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RN 3079
AN 7118

TILAPIA CULTURE IN HEATED EFFLUENTS: POTENTIAL FOR COMMERCIALIZATION IN TEMPERATE CLIMATES

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ABSTRACT

Because the Tennessee Valley is located in a temperate climate, a multi-seasonal approach has been developed for culturing the tropical fish tilapia. During the winter (October-March), temperature of condenser cooling water (CCW) from open-cycle nuclear power plants ranges from 15° to 32° C, and it is ideally suited for overwintering small fingerlings and selected brood stock in raceways. During warmer periods of the year when CCW is too warm for raceway culture, fingerlings are reared to market size in earthen cooling ponds or in farm ponds near the power plant site. Hatchery methods have also been developed for mass production of tilapia and their hybrids. The integrated approach of over-wintering, hatchery production, and growout will be discussed relative to optimal use of heated effluents.

1. INTRODUCTION

The tilapia (Sarotherodon spp.), a diverse group of tropical fish native to Africa and the Middle East, are cultured extensively as food fish in tropical and subtropical countries. Tilapia have several qualities which make them excellent candidates for culture. They grow fast, have good market potential, are relatively resistant to low-oxygen and high-ammonia concentrations, reproduce readily, have few disease problems, and can be cultured both intensively in raceways and extensively in ponds. The most unique and valuable asset of tilapia, however, is their ability to feed on plankton, the base of the food chain in pond culture systems. Thus, instead of requiring a high-protein pelleted diet, tilapia may be cultured on a less costly yet readily available supply of plankton. This is especially valuable since feeding conventional pellets may account for 40 to 60 percent of the operating costs of a fish-farming enterprise. Because of their culture assets, tilapia are considered prime candidates for culture in the United States and other temperate countries (Suffern, 1981) if economical methods can be developed for mass-producing and overwintering selected seedstocks.

1.1. Constraints to Culture in Temperate Climates

Despite the excellent culture characteristics of tilapia, several technical factors prevent development of a wide-scale culture industry in temperate climates. Because tilapia cannot survive in climates where water temperatures are often less than 10° to 12° C for prolonged periods, economical methods must be developed for overwintering seedstocks and broodfish during cooler periods of the year. A second major problem involves mass production of suitable seedstock (i.e., monosex stocks) for pond culture. Because overwintered tilapia mature and breed at a small size, overpopulation and stunting occur in pond culture which renders the harvest unmarketable. Although methods are available for producing 100 percent male populations via hormone treatment (Shelton, et al., 1978) or hybridization (Mires, 1977), the problem remains that practical and economical methods for mass-producing suitable seedstocks are still not available. Finally, although small isolated studies indicate that tilapia are highly marketable (Suffern, 1981), little work in processing or market development has been done.

1.2. TVA's Development Work

Since the late 1960's, the Tennessee Valley Authority (TVA) has been developing waste heat utilization technologies (Burns, et al., 1980; Hubert, 1980). During the past four years, TVA has been developing the technical criteria required for intensively overwintering tilapia stocks. Related studies have also been conducted on pond fertilization techniques and mass production of suitable seedstocks for pond stocking.

This paper summarizes TVA's research and development work related to the breeding, culture, and overwintering of tilapia. Applied uses of waste heat and its role in development of tilapia culture in temperate climates will be emphasized.

2. PRACTICAL CULTURE OF TILAPIA IN HEATED EFFLUENTS

Several potential benefits may be derived from the use of flowing warm water in raceway and pond culture of tilapia. These include a lengthened growing season, early sexual maturation and spawning, enhanced plankton production, dilution of harmful metabolites, attraction and harvest of tilapia from extensive cooling ponds, and most importantly, the overwintering of culture stocks.

2.1. Overwintering Studies--Prototype Facility (1978-79)

In 1978, a prototype overwintering facility was designed and built at Muscle Shoals, Alabama. The facility, a series of several small raceways (170 ℓ capacity) received a supply of warm water simulating power plant CCW temperatures.

Two raceway culture periods (30 and 32 days in duration) were monitored during the winter of 1978 to determine: (1) growth characteristics of tilapia fingerlings under raceway conditions, (2) changes in water quality as a function of feed rate and water retention time, and (3) the influence of flow rate and aeration on fish density (kg/m^3) and fish-loading rate (kg/ℓ/min) (Behrends, et al., 1980).

