao and Chang, 1983) and Florida red tilapia (Watanabe, Ellingson, Wicklund & Olla, 1988) grow faster in SW and BW than in FW.

Acclimation

Pre-acclimation to salt water and gradual transfer to high salinity have a significant effect on tilapia growth and survival, as has been reported by Al-Amoudi (1987). The author found that *O. aureus*, *O. mossambicus* and *O. spilurus* required shorter acclimation time (4 days) for a transfer to full-strength seawater than *O. niloticus* and *O. aureus* x *O. niloticus* hybrids (8 days). These results indicated that the former tilapia group is more euryhaline than the latter group. Al-Amoudi, El-Sayed, & El-Ghobashy (1996) found also that *O. mossambicus* are more resistant to thermohaline shocks than *O. aureus* x *O. niloticus* hybrids. Similarly, the physiological and respiratory responses of *O. mossambicus* to salinity acclimation have been evaluated by Morgan, Sakamoto, Grau & Iwama (1997). Fish reared in freshwater (FW) were transferred to FW, isotonic salinity (Iso, 12‰) and 75% seawater (SW, 25‰) and a number of physiological parameters were measured. The authors found that plasma Na^+ and Cl^- were elevated one day after transfer to SW, but returned to FW levels on day 4. Plasma cortisol and glucose levels were higher; while growth hormone, Na^+, K^+ ATPase activities and prolactins were lower in FW and ISO than in SW.

These results suggested that the physiological changes associated with SW acclimation in tilapia are short-term, energy demanding and may account for as much as 20% of total body metabolism after 4 days in SW. The increase in the metabolic energy diverted into osmoregulation, with increasing water salinity has also been reported in *O. mossambicus* and *O. spilurus* (Payne, Ridgway & Hamer, 1988), *O. niloticus* x *O. aureus* and common carp (Payne, 1983).

Feeding tilapia broodstock with diets containing higher salt levels may produce seeds with better adaptability to water salinity. Turingan and Kubaryk (1992) studied this assumption by feeding Taiwanese red tilapia (*O. mossambicus* x *O. niloticus*) broodstock diets containing 0.8, 3, 6, 9 or 12% salt for 2 months prior to spawning. They found that egg hatchability was higher in SW than in FW. The hatchability and larval growth were highest in fish fed 12% salt in SW and lowest in FW. In another study, Watanabe *et al.* (1985) found that the survival of fry produced from fertilized eggs of Nile tilapia spawned in FW and incubated at elevated salinities of 0, 5, 10, 15, 20, 25 and 32‰ was 85.5, 84.4, 82.5, 56.3, 37.9, 20.0 and 0%, respectively. Fry salinity tolerance increased also with increasing the salinity of spawning, hatching or acclimatization. In addition, at equivalent salinity, early exposure of tilapia broodstock to high salinity produced progeny with high salinity tolerance than those spawned in FW and hatched at high salinity.

Steroid hormones may reduce the routine metabolism of euryhaline tilapia reared at high salinity and, in turn, improve fish growth. The growth of *O. mossambicus* continuously treated with 17α-methyltestostwerone (MT) was faster than early or delayed MT-treated fish in FW and SW. The growth of continuously treated fish was 5-7 times higher in SW than in FW (Kuwaye, Okimoto,

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Shimoda, Howerton, Lin, Pang & Grau, 1993). Similar results were reported by Ron, Shimoda, Iwama & Gordon Grau (1995) who studied the effects of MT treatment and feeding rate on the growth of *O. mossambicus* reared in FW and SW. The best growth was observed in MT-treated fish fed double ration in SW. Oxygen consumption (routine metabolism) was also much lower in SW than in FW. The authors suggested that the reduction in routine metabolism in fish reared in SW may have accounted for the increase in growth rates, compared to fish reared in FW.

2.2- Temperature

Previous studies indicated that growth rates of Florida red tilapia reared at different salinities increased with increasing temperature within the range 22-32C (Watanabe, Ernst, Chasar, Wicklund & Olla, 1993). At 0‰, fish performance was maximized at 27ºC, while at 18 and 36‰, the best growth and feed consumption were obtained at 32C. Under all temperatures, fish performance was better at 18‰ than at 0 and 35‰, indicating an advantage of tilapia culture in brackishwater compared to freshwater and seawater in subtropical regions.

