Worldwide Prospects for Commercial Production of Tilapia

by

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Introduction

Tilapias are endemic to Africa, but interest in their aquacultural potential led to nearly worldwide distribution within the past fifty years. Initial enthusiasm was based on characteristics that made tilapia appropriate for subsistence fish farming in developing countries: several species are herbivorous, readily reproduce in small ponds and are highly tolerant of poor water quality. Interest in commercial production of tilapia was initially dampened by a small harvest size resulting from excessive reproduction and stunting. Within the past thirty years, however, commercially viable techniques have been developed to control overcrowding in ponds, thereby permitting growth to more marketable sizes. Total world landing of tilapia is now about 1.2 million MT annually, of which more than half (670,000 MT) is farmed. In the USA, total consumption of tilapia is about 51,000 MT, but less than one-fifth (a little more than 8,000 MT) is produced domestically. The rest is imported from Latin America and the Caribbean (where total production exceeds 200,000 MT annually). Tilapias are rapidly becoming more accepted worldwide by middle-class and upscale producers. Production will continue to expand as the market for farmed tilapia grows.

This publication is intended for prospective investors and producers to aid in the preliminary assessment of the aquacultural potential of tilapia. We presume that the readers have some background in animal husbandry and are looking for an overall description of the production characteristics of tilapia. We focused on production techniques rather than on economic analyses which can only be done on a site-specific basis. Our intention, however, was to provide sufficient detail to permit logistic and economic analyses under a given set of conditons.

The contents are based on available literature and on the cumulative experience of the authors and colleagues at the International Center for Aquaculture and Aquatic Environments at Auburn University.

1. Biological factors affecting tilapia culture

Common and scientific names

Commercially important tilapias are currently divided into three major taxonomic groups based primarily on reproductive behavior:

- substrate incubators (*Tilapia* spp),
- maternal mouthbrooders (*Oreochromis* spp), and
- paternal and biparental mouthbrooders (*Sarotherodon* spp).

Tilapias are endemic to Africa, Jordan, and Israel where more than 70 species have been identified. However, few are commercially important and even fewer are of aquacultural importance. The common and scientific names of commercially important species are:

Nile tilapia	*Oreochromis niloticus*
Silver perch (Jamaica)	"
Mojarra plateada (Colombia)	"
Blue tilapia	*Oreochromis aureus*
Java tilapia	*Oreochromis mossambicus*
Mossambique tilapia	"
Zanzibar tilapia	*Oreochromis urolepis hornorum*
"Red" tilapia	*Oreochromis* spp (1)
"White" or "pearl" tilapia	*Oreochromis* spp(2)
Galilee tilapia	*Sarotherodon galilaeus*
Black-chinned tilapia	*Sarotherodon melanotheron*
Congo tilapia	*Tilapia rendalli*
--	*Oreochromis andersonii*
--	*Oreochromis spilurus*

Large-scale commercial culture of tilapia is limited worldwide almost exclusively to the first three species listed above and to the "red" tilapia. In addition, the capture fishery of *Sarotherodon galilaeus* is commercially important in Israel, and *Tilapia rendalli* to a lesser extent is commercially significant in the capture fishery of Brazilian reservoirs. The remaining tilapia species listed are utilized in small-scale commercial or subsistence aquaculture, primarily in Africa.

As indicated, *Oreochromis* is the genus of greatest aquacultural importance. However, readers of scientific literature should keep in mind that the taxonomy of this group has evolved considerably in recent years. Twenty years ago all commercially important tilapias were grouped under the genus *Tilapia* , but in the mid-1970's the mouthbrooding species were separated from the species that incubated their eggs externally and were placed in the genus *Sarotherodon.* About 1983 the maternal mouthbrooder species of *Sarotherodon* were separated again, this time to the genus *Oreochromis.* Consequently, an important aquacultural species such as the Nile tilapia, now reported as *Oreochromis niloticus*, was called *Sarotherodon niloticus* in the literature of the late 1970's and early 1980's, and prior to that was identified as *Tilapia nilotica*.

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(1) Usually developed from *O. mossambicus* and/or *O. urolepis hornorum* stocks (for the red color) and often crossed with *O. niloticus* and/or *O. aureus* to improve growth and other aquacultural characteristics. Most lines of red tilapia do not breed true, requiring continuous selection to maintain a high percentage of red offspring.

(2) Developed from *O. niloticus* and *O. aureus* crosses. Lower fecundity and poorer survival reduce its value for commercial culture. Female "white" x male *O. niloticus* produce 50% white and 50% normal colored progeny with good survival and growth.

Geographic distribution

The original distribution of tilapias was south central Africa northward into Syria. *Oreochromis mossambicus* was apparently the first tilapia species to be exported from Africa, reported on the Indonesian island of Java in 1939. During World War II the Japanese introduced it to numerous Pacific islands. During the 1950's and 1960's, many persons and organizations, encouraged by its ready reproduction in ponds, tolerance to adverse environmental conditions, and herbivorous/omnivorous feeding habits, introduced *O. mossambicus* to numerous countries in Central America, northern South America, Caribbean islands, southeast Asia, India, Bangladesh, Pakistan, and north Australia. However, enthusiasm for its culture as a food fish soon waned as the problem of overpopulation and stunting in ponds with mixed-sex fish became apparent.