Growth rates of fingerling tilapia were not reduced significantly until average dissolved oxygen concentrations were less than 3 ppm (38 percent saturation, water temperature = 27° C). Based on pH, total ammonia nitrogen, and water temperature, the theoretical un-ionized ammonia concentration (toxic form of ammonia) ranged from 5 to 91 µg/ℓ. When sufficient oxygen was available (>3 ppm), these concentrations of ammonia did not adversely affect growth of tilapia. Final fish densities in the raceways ranged from 27 to 40 kg/m^3 (1.9 to 2.5 lb/ft^3), while final fish-loading rates ranged from 1.2 to 1.7 kg/ℓ/min (10 to 14 lb/gal/min).

Based on the 1978 results, a 100,000-fingerling capacity raceway facility was built at the Browns Ferry Nuclear Plant (BFN) near Athens, Alabama.

2.2. Overwintering Facility Design--BFN

The demonstration facility at BFN consists of six fiberglass raceways (3.7 m by 1.2 m by 1.2 m) located inside a 14.6-m by 7.6-m double-polyethylene greenhouse structure; a CCW delivery system capable of providing a maximum of 190 ℓ/min/raceway and a series of redundant backup systems for water flow, aeration, electrical service, and space heating (Waddell, unpublished paper). A deep well with a flow of 230 ℓ/min (≅15° C) is used for blending and as an auxiliary water source during multiple unit shutdowns. Eighteen aquaria (100 ℓ capacity) have also been installed to evaluate spawning characteristics of tilapia as a function of photoperiod and CCW temperatures.

The BFN primarily uses an open-mode cooling system with CCW temperatures averaging 14.4° C above ambient. Effluent CCW temperatures range from 15° C in January to 46° C in August. As a safety feature, the CCW delivery system was retrofitted upstream of the radiological effluent injection site. This measure eliminates the most significant source of radioactivity normally found in liquid effluents from nuclear power plants. Also, condenser cooling water can be supplied to the delivery system from any of the three power production units. This increases reliability of the warmwater source, although not to the extent that backup systems are not required.

2.3. Overwintering Studies--BFN (1979-81)

In mid-October 1979, 70,000 tilapia fingerlings, ranging in weight from 3.0 to 15.0 g, arrived from Auburn University[1] and were stocked into six raceways. Two different species of tilapia, *Sarotherodon aurea* and *S. nilotica* were supplied as test species because of their favorable growth rates and relative cold tolerance (Lee, 1979). Growth, survival, and feed conversion values were satisfactory during the winter period. By early February, the fish had increased their initial weight by 250 to 300 percent. Unfortunately, on February 11, 1980 a multiple unit shutdown coupled with an unrelated computer and alarm failure resulted in intrusion of ambient river water and massive mortality of tilapia stocks. The fish were exposed to ambient river water (5° C) for about 18 hours before CCW temperatures rose to preshutdown levels. Complete mortality of the less cold tolerant *S. nilotica* occurred, while *S. aurea*, the most cold tolerant of the tilapia species, experienced 95 percent mortality. More tilapia fingerlings were acquired from Florida and reared in the raceways during the remainder of the overwintering period. In mid-April, most of these fingerlings were taken to Auburn University for pond and cage production tests. During the 1980-81 overwintering period, emphasis was placed on overwintering a diversity of broodstock and fingerlings for expanded breeding and pond culture studies respectively. Four stocks of brood-sized tilapia (*S. aurea*, *S. nilotica*, *S. hornorum*, and *S. mossambica*) and two all-male hybrid strains (*S.* mossambica ♀ x *S. hornorum* ♂) and (*S. nilotica* ♀ x *S. hornorum* ♂) were successfully overwintered. By early April, the hybrid *S. mossambica* ♀ x *S. hornorum* ♂ had increased its initial weight (2.5 g) by 570 percent. Few operational problems were encountered during the 1980-81 overwintering period, due primarily to the adding of several automatic backup systems (Waddell, unpublished paper).