However, it should be mentioned that cold tolerance of tilapia reared under different salinities is species specific. *O. spilurus* reared in seawater survived and grew well under declining temperature, while *O. aureus* showed lower growth and survival. Similarly, Allanson, Bok & VanWyk (1971) found that *O. mossambicus* tolerated 11°C at 5‰, while fish reared in freshwater did not survive at that temperature. Those authors suggested that the ability of *O. mossambicus* to tolerate low water temperature is associated with the maintenance of high plasma sodium and chloride concentration.

On the other hand, Jennings (1991) found that cold tolerance of *Sarotherodon melanotheron* did not differ with water salinity ranging from 5 to 35‰. On the contrary, it has been reported that the major obstacle of cage culture of this species in seawater in Kuwait and Malta was the decrease in water temperature during winter times.

3- Nutrition

The nutritional requirements of tilapia farmed in seawater environments, including protein, lipids, carbohydrates, protein-to-energy ratios, vitamins and mineral requirements have not been well studied. Only few studies have been conducted in this regard. The results of those studies are described below. It is, therefore, imperative that more research be carried out alongside this line.

3.1- Protein requirements

The protein requirement of Florida red tilapia reared in seawater pools has been investigated by Clark, Watanabe & Ernst (1990). The performance and survival of fish fed isocaloric diets containing 20, 25 and 30% CP were not significantly different. This simply demonstrates the feasibility of lowering feed cost by using low-protein diets without reducing fish performance. Shiau and Huang (1990) reported also that tilapia hybrids (*O. niloticus* x *O. aureus*) reared in seawater can perform well on high energy (3.1 kcal/g)- low protein diet (20% CP). Similarly, Orachunwong, Thammasart & Lohawatanakul (2001) compared two commercial feeds (20 and 25% CP) for red tilapia cage-cultured in BW ponds (15-18‰). They found that final yield, average final body weight and FCR were not significantly different (see Table 2). However, the cost of the 20% CP diet was 17% lower than the 25% CP diet. Consequently, production cost was lower for the 20% CP diet.

Table 2. Performance of red tilapia (*O. mossambicus x O. hornorum*) fed 20% and 25% CP diets in floating cages suspended in brackishwater earthen ponds (15-18 ‰). (modified from Orachunwong *et al.*, 2001).

Item	20% CP	25% CP
Culture period (days)	144	144
Stocking density (fish/m^3)	50	50
Initial mean body weight (g/fish)	80	80
Harvest mean body weight (g/fish)	548	606
Harvest biomass (kg/ m^3	26.5	28
Survival rate (%)	97	92
Average daily gain (g/fish)	3.26	3.65
Feed conversion ratio	1.4	1.39

The above results may indicate that tilapia reared in seawater and brackishwater environments may require lower protein levels than fish reared in fresh water. However, El-Sayed, Mansour and Ezzat (2003) found that spawning performance and protein requirements of Nile tilapia broodstock were significantly affected by water salinity. The fish were fed test diets containing 25, 30, 35 and 40% crude protein at three water salinities (0, 7 and 14‰). The size at first maturation increased with increasing dietary protein at all salinities. At 25 and 30% protein levels, broodstock reared at 0 ‰ reached their sexual maturity at bigger sizes than those reared at 7 and 14‰. At 0 ‰, spawning intervals were not significantly affected by dietary protein levels, while at 7 and 14‰, spawning intervals significantly decreased with increasing dietary protein levels. Spawning frequency and number of eggs per spawn were increased with increasing dietary protein levels. The total number of spawnings per female and absolute fecundity were better in fish fed 40% protein in freshwater than at 7 and 14‰ salinity. It seems therefore, nutrient requirements of tilapia reared in seawater and brackishwater are species specific.

3.2- Lipid requirements

As far as I know, no studies have been conducted to investigate the requirements of tilapia under different salinities. Only recently, El-Sayed *et al.* (2005) have tackled this issue. Those authors studied the effects lipid source on the reproductive performance of Nile tilapia broodstock reared at different salinities (0, 7 and 14‰). They found that Nile tilapia broodstock reared in brackishwater required n-3 HUFA for optimum spawning performance, while the reproductive performance of fish reared in freshwater was not affected by dietary lipid source. Yet, the effect of lipid source on the performance of other developmental stages of Nile tilapia (and also of other tilapias) is not known.

