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Tilapia Tolerance of Saline Waters: A Review

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Abstract.—Members of the family Cichlidae that are generally referred to as tilapias (*Tilapia* spp.) characteristically demonstrate some degree of euryhalinity. A survey of existing literature indicates that *Tilapia zilli* and *Tilapia mossambica* are among the most salinity-tolerant species, although neither is among the most desirable for culture. A tolerance for high salinity has been demonstrated in at least some crosses that produce red hybrid tilapia. Most known heritage crosses with that result to date have involved *T. mossambica*. The red hybrid may become a preferred culture fish in brackish and seawater systems as well as in fresh water.

Many species of tilapia (*Tilapia* spp.) are broadly euryhaline (Chervinski 1961a), while others are restricted to fresh or low-salinity waters. It has been speculated that tilapias evolved from a marine ancestor and secondarily invaded freshwater environments (Myers 1938; Steinitz 1954). Various species of *Tilapia*, most of which have not been cultured, occur in African lakes; others occur in Middle Eastern lakes where salinities may reach or exceed that of seawater during seasonal drought periods. Reports on tilapia species of little or no aquacultural interest from lakes, estuaries, and coastal areas of Africa include those of Mortimer (1962), Coe (1966, 1967, 1969), Morgan and Kalk (1970), Fagade (1971), Fryer and Iles (1972), Clarke (1973a), Beadle (1974), Reite et al. (1974), Pauly (1976), Whitfield and Blaber (1976), Philippart and Ruwet (1982), and Payne (1983). *Tilapia galilaea*, found in Israel as well as in Egypt, grows and reproduces over a relatively wide salinity range (El-Zarka et al. 1970; Kirk 1972). These fish can survive direct transfer from fresh water to 19.5‰ salinity (Chervinski 1961c), but generally the species is of little value to aquaculture (Sarig 1955).

Prior to the development of various techniques to control overpopulation and consequent stunting of cultured tilapias, Hickling (1963) advocated rearing the fish in brackish water as a means of limiting reproduction. He also indicated that some growth improvement could be obtained through brackish-water culture. Although no species name is provided in the paper, Hickling (1963) was most likely referring to *T. mossambica* in his discussion.

Many tilapia culturists currently prefer *T. aurea* and *T. nilotica* to *T. mossambica*. Because *T. mossambica* was the first tilapia to receive widespread distribution outside the native African and Middle Eastern range of the genus, it is still widely cultured and has often been hybridized with other introduced tilapia species. Such hybrids, as well as species misidentifications, may account for some of the apparent discrepancies among results from similar studies performed on what were reportedly the same species.

Previous reviews of tilapia salinity tolerance have been written by Fryer and Iles (1972), Balarin and Hatton (1979), Chervinski (1982), Philippart and Ruwet (1982), and Wohlforth and Hulata (1983).

This review contains citations listed by those authors plus additional references.

Studies involving tilapia in saline waters include basic research on the physiology of salinity stress in fish as well as more practical research on aquacultural practices. In both instances, relatively few species (mostly those of aquacultural interest) have dominated the literature. Species of minor aquacultural interest have largely appeared in reports of their occurrence in brackish water arising from life-history or ecological studies. An exception, *T. zilli*, has been the subject of several papers on its tolerance for, and performance in, saline waters (El-Zarka 1956; Bayoumi 1969; El-Zarka et al. 1970; Fryer and Iles 1972; Chervinski and Hering 1973; Farghaly et al. 1973; Chervinski and Zorn 1974; Leatherland et al. 1974; Balarin and Hatton 1979; Whitfield and Blaber 1979; Payne and Collinson 1983). *T. zilli* survive and grow in salinities of at least 40‰ (Chervinski and Hering 1973; Balarin and Hatton 1979) and reproduce at salinities of at least 29‰ (El-Zarka 1956; El-Zarka et al. 1970). Payne and Collinson (1983) reported reproduction at 40‰ salinity, but Chervinski and Zorn (1974) found no reproduction in waters of 38.8 to 43.7‰. A few laboratory studies on the salinity tolerance of other minor tilapia species have also been published (Chervinski 1961a; Fukusho 1969; Leatherland et al. 1974).

Species of Aquacultural Interest

Tilapia aurea and T. nilotica

Several studies have been conducted with *T. aurea*, *T. nilotica*, and their hybrids in relation to saline waters; most have dealt with the introduction of fish to brackish water in culture ponds or in the laboratory. Both species have been reported in brackish lakes in Egypt (Fryer and Iles 1972; Kirk 1972), and both once occurred in Lake Quarun but were displaced by *T. zilli* as the lake became more saline (Fryer and Iles 1972). Kirk (1972) reported that *T. nilotica* was recovered from the Bitter Lakes of Egypt at salinities ranging from 13 to 29‰.

Through acclimation, Coleman et al. (1977) were able to maintain *T. aurea* in two-thirds strength seawater (23‰). Fukusho (1969) reported that *T. nilotica* tolerated direct transfer to 50% seawater (17.5‰), but not 75% seawater (26‰). Lotan (1960) indicated that *T. nilotica* survived direct transfer from fresh water to 60% seawater (21‰) and could be acclimated to 150% seawater (53‰). According to Balarin and Hatton (1979), Lotan (1960) misidentified *T. aurea* as *T. nilotica*.