Attempts to control crowding in aquaculture ponds included the introduction of other tilapia species which grew faster and larger under many culture conditions and reached sexual maturity at a greater size and age than *O. mossambicus*. Two other species introduced outside Africa are currently responsible for virtually all worldwide large-scale commercial culture of tilapia. The tropical and subtropical countries of current distribution outside Africa of the three culture species are:

O. niloticus	Indonesia, Bangladesh, Thailand, Japan, Taiwan, China, Vietnam, India, Philippines, Mexico, Guatemala, El Salvador, Nicaragua, Costa Rica, Honduras, Belize, Panama, Colombia, Brazil, Ecuador, Bolivia, Peru, Venezuela, Jamaica, Dominican Republic, Cuba, Haiti, Trinidad, Puerto Rico, Israel, Jordan, Saudi Arabia
O. aureus	Philippines, Taiwan, Mexico, El Salvador, Puerto Rico, Panama

Distinguishing anatomical characteristics

Tilapias belong to the Cichlidae family which can be distinguished from other families of bony fish by the presence of an interrupted lateral line, running superior along the anterior part of the fish and inferior along the posterior portion. Tilapias can generally be separated from other native cichlids in non-African countries by coloration and/or the presence of a pharyngeal plate used in the grinding of vegetable matter. (The pharyngeal plate of rasping teeth in adult fish feels almost like rough sandpaper when your small finger is inserted deep into the esophagus.)

O. mossambicus can be readily distinguished from the other two principal culture species, *O. niloticus* and *O. aureus* by the presence of yellow pigmentation in the gular region (most notable when comparing juveniles), an upturned, protruding snout and black color in older males and lack of vertical banding on the tail.

O. niloticus can be distinguished from *O. aureus* by the relatively strong, vertical banding in the caudal (tail) fin and by the gray-pink pigmentation of the gular region.

Age/size at sexual maturity

The three principal cultured tilapias, all of the genus *Oreochromis*, are maternal mouthbrooders. In all cases, the polygamous male excavates a nest in the pond bottom, generally in water shallower than 1 meter. The male will also establish a spawning site on solid substrate, such as concrete -- the male is not specifically excavating a depression for a nest but rather is cleaning a nesting site down to solid substrate. After a short mating ritual, the female spawns in the nest (2-4 eggs/g of female) and incubates the externally fertilized eggs in her buccal cavity until they hatch. Fry remain in the female's mouth through yolk sac absorption, and often seek refuge in her mouth for several days after swim bladder inflation.

Sexual maturity in tilapia species is a function of age, size, and environmental conditions. *O. mossambicus* , in general, reaches sexual maturity at a smaller size and younger age than *O. niloticus* and *O. aureus*. Tilapia populations in large lakes mature at a later age and larger size than the same species raised in culture ponds. For example, *O. niloticus* matures at about 10 to 12 months and 350 to 500 g in several East African lakes. The same population under conditions of near maximum growth will reach sexual maturity in farm ponds at an age of 5 to 6 months and 150 to 200 g. When growth is slow in farm ponds, sexual maturity will be delayed a month or two but fish may spawn at weights as low as 20 g.

Under fast growing conditions in culture ponds *O. mossambicus* may reach sexual maturity in as little as three months of age, at which time they seldom exceed 60 to 100 g. In poorly fertilized ponds sexually mature fish may be as small as 15 g.

Disease tolerance

Tilapias are more resistant to viral, bacterial and parasitic diseases than other commonly cultured fish. At temperatures greater than 16° to 18°C and in the absence of severe environmental stress, tilapia rarely become diseased. However, viral, bacterial and parasitic problems have all been reported, especially after stress from low temperature, handling, severe crowding or poor water quality. Fungal infections, especially from *Saprolegnia*, are particularly common after handling when water temperature is below 20°C.

Lymphocystis is a viral disease reported for tilapia. Likewise, a whirling viral disease recently caused heavy losses of tilapia fry in Israel.

Columnaris, caused by *Flexibacter columnaris,* is the most common myxobacterial pathogen for tilapia. Skin lesions may be problematic under high temperature and ammonia stress, and gill infections may also cause heavy losses among fry, especially at low temperatures. The most common bacterial diseases are hemorrhagic septicemias, especially from *Aeromonas hydrophila* and, under hyper-intensive culture, *Edwardsiella tarda*.

In recent years *Streptococcus innae* infections have also caused heavy losses of tilapia, primarily in recirculating and intensive flow-through systems following skin abrasions at higher temperature and salinity. Sick fish show erratic swimming, a curved body, and lessions in the eyes and in internal organs.

"Ich" or "White spot", caused by the protozoan parasite *Ichthyopthirius multifiliis*, can cause serious losses of fry and juveniles in intensive recirculating systems. "Ich" problems are much less likely in tropical areas where most commercial tilapia production occurs because water temperatures are generally warmer than 20-24°C, the optimal temperature range for this disease organism. The protozoan *Trichodina* may also reach debilitating densities on stressed fish at low water temperatures.

Monogenean and digenean helminthic parasites are common infections of tilapia, but are normally of low pathogenicity with little effect on fish growth.

Parasitic crustaceans, such as *Argulus, Ergasilus* and *Lernaea*, have caused some serious losses, but most reports are from Africa and from Israel where tilapias are associated with common carp.

<u>Tolerance to key water quality parameters</u>

Tilapia are more tolerant than most commonly cultured fish to salinity, high water temperature, low dissolved oxygen, and high ammonia concentrations:

Salinity

The tilapias most used in commercial culture are freshwater species, but all are tolerant to brackishwater. *O. niloticus* is the least saline tolerant of the commercially important species, but grows well at salinities up to 15 ppt. *O. aureus* grows well in brackish water up to 20 ppt salinity. *O. mossambicus* and *O. spilurus* grow and even reproduce at salinity levels near or at full-strength seawater.

As a result of salinity tolerance, *O. spilurus, O. mossambicus* and the mossambicus-derived "red" tilapias are preferred for culture in salt water. Another consequence of differences in salinity tolerance is that *O. niloticus* may be the tilapia species of choice in coastal brackishwater ponds when tilapia reproduction is undesirable.