3.3- Vitamin requirements

Again, very little information is available on vitamin requirement of tilapia grown in seawater. Only Thiamine (Lim & Leamaster, 1991) and Riboflavin (Lim, Leamaster & Brock, 1993) requirements have been quantified for red hybrid tilapia. When the fish were reared at 32‰, they required 2.5 and 5 mg/kg thiamine and riboflavin, respectively.

3.4- Feed consumption/frequency

It has been reported that the metabolic rate of tilapia increases with increasing water salinity (Bashamohideen and Parvatheeswararao, 1976). It is very likely that feed consumption, digestion and utilization by these fishes will be affected by the changes in water salinity. In support, Watanabe *at al.* (1988) found that the daily feed consumption of Florida red tilapia fed a 32% CP diet increased with increasing salinity from 0 to 32‰. In another study, the maximum growth of these fish was obtained at satiation feeding rates, while feed conversion was improved at lower feeding rates (Clark *et al*., 1990).

A feeding trial was conducted to evaluate the appropriate feeding frequency for cage-cultured red tilapia (*O. mossambicus* x *O. hornorum*) in Thailand (Orachunwong *et al*., 2001). Fish were stocked in floating cages suspended in earthen BW ponds (15-18‰) and fed a commercial tilapia feed (25% cp) *ad libitum* 2, 3, and 4 times daily. Feeding 3-4 times day^{-1} has resulted in better growth and FCR than twice a day. Dividing the daily ration of tilapia reared in cages into 3-4 feedings would probably reduce feed loss compared to once or twice a day. When the fish were reared in cages suspended in BW ponds (15-20‰) and fed diets containing 20-32%CP diets, for 143-154 days, they attained a yield of about 21 mt/ha/crop (Orachunwong *et al*., 2001).

4- Tilapia culture in sea cages

The scarcity of freshwater, and the competition for it with other activities such as irrigation, drinking and other urban activities, make its use for tilapia culture unguaranteed and unsecured. The challenge which faces fish farmers and aquaculture researchers is to use brackishwater and sea water, which is available in most of the tropics and subtropics, for tilapia culture. The euryhaline characteristics of tilapia make them an ideal candidate for culture in the saline waters.

Tilapia cage culture in sea water has been tried by a number of researchers, with varying degrees of success, depending on cultured species, size and sex, stocking density and cage size and shape. Watanabe, Clark, Dunhkam, Wicklund, & Olla (1990) successfully raised Florida red tilapia in seawater cages in the Bahamas with survival of 84.1- 93.5%. However, the results of that study may not be reliable due to the short duration through which it was carried out (30 days). Persand and Bhikajee (1997) reared red tilapia (*Oreochromis* spp.) in cylindrical seawater cages in Mauritius, for 95 days. The SGR (1.13%) and yield (9 kg m^{-1}) were considered low as compared to other similar rearing studies, such as that of Cruz and Ridha (1991) who found that the SGR of *O. spilurus* grown in sea cages in Kuwait was 1.9%. The difference between both results may have been related to stocking density and species and size, duration of the trials and environmental conditions. Moreover, Al-Ahmed (2002) described the culture of *O. spilurus* in sea cages in Kuwait. Fry are stocked at 600 m^{-3}, while 200 fish m^{-3} are considered optimum for growout phase. In one study, the fish grew from 118-323.3 g in 101 days, with a growth rate of 2.03 g d^{-1} and a production of 44 kg m^{-3}. In another study, the fish gained 2.31-3.49 g d^{-1}, with a FCR of 1.47-2.13 and a survival of 95-97.7%. The main limitation of tilapia culture in sea cages in Kuwait is the decrease in water temperature during winter times (Mid-November to mid-April).