A limited amount of work has related temperature and salinity to performance by *T. aurea* and *T. nilotica*. Chervinski (1966) found that *T. aurea* was better able to tolerate cold temperatures in 5‰ salinity than in fresh water. Beamish (1970) determined that the preferred temperature of *T. nilotica* was 20–25°C at salinities of both 0 and 30‰.

The optimum salinity range for growth has not been well established for either *T. aurea* or *T. nilotica*. Chervinski (1966) reported that growth of *T. aurea* was nearly the same in fresh water and 10‰ salinity, although mortalities were higher in the brackish water. Good growth has been reported in salinities up to 40‰ for the same species (Chervinski and Yashouv 1971; Chervinski 1972; Chervinski and Zorn 1974), although *T. aurea* were affected by external lesions in high-salinity water (Chervinski and Zorn 1974). Payne and Collinson (1983) reported that the most effective growth for *T. aurea* occurred in brackish water of 10–15‰ salinity; best growth of *T. nilotica* occurred at 5–10‰. Hybrids between the two species have demonstrated rapid growth at salinities up to 18‰ (Fishelson and Loya 1969; Loya and Fishelson 1969). Somewhat contradictory is a study by Payne (1983) in which *T. aurea* × *T. nilotica* hybrids grew well at 6‰, but more poorly at higher salinities. Because studies of this nature have not been conducted over a broad salinity range simultaneously, it is difficult to compare them with each other.

Tilapia nilotica fry are intolerant of direct transfer from fresh water to seawater until 45 d posthatch (Watanabe 1985); tolerance increases to a maximum at 150 d posthatch. Similar results were reported in *T. aurea*.

Tilapia aurea has reproduced in salinities of 4.3‰ (Perry and Avault 1972) and 6‰ (Chervinski 1966). No reproduction occurs within the salinity range of 36.6 to 44.6‰ (Chervinski and Yashouv 1971), but the salinity at which reproduction is curtailed has not been adequately established. Reproduction by *T. nilotica* has been observed at 18.9‰ salinity (Chervinski 1961b).

Tilapia mossambica

The most widely studied species of tilapia with respect to saline waters is *T. mossambica*. It has commonly been a subject of physiological studies, most of which have employed maximum salinities no higher than 35‰ (Dharmamba and Nishioka 1968; Job 1969a, 1969b; Clarke 1971, 1972, 1973a, 1973b; Kruger 1971; Zambrano et al. 1972; Dharmamba et al. 1973; Krishnamurthy and Bern 1973; Narasimham and Parvatheswararao 1973; Venkatachari 1974; Dharmamba and Maetz 1976; Assem and Hanke 1978, 1979b; Loretz 1979; Mainoya 1982; Mainoya and Bern 1982).

Following their introduction into fresh waters around the world, *T. mossambica* have been subsequently found thriving in marine environments. Such habitat shifts have taken the fish into estuaries in Puerto Rico (Austin 1971) and Papua New Guinea (Gluckman et al. 1976) and into a brackish pond in Hawaii (Neil 1966). A breeding population has been reported from an atoll in the Pacific Ocean (Lobel 1980) where salinities doubtless are no lower than 35‰.

Tilapia mossambica does not tolerate direct transfer to full-strength seawater from fresh water (Fukusho 1969), but the fish can be readily acclimated to 35‰ salinity (Miller and Ballantine 1974) and higher. Acclimation salinities of 60, 70, and 120‰ were achieved by Assem and Hanke (1979a), Potts et al. (1967), and Whitfield and Blaber (1979), respectively. Direct transfer to 27‰ salinity appears possible without mortality (Assem and Hanke 1979b). In addition, although 5-mm *T. mossambica* cannot survive direct transfer from fresh water to seawater, they will survive the reverse transfer (Brock 1954). Maximum salinity tolerance by *T. mossambica* is reached when fish are 52 mm long (Watanabe 1985).

The salinity tolerance of hybrid tilapia fry (*T. mossambica* female × *T. nilotica* male) begins to increase 7 d posthatch. In contrast, improved salinity tolerance of *T. nilotica* or *T. aurea* occurs much later (Watanabe 1985).

Numerous reports of rearing *T. mossambica* in brackish water have been published. Some of the earliest work, attributed to *T. mossambica*, was performed by le Mare (1950) and Schuster (1952), as discussed by Hickling (1970). Good growth in brackish water was reported by both authors; le Mare (1950) reported a salinity of 20‰. Good growth has also been reported at 30‰ (Chimits 1957) and 35‰ (Uchida and King 1962; Canagaratnam 1966). Growth is reportedly better at a salinity of 17.5‰ than of 35‰ (Canagaratnam 1966); an increased metabolic rate due to osmoregulatory stress may occur at salinities higher than 17.5‰ or lower than 8.75‰ (Bashamohideen and Parvatheswararao 1972). The improved growth of *T. mossambica* in brackish water compared with growth at high and low salinities seems to be physiologically related to osmoregulatory function.