2.4. Tilapia Breeding and Hybridization Studies

Production of all-male tilapia fingerlings by hybridization is advantageous for several reasons. Unwanted reproduction in culture ponds can be avoided if all-male fingerlings are stocked. Also several crosses exhibit hybrid vigor for cold tolerance and growth (Lee, 1979), both significant factors for culture in temperate climates. During 1980, 36 small nylon nets (1.2 m by 1.2 m by 2.7 m, 0.15-cm mesh) were suspended in an earthen pond and evaluated as portable breeding units for producing hybrid tilapia fry (Behrends and Smitherman, 1981). Adult fish (brooders) were stocked into the nets in June, and fry (and eggs) were collected every two weeks for a 6-week period. Three different crosses which theoretically produce 100 percent male offspring were evaluated. Of these, only the female S. mossambica x male S. hornorum cross produced significant numbers of fry. At a stocking rate of 24 brooders (20 females and 4 males), 10,860 fry and fertilized eggs were produced during a 6-week period.

Subsequent net-breeding trials were conducted to quantify the relative ease of producing S. aurea, S. nilotica, S. hornorum, and S. mossambica, and all their hybrids (Behrends and Smitherman, unpublished data).

Breeding studies were continued during the winter of 1980-81 to ascertain the feasibility of inducing tilapia broodstock to spawn early via photoperiod and temperature manipulation. Generally, tilapia will not spawn in north Alabama until late May. However, by late February all four species were exhibiting breeding behavior and spawning occurred in all species by mid-March. Invariably, early spawning occurred only after CCW temperatures were above 24° C and photoperiods were greater than 11 hours. However, our data strongly suggests that temperature was a much stronger stimulus to spawning than photoperiod, as long as the photoperiod was greater than 11 hours. This is a favorable implication for hatchery work at closed-cycle plants where CCW temperatures are much warmer during winter months.

The early spring spawning approach to fingerling production may have advantages over the traditional overwintering approach. Instead of overwintering summer-produced fingerlings, selected groups of broodfish could be overwintered and induced to spawn in early March. Theoretically, for each kg of female broodstock overwintered, 3,000 fry could be produced in the initial spawn, thus increasing the capacity of the overwintering system. More breeding and nursery areas would be required for this operation. Early spring spawning would require that young-of-the-year tilapia reach marketable weight during their first culture season. This procedure remains to be tested.

2.5. Pond Growout of Tilapia

Pond production of tilapia can be accomplished with pelleted feeds, organic fertilizers, or a combination of both. TVA has developed an integrated warmwater aquaculture system for reclaiming valuable plant nutrients from animal wastes which accumulate during livestock feeding in confinement (Behrends, et al., 1980, in press; Behrends, 1980; and Maddox, et al., 1979). During the past five years, experiments were conducted to develop criteria for such a system (figure 1). Results of yield trials indicate that for optimum production of market-sized fish, plankton culture ponds should be fertilized daily during March through October with up to 60 kg/ha/day of fresh swine manure (dry-matter basis). Warm CCW should be directed into the ponds at a rate sufficient to flush them every 10 days. Shorter retention periods (5 days or less) result in less plankton production and hence, less fish production. Longer retention periods (15 days or more), although allowing greater plankton production, also result in less