Salinity influences the spawning ability of tilapia. *Oreochromis mossambicus* is reported to grow and spawn in full strength seawater while *O. aureus* and *O. niloticus* can reproduce in salinities of 10 to 15 g/L. However, the three tilapia mentioned above have better reproductive performance in low salinities and freshwater. *O. niloticus* and *O. aureus* produce fry equally well in freshwater and 5 g/L salinity but fry numbers begin to decline at 10 g/L salinity. Reproductive performance of *O. mossambicus* begins to decline in salinities above 10 g/L when compared with performance in freshwater. Red tilapia hybrids with *O. mossambicus* genes will have a reproductive performance in saltwater similar to pure *O. mossambicus*. Ideally, tilapia hatcheries should be located in freshwater or in water with less than 5 g/L salinity and the fry transferred to higher salinities for further growth.

Water temperature

Inability of tilapia to tolerate low temperatures is a serious constraint for commercial culture in temperate regions. The lethal low temperature for most species is 10° or 11°C, but *O. aureus*, the most cold tolerant, tolerates to 8° or 9°C. When hybridized with other *Oreochromis* species, cold tolerance appears to be inherited from the *O. aureus* parent.

Feeding generally ceases when water temperature falls below 16° or 17°C. Disease-induced mortalities after handling seriously constrain management below 17° or 18°C. Reproduction is inhibited at water temperatures below 20^0 C , slow in waters of 21 to 24^0 C and most frequent in waters above 25^0 C. Subtropical regions and tropical regions with a cool season will see a reduction in the number of fry produced during times when daily water temperature averages below 24^0 C.

Preferred water temperatures for tilapia growth are approximately 29° to 31°C. When fish are fed to satiation, growth at the preferred temperature is typically three times greater than at 22°C. Maximum feed consumption at 22°C is only 50 to 60% as great as at 26°C.

Tilapias reportedly tolerate temperatures up to 40°C, but stress-induced disease and mortality are problematic when temperatures exceed 37 or 38°C.

Dissolved oxygen

Low dissolved oxygen is usually the first water quality constraint to growth in intensively managed ponds. Commonly cultured species of tilapia survive routine dawn dissolved oxygen (DO) concentrations less than 0.5 mg/l, levels considerably below the tolerance levels for most other cultured fish. Survival in water with low DO is due, in part, to their ability to extract dissolved oxygen from the film of water at the water-air interface when DO is below 1 mg/l. For this reason, heavy growth of floating plants likely reduces their survival in ponds with low DO.

In spite of tilapias' ability to survive acute low DO, ponds should be managed to generally maintain DO above 2 or 3 mg/l because metabolism and growth are depressed when levels are below this level for prolonged periods.

pH

Tilapia seem to grow best in water that is near neutral or slightly alkaline. Growth is reduced in acidic waters (possibly due to less production of natural food organisms) but commonly cultured tilapia species survive at pH as low as 5. Afternoon increases in pH to 10 apparently do not seriously affect tilapia production. The lethal alkaline limit is pH 11 or greater.

Ammonia

Ammonia toxicity is closely correlated with pH and, to a lesser extent, by water temperature and DO. At high pH a greater percentage of total ammonia converts to the toxic un-ionized form. At pH 7 less than 1% of the total ammonia is in the toxic un-ionized form; at pH 8 about 5 to 9% is un-ionized, at pH 9 30 to 50%, and at pH 10 80 to 90%. Consequently, ammonia toxicity is more problematic in poorly buffered ponds (alkalinity below 30 mg/l $CaCO_3$) which frequently experience afternoon pH levels of 9 or even 10.

Ammonia is more toxic at higher temperature; the ranges in percentage unionized form given above reflect conditions at 24 to 32°C. Low DO also increases ammonia toxicity but in fish ponds this is largely balanced by decreased toxicity produced by an increasing concentration of CO_2 which lowers pH.

Massive mortality of tilapia occurs within a couple days when suddenly transferred to water with unionized ammonia concentrations greater than 2 mg/l. However, when acclimated to sub-lethal levels, approximately half the fish will survive three or four days at unionized ammonia concentrations as high as 3 mg/l.

Prolonged exposure (several weeks) to unionized ammonia concentration greater than 1 mg/l causes losses, especially among fry and juveniles in water with low DO. The first mortalities from prolonged exposure begin at unionized ammonia concentrations as low as 0.2 mg/l.

Unionized ammonia begins to depress appetite of tilapia at concentrations as low as 0.08 mg/l.

Susceptibility to predation by birds

All fish are susceptible to predation by birds. Tilapias are no exception. In some regions ponds are constructed deeper to reduce access by wading birds. Fingerlings of the selected lines of "red" and "white" tilapia are particularly susceptible to predation by birds because they are easily seen. Cormorants can cause heavy losses, especially in nursery ponds. Predatory birds often drop live tilapia into adjacent ponds, a potentially serious problem when genetic purity is critical.

Natural feeding behavior

Tilapias ingest a wide variety of natural food organisms, including plankton, succulent green leaves, benthic organisms, aquatic invertebrates, larval fish, detritus and decomposing organic matter. In ponds with heavy supplemental feeding, natural food organisms typically account for 30 to 50% of tilapia growth, whereas in full-fed channel catfish ponds only 5 to 10% of the fish growth is traced to ingestion of natural food organisms. The ability of a single tilapia species to utilize so many types of natural food (as well as artificial feeds) makes polyculture with other fish less important than for common/chinese carp culture.

Tilapias are often considered filter-feeders because they can efficiently harvest planktonic organisms from the water column. However, "filter-feeder" is somewhat a misnomer because tilapias do not physically filter the water through gill rakers as efficiently as silver and bighead carps. Gills of tilapia secrete a mucous which entraps planktonic cells; the plankton-rich bolus is then ingested. This mechanism allows tilapia to harvest micro-phytoplankton as small as 5 microns in diameter. Tilapia are mistakenly thought to be suffering oxygen stress as they feed on concentrations of planktonic algal cells that float to the surface in late morning or early afternoon. Digestion and assimilation of plant material occurs along the length of a long intestine, usually at least 6 times the total length of the fish. *O. mossambicus* is less efficient than *O. niloticus* or *O. aureus* in ingesting planktonic algae.