Survival in ponds has been reported at salinities as high as 42‰ (Gundermann and Popper 1977; Pinto 1982). *Tilapia mossambica* has been reared in intensive culture systems at salinities of 5 to 19‰ (Kuhlmann 1976), and for an extended period at 8‰ (Otte and Rosenthal 1979).

Spawning by *T. mossambica* has been reported at 30‰ (Vaas and Hofstede 1952; Chimits 1957; Fryer and Iles 1972), and at 35‰ (full-strength seawater: Brock 1954; Hora and Pillay 1962; Uchida and King 1962; Canagaratnam 1966; Liao and Chang 1983). Popper and Lichatowich (1975) reported prolific reproduction of *T. mossambica* at 49‰ salinity. Some authors, however, have indicated that spawning did not occur above 30‰ (Vaas and Hofstede 1952; Fryer and Iles 1972). Optimum salinity for either enhancing or reducing reproduction by *T. mossambica* has not been determined, although Uchida and King (1962) indicated that fry production was three times higher in water of 10‰ salinity than in fresh water.

Tilapia spilurus

Osborne (1979) indicated that the growth of *T. spilurus* was not impaired in the high-salinity water of the Red Sea. Growth of *T. spilurus* and *T. aurea* × *T. spilurus* hybrids in full-strength seawater was moderate, but survival was good in Kuwait (Hopkins et al. 1985). Growth was somewhat reduced compared with that of the Taiwanese red hybrid tilapia, but the red hybrid demonstrated poor survival when water temperatures fell into the 23–24°C range during normal seasonal changes.

Additional work in Kuwait (Ridha et al. 1985) demonstrated that *T. spilurus* spawned from May to October in seawater. Fecundity in seawater was about one-half that in groundwater.

Red Hybrid Tilapia

In recent years, red tilapias have become available and have gained popularity among researchers and consumers. The popularity of red hybrids is due, in part, to their similarity in color and general body shape to such desirable marine fishes as the red snapper (*Lutjanus campechanus*). It has been widely thought that red hybrid tilapias can bring a premium price in regions where red snappers are found in the market, whereas tilapias of normal coloration would have to be priced much lower. However, consumers in some countries such as Jamaica have recognized that palatability does not differ between normal and red tilapias and have shown a distinct preference for the less-expensive form (Franklin Ross, personal communication; author, personal observations).

Galman and Avtalion (1983) reviewed the origin of red tilapia. According to those authors, Ang (in the Philippines) produced a red hybrid by crossing a female *T. mossambica* × *T. hornorum* hybrid with a male *T. nilotica*. In Taiwan, Kuo obtained reddish-orange tilapia from a cross between a mutant female *T. mossambica* of the same color and a normal male *T. nilotica*. Crosses leading to red hybrids have also been successfully made in Guam and Florida (Galman and Avtalion 1983). The latter crosses were apparently made with some combination of *T. aurea, T. mossambica,* and *T. hornorum*.

At least three of the species commonly used in the production of red hybrids, *T. mossambica, T. aurea,* and *T. nilotica,* are moderately to highly euryhaline, and the fourth, *T. hornorum,* occurs naturally in brackish water (Philippart and Ruwet 1982). Thus, it seems likely that most red hybrids would be appropriate for saline-water culture. That hypothesis is supported by at least three published studies. In one, a mutant red *T. mossambica* × normal *T. nilotica* hybrid grew more rapidly in water of 17‰ salinity than in fresh water (Liao and Chang 1983). Maturity occurred later among fish reared in brackish water, but some bruising and parasite problems were encountered that were apparently avoided in the freshwater rearing treatment. Additional work in Hawaii (Meriwether et al. 1984) and Taiwan (Watanabe 1985) has demonstrated that growth of red hybrid tilapia is more rapid in brackish water and full-strength seawater than in fresh water. An Israeli red hybrid has been developed, but it apparently lacks the salinity tolerance of those developed in Taiwan and Florida (Robert Burns, personal communication). The Israeli hybrid reportedly was not derived from *T. mossambica*.

Reports from the Bahamas (Bori Olla, Robert Wicklund, and Robert McGeachin, personal communications) indicate that red hybrid tilapias originating in the United States have performed well in full-strength seawater. Breeding of those fish is currently being conducted in a freshwater hatchery, however, because they did not spawn in full-strength seawater. That result has also been confirmed in studies of Taiwan red hybrid tilapia conducted in Kuwait (Ridha et al. 1985).

Conclusions

The species of *Tilapia* most tolerant of brackish and high-salinity waters are *T. zilli* and *T. mossambica*. The former is of little interest to aquaculturists because of its relatively slow growth and the latter has the disadvantage of reproducing at a very early age, which results in overpopulation and stunting. In addition, *T. mossambica* is less acceptable than many other tilapias in some markets because of its dark coloration and black peritoneum.

The red hybrid tilapias, which have shown growth in, and high tolerance for, saline waters, appears to be a good candidate for brackish and seawater culture systems. Their culture appears feasible in salinities up to at least 50% seawater (17.5‰).

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