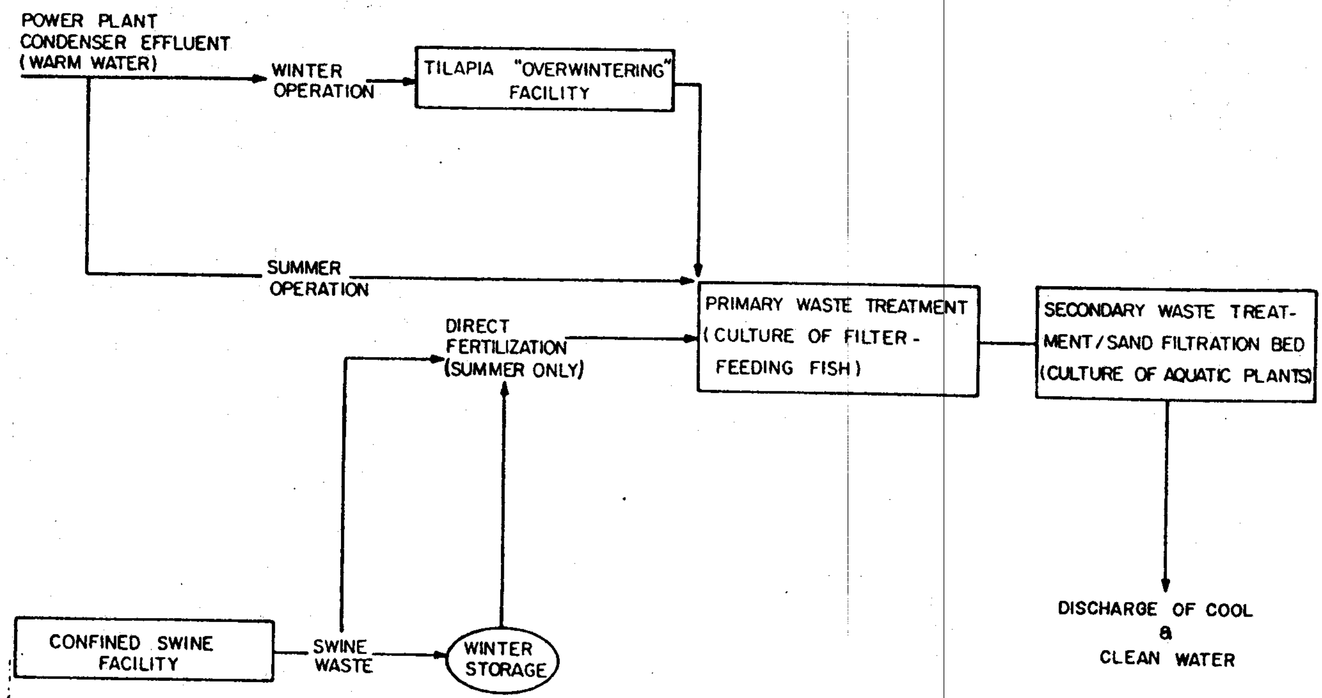

FIGURE 1. BIOLOGICAL RECYCLING OF LIVESTOCK WASTE NUTRIENTS AND ENERGY.

fish production due to the buildup of toxic metabolites, such as ammonia. At a stocking rate of 10,000 to 15,000/ha, production in excess of 6,000 kg/ha is possible during a 6-month growing season (Behrends, et al., in press). Fertility rates and stocking densities have also been developed for static water systems (i.e., no flowing water), and other manure sources (Moav, et al., 1977; Collis and Smitherman, 1978; and Stickney and Hesby, 1977).

Culture ponds can also be used in intensely fed production systems if large volumes of warm water are available to supply oxygen and dilute culture-related metabolites. In Taiwan, tilapia standing crops of near 110,000 kg/ha have been achieved in flowing water ponds with aeration and a nutritionally balanced diet (Lovell, 1980). Intensive pond production systems, although feed intensive, may have application at power plant sites where land may not be available for development of large extensive production systems.

3. OPTIMIZING USE OF HEATED EFFLUENTS IN TILAPIA CULTURE

One of the most commonly voiced concerns in power plant aquaculture relates to the problem of wide seasonal variation in effluent temperatures. This is especially critical at open-cycle power plants where CCW temperatures may vary as much as 25° to 30° C. Culturally, this problem can be minimized by designing systems to accommodate these large fluctuations in temperature. TVA has proposed adoption of a multiseasonal approach to culturing tilapia which optimizes the use of warm flowing water on an annual basis.