Some species of tilapia, including *Tilapia rendalli* and *T. zillii*, actively feed on fresh leaves of succulent plants but slower growth and inability to effectively harvest plankton eliminate them as preferred commercial culture species. Macrophytes are not considered a preferred food for *O. niloticus* or *O. aureus*. These commercially important species are generally ineffective in eliminating already established stands of emergent weeds but are sufficiently herbivorous to prevent establishment of most emergent and many floating plants in aquacultural ponds.

Consumption of plant tissue does not automatically imply the ability to digest and assimilate the nutrients into fish flesh. Most fish species derive no nutrition from plant tissue consumed accidentally in pursuit of other food. Tilapia, however, obtain substantial nutritional benefit from plant material. Digestion of filamentous and planktonic algae and higher plants is aided by two mechanisms: by physical grinding of plant tissues between two pharyngeal plates of fine teeth and by a stomach pH below 2 which ruptures the cell walls of blue-green algae and bacteria. The commercially important *Oreochromis* digest 30 to 60% of the protein in algae, with blue-green algae being digested more efficiently than green algae.

Animal manures function as both fertilizer and feed in tilapia ponds. Swine and poultry excrete little carbohydrate that is digestible by tilapia, but approximately half the protein remaining in swine manures (undigested dietary protein, bacteria, and sloughed-off intestinal tissue) is digestible to tilapia.

When feeding, tilapia do not disturb the pond bottom as aggressively as common carp, but they effectively browse, primarily during daylight hours, on live benthic invertebrates and bacteria-laden detritus.

Tilapias also feed on mid-water invertebrates. They are not generally considered piscivorous, but juveniles actively attack larval fish. This cannibalistic feeding behavior is an important consideration for tilapia seed production management strategies.

Like many cichlids, advanced juveniles and adult tilapias are strongly territorial. The primary cue is apparently visual because water turbidity reduces aggressiveness. A consequence of territorial behavior is unequal growth at high densities when limited food is concentrated in few places.

In general, tilapias utilize natural food organisms so efficiently that standing crops of fish exceeding 3000 kg/ha can be sustained without supplemental feed in well fertilized ponds. The nutritional value of the natural food supply is important, even for commercial operations with heavy feeding.

2. Commercial culture practices

Discussion of commercial culture systems is divided into three phases: fry production, nursery, and growout.

Fry production

Fish assure continued survival of the species in nature by providing greater parental care or by producing more offspring (high fecundity). Carp, for example, spawn only once or twice a year and provide no parental care after fertilization but compensate by spawning up to millions of eggs. In nature few offspring survive to maturity but under controlled conditions a female carp produces hundreds of thousands of offspring in a single spawn. Female tilapias, in contrast, produce only a few hundred offspring per spawn. Under appropriate environmental conditions they spawn frequently (every 4 to 6 weeks) and at a young age (usually less than 6 months), but overall fecundity is low.

The reproductive habits evolved by tilapia were sufficient to assure survival in the wild. Only a few hundred offspring per spawn was needed in the wild because female *Oreochromis* tenaciously protect their offspring for several days after incubation. Low fecundity, however, is not a desirable aquacultural trait because a greater number of female broodfish are required to sustain a commercial aquaculture operation. On the positive side, however, the need for many broodfish decreases the risk of inbreeding depression, an important management problem in the farming of more fecund species.

It is ironic that, in spite of the overall low fecundity of tilapias, frequent spawning at a young age causes overpopulation and stunting in mixed-sex culture before fish reach commercially marketable weights. Monoculture of mixed-sex and mixed-age fingerlings seldom produces adults with average weights greater than 100 g. Young, uniform-size 1-g *O. niloticus* and *O. aureus*, growing at near-maximum rates (abundant food supply at relatively low densities), often reach average weight near 250 g before overcrowding and stunting. However, inconsistent results and low harvest weight usually make this production strategy unacceptable for commercial operations.

Overpopulation can be prevented by growing mixed-sex tilapia in cages because eggs fall through the bottom of the cage before the female can recover them for incubation. Overpopulation can also be prevented by polyculture with a predator fish stocked at 500 to 2000/ha, depending on the aggressiveness and territoriality of the predator species. However, the consistent availability of a second culture species, as well as the additional harvesting and sorting required, add complexity to the operation. For commercial enterprises requiring large fish for market, an even greater constraint to mixed-sex production techniques may be the slower growth of females, typically weighing only 50 to 70% as much as the males as adults.

Consequently, large-scale commercial growout of tilapia is almost exclusively with "all-male" (>95% male) fish. All-male culture not only prevents or reduces spawning but also takes advantage of the faster growth of males. The most widely used technique for producing all-male fingerlings is by a procedure called sex reversal, sex inversion, or sex direction. Other less common, but commercially feasible, techniques are hybridization and manual separation of the sexes.

Sex reversal

Sex reversal is the process of administering male steroids to recently hatched fry so that the undifferentiated gonadal tissue of genetic females develops into testicular tissue, producing individuals that grow and function reproductively as males. The procedure must be initiated before the primal gonadal tissue starts to differentiate into ovarian tissue which, at average water temperatures of 24° to 28°C, occurs in *Oreochromis* spp at a size and age of only 11 to 13 mm and 3 to 4 weeks after hatching.

Large quantities of fry of the required age/size are usually produced in open ponds, concrete tanks, or net enclosures. The latter technique utilizes pond space more efficiently but requires more labor and equipment.

Tanks. In relatively small artificial tanks broodfish are commonly stocked at a rate of 0.3 to 0.7 kg/m^2, depending on the amount of water exchange, with female:male total weight ratios of 2-3:1. Fry are frequently skimmed from the water surface beginning about 10 days after stocking. Brood tanks must be drained and recycled every month or two because fry that escape harvest soon become cannibalistic on recently hatched fry. Monthly fry production in tropical regions like the Philippines where this procedure has been utilized is approximately 1 per g of brood female (annual production of one million fry per 100 kg brood females and 30 to 50 kg of brood males).