Commercial farming of *O. spilurus* in open–sea cages (125 m^3) at a salinity of 37-38‰ has also been carried out in Malta (Agius, 2001), with very promising results. The fish (50 g) were stocked in the cages at the end of June and reached 450-500 g at the end of November (after 5 months), with a mortality rate less than 2%. Once again, as in case of Kuwait, the main obstacle that limits the expansion of this culture system in Malta is the low water temperature during winter months. It is clear, thus, that rearing certain species of tilapia in seawater cages can be an excellent alternative tilapia culture system, if environmental conditions are favourable.

5- Economic Potential

Despite that the economic potentials of tilapia culture in seawater has not been well-investigated, the available information revealed that rearing these fishes in saltwater environments can be cost effective, if proper management measurements are adopted. Head, Zerbi & Watanabe (1996) found that feed, processing and distribution and sex-reversed fry represented the highest variable costs in commercial-scale, seawater pond production of Florida red tilapia in Puerto Rico, while salaries and depreciation accounted for the highest fixed costs. At a stocking density of 2 fish m^{-2}, the proposed production was not economical, while increasing the density to 3.5 and 4 fish m^{-2} increased the profitability of the operation. Using locally prepared feed together with the integration of hatchery and growout operations are also suggested for reducing operational costs and increasing return.

Similarly, Head and Watanabe (1995) evaluated the economics of a commercial-scale, recirculating, brackishwater hatchery for Florida red tilapia (*O. urolepus hornerum* x *O. mossambicus*) in the Bahamas, using previously-collected production data. Salaries and benefits were the largest fixed costs. Air-freight shipping to Miami, Florida, represented the largest variable cost when air charters were used. The study indicated that the system is economically feasible if fry can be sold year-round, while seasonal market demand may limit the economic return. The authors reported also that more economic success can be achieved if more economical building construction, modifications in rearing tank design, and vertical integration of hatchery and growout operations, with external sales of excess fry and broodstock are adopted.

Samonte, Agbayani & Tumaliuan (1991) compared the economic feasibility of the polyculture of tiger shrimp (*Penaeus monodon*) with Nile tilapia in brackishwater ponds in the Philippines. A stocking combination of 6,000 shrimp and 4,000 tilapia ha^{-1} produced the highest total yields and net income compared to monoculture of tilapia or shrimp. Two crops per year provided a 70% return on investment and 1.2 years payback. Sensitivity analysis revealed that shrimp/tilapia polyculture was profitable up to a 20% decrease in the selling price of both species.

6- Global markets of Tilapia

Most of produced tilapia is consumed in domestic markets in production areas, especially in rural Asia, Africa and South America. It plays a crucial role in food security and poverty alleviation in these regions. However, the demand for tilapia is growing in non-traditional, non-producing countries. Therefore, global trade in tilapia products has witnessed an impressive flourishing in the last two decades, and are expected to continue (Vannuccini, 2001). One of the major advantages of global tilapia marketing is their competitive prices and their white flesh that make them an important substitute for white fish species which face shortages in supply (Vannuccini, 2001). It is also more profitable for North America and European markets to import tilapia from producing regions than farming them, mainly due to the low cost of labour, energy and operating costs in these regions (Watanabe, Losordo, Fitzsimmons & Hanley, 2002).

The US market is the largest market for tilapia import in the world. The tilapia import quantities have sharply increased in recent years, to jump from 56,334 mt in 2001 to 90,206 mt in 2003, with an increase of over 60% in just three years. A wide variety of tilapia products, including live fish, fresh fish and frozen fillet, are currently marketed.
Tilapia imports from South America and the Caribbean region to the US market are increasing. Fourteen countries from those regions are currently exporting tilapia and tilapia products to the USA. The largest exporter are Ecuador, Costa Rica and Honduras. The three countries accounted for over 90% of all imported fresh fillets in 2003 (El-Sayed, 2006). Some aquaculture producers in Ecuador have switched from shrimp production, due to falling prices in the shrimp market, to tilapia production. Other countries, such as Panama and Nicaragua are becoming important tilapia exporters to the US market. It is very likely that the US tilapia market will attract the attention of large tilapia producers such as Brazil and Mexico.

In conclusion, it is evident from the foregoing discussion that the potentials of tilapia culture in brackishwater/seawater are high, if proper management measurements are adopted. However, extensive work is needed alongside this line, particularly on the nutritional requirements and economic potentials of tilapia reared under different water salinities.

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