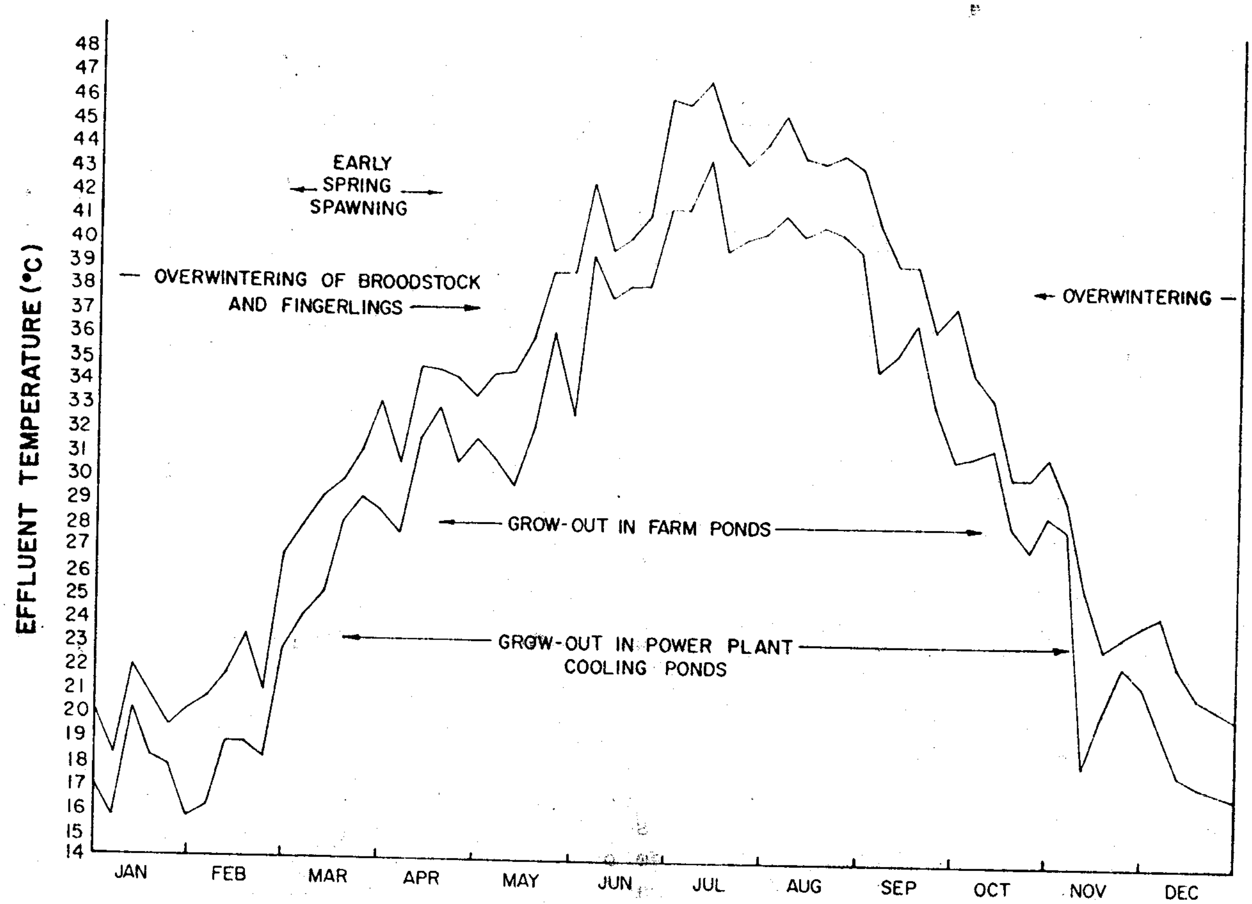

FIGURE 2 BROWNS FERRY CONDENSER EFFLUENT TEMPERATURES AND RELATED TILAPIA CULTURE ACTIVITIES

Figure 2 illustrates the proposed culture activities as they relate to the CCW temperature of BFN. The upper and lower lines represent the mean maximum and mean minimum temperatures respectively. During winter and spring, emphasis will be on hatchery operations and producing stocker-sized fingerlings, while final growout will be performed in ponds during late spring, summer, and fall. Final growout can be performed at the power plant site in appropriately sized cooling ponds or in conventional farm ponds near the power plant site. The farm pond approach has considerable appeal since it has the potential for expanding the land base for tilapia culture to thousands of acres.

CONCLUSION

Although more development work will be required before tilapia culture becomes an aquaculture industry in temperate climates, recent developments in hatchery and overwintering systems will certainly expedite the extension process.

TVA will continue its development work in tilapia culture with an emphasis on extending it from the power plant site to the farm.

ACKNOWLEDGEMENTS

TVA expresses its gratitude to Auburn University's Department of Fisheries and Allied Aquacultures for its cooperation in providing fingerlings and expertise. We also acknowledge John B. Kingsley, Philip W. Barron, and H. Steven Coonrod II for their technical help.

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