Open ponds. Reproduction ponds are usually 60 to 90 cm deep and less than 0.2 ha. Broodfish are stocked at a rate of 0.2 to 0.5 kg/m^2 (2000 to 5000 kg/ha). One male per 2 or 3 brood females is more efficient but not critical. Ponds should be equipped with a 30-cm deep harvest basin lined with large-mesh netting before filling with water. No chemical treatment to control predaceous insects is normally needed. Brood ponds are drained and completely harvested 15 to 20 days after stocking broodfish, depending on water temperature. Fry harvest should be 15 days after stocking the parents when the average of the daily high and low water temperatures is 28 to 30^0 C and 20 days when daily water temperatures average 24 to 26^0 C. When water has drained down to the rim of the harvest basin, broodfish are removed by lifting the netting. Fry are gently skimmed from the water surface. The same broodfish can be reused in the next spawning cycle after thoroughly disinfecting the pond bottom to eliminate all unharvested fry. Monthly fry production, like the tank method, is approximately 1 per g of brood female (annual production of one million fry per 100 kg of brood female and 50 to 100 kg of brood males). The technique is less labor-intensive than the small tank technique but often produces some over-size fry which must be removed by grading through a 2.5- to 3.0-mm square mesh screen. Fry survival is lower in open ponds than in tanks and net enclosures because fry are often stressed during harvest and some fry are stranded on the pond bottom as the water recedes during draining.

Cages. A more intensive method to produce tilapia fry for sex reversal is in fine-mesh cages. The main management variables are broodstock densities, frequency of fry harvest, and, to a lesser extent, broodstock replacement or rotation strategies. Broodstock replacement means all brood fish are replaced after a single spawning cycle in the cages. In a broodstock rotation strategy, brood fish are sexed after a spawning cycle and maintained separately for 10 to 14 days before rotation back to a spawning cage. The advantage of broodstock rotation is that the reproductive cycle of the brood females is more synchronized, permitting a higher percentage of females to spawn during the next cycle.

Broodfish are usually stocked in 1-mm mesh cages at a rate of 0.2 to 0.6 kg/m^2. If harvest frequency is every 2 to 3 weeks, the female:male sex ratio is 2-4:1. If harvest frequency is every 5 to 7 days, the optimum sex ratio of brood fish may be closer to 1:1. The higher proportion of males are suggested for harvest frequency of 5 to 7 days because the harvest consists primarily of fertilized eggs, rather than fry; the additional males may reduce the risk of lower fertilization rates which could cause disease problems among fertilized eggs due to fungus and bacteria attacking dead eggs during artificial incubation. Ideally, incubating females should not release there eggs when they are disturbed at harvest. *Oreochromis mossambicus* females hold their eggs and yolk-sac fry tightly in their mouths and rarely release their eggs when disturbed. However, some strains of *O. niloticus* females will frequently release their eggs when disturbed.

Harvesting every 2 to 3 weeks without broodstock replacement, monthly production is 1 to 2 fry per g of brood female. Fry harvest per spawning cage may be double if broodfish are replaced each cycle, but this practice is considerably more labor-intensive. A disadvantage of weekly seed collection is that hatchery facilities are needed for incubation, but benefits include reduced fouling of nets (if left to air dry a few days after harvest), increased fry per gram female , and uniformly smaller/younger fry. When eggs are completely harvested every 5 to 7 days and brood fish are rotated, monthly seed collection from the spawning cage is 4 to 8 eggs per g of brood female in the spawning cage (1.5 to 3 eggs per g of female if calculations are based on all brood females, including the "recovering" females). Survival of artificially incubated tilapia eggs is about 80%.

Fry of appropriate size and age are usually sex reversed in concrete tanks or net enclosures. In 1-mm mesh net enclosures suspended in ponds, fry are stocked at densities of 3000 to 5000/m^2. Stocking densities in concrete tanks depend on water exchange rates, keeping in mind that at a density of 4000 fry/m^2, the daily ration near the end of the treatment period will likely exceed 100 g/m^2 of tank.

Fry are fed a diet containing 40 to 60 mg 17-a-methyltestosterone/kg of feed for 3 to 4 weeks. The diet can be purchased commercially or prepared by dissolving the testosterone in alcohol (or sometimes in fish oil) and evenly mixing with a finely ground fish feed. Fry are fed 20% of their body weight daily during the first week. The amount of feed offered is reduced from 20% the first week to 10% of body weight during the second and third weeks. Fry are fed 10% of their body weight the fourth week. The ration should be offered daily, divided into at least two meals.

Dry powdered feed can be spread on the water surface or placed inside a floating ring made of rubber hose or plastic pipe to keep the feed from drifting outside the cage. The required amount of feed can be moistened and made into dough balls and placed on trays located under the water surface. At the end of the treatment fry normally weigh 0.1 to 0.5 g, depending primarily on water temperature and diet quality.

Normal fry survival is 70 to 80%. Occasional mass mortalities from parasites and disease have been reported, especially in hatcheries where fry are treated in clear, recycled water. The presence of abundant phytoplankton in treatment water does not reduce efficacy. Likewise, cooler water temperature decreases growth rate (and may prolong treatment duration one week) but does not negatively affect efficacy.

Percentage of phenotypic males after treatment usually exceeds 95% provided treatment begins with fry of the required size and age, but success may occasionally be only 80 to 90%. Reasons for occasional poor results are not clearly understood, but marginal initial size/age and very rapid growth during treatment (final weights exceeding 0.7 g) are suspected. Rapid growth, resulting from a combination of high water temperature and high feed quality, may cause fry to pass too quickly through the narrow window of susceptibility to sex reversal. Efficacy of the sex reversal treatment is similar for *O. niloticus, O. aureus* and *O. mossambicus.*, except maximum acceptable initial size for *O. mossambicus* may be slightly smaller.

Still under investigation is a technique to produce "super male" *O. niloticus* (YY) which, when crossed with normal females (XX), produces all-male offspring. The procedure is based on the fact that the genetic sex of a fish does not change with sex reversal, even though the appearance and reproductive capabilities of the fish may be altered. Several steps are required to produce super-males. Normal fry are first sex reversed with a female steroid, resulting in "females" that are genotypic males (XY). The XY females are identified after maturity by progeny testing and are then crossed with normal males (also XY). Theoretically, one-fourth of the progeny are YY super-males (1XX normal female +2XY normal males +1YY super-male). The technique shows promise but has not yet been adopted commercially, and is further complicated because the sex in tilapia is also influenced by other genetic and possibly environmental factors.

Hybridization

Hybrid vigor was the motivation of early hybridization work with tilapia. Improved growth among tilapia hybrids has proven to be minimal, if at all, but an unexpected result of early work was 100% male progeny from some crosses. The sex-determining mechanism among tilapias is complicated and incompletely understood. Among the commercial tilapia species, few crosses produce 100% male offspring. Other crosses produce a high percentage of males, while others produce only 50 to 75% males:

Crosses yielding 100% male offspring are:

female parent	X	male parent
O. mossambicus		*O. urolepis hornorum*
O. niloticus		*O. urolepis hornorum*

Note: crosses include some "red" lines of *O. hornorum* and *O. mossambicus.*

Crosses producing 85-99% males are:

O. niloticus	*O. aureus*
O. mossambicus	*O. aureus*

Note: selective breeding in Israel has led to *O. aureus* lines producing all or nearly all male progeny.

Crosses producing only 50-75% males:

O. mossambicus	*O. niloticus*
O. aureus	*O. niloticus*
O. urolepis hornorum	*O. niloticus*
O. aureus	*O. mossambicus*
O. urolepis hornorum	*O. mossambicus*

Note: reciprocal crosses of combinations producing 100% male offspring produce only 75% males. (Example: *O. niloticus* female x *O. hornorum* male = 100% males, but *O. hornorum* female x *O. niloticus* male = 75% males.)

An important advantage of hybridization over sex reversal is that artificial steroids are not required. The following disadvantages, however, are why hybridization is now seldom used for large-scale production of all-male tilapia fingerlings:

- Two species of tilapia must be maintained, instead of one.
- Genetic purity of both parental stocks is essential for production of all-male progeny. (A fertile hybrid is difficult to distinguish from one of the parents and does not produce all-male offspring. Maintenance of pure stocks requires strict precautions to prevent contamination through the water supply, by birds, or in seines.)
- Errors in sex identification of broodfish lead to female offspring.

- Partial reproductive incompatibility between two different species of tilapia reduces fry output.

Procedures have been developed to address these constraints, but, in most cases, breakdowns in equipment and worker discipline soon result in unacceptably high percentages of females. Nearly 100% male hybrids from *O. niloticus* female X *O. aureus* male crosses are produced at some Israeli operations, in part, because they are motivated by the additional cold tolerance imparted by the *O. aureus* parent and the fast growth of the hybrid. Greatest fingerling production is achieved by harvesting offspring from brood ponds at a small size, most commonly 0.2 to 1.0 g. Larger fingerlings would reduce output through cannibalism. Harvesting can be accomplished by single, complete harvests or a series of partial harvests. However, brood ponds must be drained and recycled at least every three months to assure that no hybrids mature and spawn with parents.

<u>Manual separation of sexes</u>

Manual separation of sexes, or "hand-sexing", can be accomplished by visually inspecting the genital papilla of tilapia fingerlings. *O. mossambicus* fingerlings can be separated at 15 to 25 g because the distinguishing characteristics of the male and female papilla are easily discernible. *O. niloticus* and *O. aureus* males are more difficult than *O. mossambicus* to separate from females by the genital papilla. *O. niloticus* and *O. aureus* fingerlings should be at least 25 to 30g for successful separation of the males and females. An experienced field hand generally achieves at least 95% accuracy. Advantages of "hand-sexing" are that no steroids are required and the constraints of hybridization are eliminated. The technique is commercially feasible (and often the most appropriate technique) for small- and medium-scale operations, but the following constraints reduce its value for large-scale operations:

- Half the fish production from nursery ponds (females) is a by-product of limited value. Reliance on hand-sexing thereby reduces farm output by 10 to 12% because nursery from 1 g to sexable-size usually requires 20 to 25% of total pond space.
- Hand-sexing is labor-intensive. Maximum sustainable sexing rate for most experienced workers is approximately 2000 fingerlings per hour, yielding less than 1000 males per hour.
- Sexing errors can be highly variable, depending on level of experience and pressures to sex more and smaller fish.

Commercial quantities of 1-g, mixed-sex fingerlings can be produced by partial harvesting with a 6-mm mesh seine every 1 to 2 weeks, beginning 5 to 7 weeks after stocking brooders. Brood ponds remain productive for 3 to 6 months provided partial harvests are frequent and efficient. Including turnaround time between cycles, in well managed ponds stocked with broodfish at approximately 1000 kg/ha, the average monthly harvest of fingerlings weighing 0.5-1 g is 0.3-0.5 million/ha.

Nursery

Tilapia usually weigh 0.15 to 0.8 g at completion of sex reversal. Likewise, hybridization and single-species brood ponds are most productive when progeny are harvested at about 1 g. Fish are usually reared to a larger size before stocking in growout ponds to more efficiently utilize pond space and because survival is more predictable with larger stockers.

In tropical countries the duration of nursery is usually 5 to 13 weeks, depending on desired final size. Desired final size may be less than 10 g but usually does not exceed 50 g. Relatively small fingerlings are desired when transport to growout ponds is distant and when verification of percentage males is not required. Intermediate-size fingerlings are required for hand-sexing. Large fingerlings may be produced when nursery survival has proven predictable and for growout in cages. With a relatively good diet and water temperatures above 25°C, fingerlings reach a weight of 10 to 15 g in 5 to 6 weeks and 25 to 30 g in 8 to 10 weeks. Sub-optimal water temperatures greatly influence appetite and growth of tilapia fingerlings. In the presence of abundant food tilapia fingerlings grow nearly twice as rapidly at an average temperature of 26°C as at 22°C. Lower temperatures affect growth (therefore nursery duration) but have little affect on targeted final standing crop or expected feed conversion efficiency as long as fish are not overfed.

Recommended stocking density for the nursery phase is mainly a function of nutrient inputs and target size after nursery. With a good quality diet, no aeration or water exchange, final biomass after the nursery is about 2000 to 3000 kg/ha. Average survival is commonly 60 to 80%. Therefore, assuming 70% survival, stocking density in standing water ponds for rearing to 25 g is 140,000 to 200,000/ha. With moderate water exchange (10 to 20% daily) stocking density can be doubled.

In nursery ponds with rich plankton blooms it is often economically appropriate to withhold feed during the first weeks of nursery because abundant natural food is adequate for good growth while the standing crop of fish is less than 300 to 500 kg/ha. In these cases ponds are usually manured before (1000 to 2000 kg/ha) and during the first week or two of nursery (300 to 800 kg/ha-week).

Nearly full nursery ponds may be partially harvested by seining, but tilapia are very effective at escaping underneath seines. Therefore, harvests are usually completed by draining the pond down to a harvest basin.

Growout

Levels of management intensity

Growout strategies for tilapia range from simple to very complex techniques. Simple strategies are characterized by little control over water quality and nutritional value of the food supply and by low fish yields. As greater control over water quality and fish nutrition is imposed, the cost and fish yield per unit area also increases. The description of the progression from low to high management intensity is divided in this report into eight levels, each characterized by a distinct change in a management parameter. Levels 1 to 5 are normally practiced in open ponds, while levels 6 and 7 employ artificial culture units. Any of the eight management intensity levels can be the most appropriate under a given set of circumstances (natural resources, infrastructure, management skill, availability of capital, cost and availability of nutrient inputs, market value of the fish, etc.).

Level 1. Extensive. The culture unit is a drainable earthen pond. Control of the water supply may be incomplete. Stocking density is low, 1,000-2,000/ha, and the only nutrition is from natural food organisms produced by the nutrients contained in the pond soils and water. Yields range from 300 to 700 kg/ha/crop. This level of intensity is economically viable only when land is cheap and pond construction costs are low or justified for other uses, such as irrigation or cattle watering.

Level 2. Semi-intensive. This level of management intensity is common for small-scale tilapia operations with limited capital or where high quality feeds are unavailable. The culture unit is an earthen pond which is filled and drained as needed. Ponds are fertilized with inorganic and /or organic fertilizers to increase production of pond foods. Nutritionally incomplete agricultural by-products are often fed as supplemental feeds to increase yields. Organic nutrient loading (manures plus feeds) frequently average 30 to 50 kg dry weight/ha/day, with maximum sustainable loading generally not exceeding 100 to 150 kg dry weight/ha/day. Where manure availability and labor permit, manures should be applied daily for maximum benefit. Thus, placing animal enclosures over or next to tilapia ponds is a good way to assure that manure is applied daily while cleaning the enclosures. The quantity of market-size livestock required usually varies from 500 to 2,000 chickens and/or ducks or 50 to 100 swine per hectare of pond. Fewer animals per area are used with standing water ponds while higher numbers per area are used where water can be partially exchanged (5 to 10%/day). Young animals can be stocked at much higher rates per pond area but would have to be reduced as animal size and manure production increase. Stocking rates of tilapia are 5,000 to 20,000/ha and fish yields are 1,500 to 2,500 kg/ha/crop in ponds fertilized with chemical fertilizers, 2,000 to 6,000 kg/ha/crop in manured ponds and 4,000 to 8,000 kg/ha/crop in fertilized ponds supplied with agricultural by-products. Production cycles are typically six months. These operations are often labor-intensive and require coordination of the integrated activities. Per unit cost of production can be relatively low, especially where commercial livestock operations have large amounts of manures available at no or little cost.

Level 3. Intensive - emergency aeration. The culture unit is an earthen pond with the water supply and discharge controlled. Stocking density is 10,000 to 30,000/ha. Fish are fed a high quality, pelleted diet. The daily ration is usually 2 to 4% of total fish biomass, with maximum daily rates commonly set at 80 to 120 kg/ha. Natural food organisms are no longer the primary food supply but feed conversion efficiency is improved by natural foods. No aeration or water exchange is routinely practiced, but may be occasionally provided during sudden oxygen depletion. In comparison with the preceeding management intensity, farm mangement is simpler and less labor-intensive. The relatively high cost of feed increases per unit cost of production, but these costs can be compensated by higher fish yields, 5,000 to 10,000 kg/ha/crop.

Level 4. Intensive - routine aeration. The culture unit is an earthen pond in which water supply and discharge are closely controlled. Stocking density is 10,000 to 30,000/ha, and fish are fed a nutritionally complete, pelleted diet providing all nutritional needs of the fish. Tilapia have no nutritional need for natural food organisms but feed conversion efficiency is improved through their consumption of natural foods. Aeration is routinely provided to maintain dissolved oxygen within desirable concentration. No water exchange is practiced. High ammonia, rather than low dissolved oxygen, is often the most limiting water quality constraint. Fish yields are 8,000 to 15,000 kg/ha/crop.

Level 5. Intensive - continuous aeration plus partial water exchange. This management strategy is often motivated by high land values and a relatively scarce water supply. The culture unit is a small circular or rectangular earthen pond (not more than one hectare) or a circular concrete tank (100 to 400 m^2) in which water supply and discharge are controlled. A drain pipe is commonly located in the center of the culture unit to assist in the removal of settleable solids when water is exchanged. Stocking density is 5 to 10/m^2 and fish are fed a nutritionally complete, pelleted ration. Tilapia are stocked so densely that pond food organisms no longer play an important role in fish growth. Aeration is continuous and a circular water flow carries the settleable solids to the center of the culture unit. Water is partially exchanged 2 to 3 times daily in order to discharge nitrogenous wastes. Yields are 20,000 to 100,000 kg/ha/crop, depending primarily on the amount of water exchanged.

Level 6. Continuous water flow (raceways). The culture unit is a small (100 to 400 m^2) rectangular or circular earthen or concrete pond, often with a central drain. Male tilapia are stocked at 70 to 200/m^3 and fed a nutritionally complete feed. Normally, no mechanical aeration is practiced because water exchange maintains high dissolved oxygen as well as removes nitrogenous wastes. The equivalent of 1 to 3 complete exchanges of water per hour is normal. A source of gravity-fed (or at least low-lift) water is required to raise fish economically. Yields can be as high as 70 to 200kg/m^3/crop.

Level 7. Cages. Cages are enclosures sealed on all sides with wire or net mesh. The mesh size retains the tilapia but permits water exchange and removal of wastes. Cages are placed in lakes, reservoirs, rivers, and the ocean. Male tilapia are stocked at 50 to 100/m^3 in large volume cages ($> 5\ m^3$) and up to 600/m^3 in small volume cages ($< 5\ m^3$) and fed a nutritionally complete, pellet. A floating (extruded) pellet is preferred to a sinking pellet. However, sinking pellets can be fed if provided slowly so the fish can consume them before they sink through the cage bottom. A small wire or plastic mesh feed retainer is required to reduce floating feed loss from the cage due to water currents caused by the feeding fish. Yields of 50 to 300 kg of tilapia /m^3 are possible. Small cages are more productive per unit volume because of more efficient water exchange. However, high productivity of smaller cages is at least partially offset by higher construction cost per unit volume and increased labor requirements for feeding and maintenance. Large cages are economically superior when water flow improves water exchange. Cage culture is usually not practiced in ponds but in undrainable lakes, reservoirs and backwaters of rivers. Cages must be suspended above the pond bottom to prevent successful spawning within the cage. Risk from aquatic predators and scavengers is site-specific.

Level 8. Water reuse. This level of intensity is normally practiced only in regions where water temperature seasonally falls below acceptable levels for tilapia or fresh water is scarce. Most systems are located indoors so that the aquatic environment can be closely controlled. Water temperature, dissolved oxygen, ammonia and nitrite levels are controlled by combinations of water exchange, aeration, and biofiltration. Mechanical and biofilters permit water reuse to lower the cost of heating water and to conserve water. Tank water is aerated or supplied with pure oxygen to keep dissolved oxygen concentrations high. Depending on water availability and heating costs, freshwater is added at the rate of less than 1% up to 10% of tank volume per day. Tilapia are typically stocked at 50 to 100 /m^3 of water, and fed nutritionally complete pelleted diets. Fish yields are 20 to 50 kg/m^3/crop (150 to 600 mt/ha). With heavy aeration and biofiltration, water requirements may be as low as 20 m^3/mt of fish yield, but 100 to 500 m^3 of water/mt of fish yield is more common. Risk of crop failure is high. Total fish mortality can occur within minutes because of the high standing crop of fish. Per unit cost of production is usually higher than with less intensive production strategies, often making it difficult to compete with processed tilapia raised in tropical climates. Profitability may hinge upon the demand for a high value product, such as live fish.

Growth as a function of stocking density

Tilapia given adequate nutrition and water quality grow at a maximum rate over a wide range of stocking densities. Tilapia of an equivalent size stocked at 1/m^2 will grow as fast as tilapia stocked at 100/m^2 with proper nutrition and water quality. Growth is retarded when high fertilization or feeding levels per unit area required to support high stocking densities produce poor water quality. When feeding a nutritionally incomplete diet, growth may be further slowed at high densities because each fish does not get sufficient natural food to supplement the nutritional deficiencies of the diet.

Tilapia reared at low density on only natural pond foods will grow at optimal rates until food becomes limiting. When stocking density is increased, food supplies become limiting and growth slows. To maintain rapid growth at densities higher than 1 or 2 fish/m^2, feed must be offered. Fish fed a nutritionally complete diet do not need natural foods for rapid growth. Stocking density can be increased and fast growth maintained by increasing the amount of feed offered as long as water quality is adequate. Generally, as long as daily feeding rates do not exceed 80 to 100 kg/ha, the unassimilated nutrients from feeds only increase production of the natural food organisms without seriously degrading water quality. At higher feeding rates, deteriorated water quality often constrains fish growth. Respiration by phytoplankton, bacteria and fish causes the dissolved oxygen concentration to drop below optimum levels for rapid fish growth. Mechanical aeration can correct this problem, allowing rapid growth at higher stocking densities and feeding rates. However, as additional feed is added in response to high fish densities ammonia, a product of protein metabolism, often becomes the next limiting factor for fish growth. The concentration of nitrogenous wastes can be reduced by water exchange.

Higher stocking densities usually result in higher fish yields, but individual fish growth is often sacrificed. Tilapia may require additional time to reach marketable size at high stocking densities. The longer tilapia remain in the culture pond, the greater the risk of disease and the probability that a few unwanted females will produce offspring that compete for food. Thus, the producer has to find the economically optimum stocking rate providing highest yields with rapid fish growth to marketable size.

Producers have three alternatives to shorten the growout cycle: stocking density can be reduced, feed quality can be improved, and environmental conditions can be modified with aeration and /or water exchange to permit higher feeding rates. In regions where energy to aerate or pump pond water is expensive or where a gravity-fed water supply is unavailable, the only economically feasible alternative to maintain faster growth is reduced stocking density.

Fish densities used for producing 5- to 7-ounce tilapia fillets

High stocking density and/or flowing water used in management intensity levels 5, 6 and 8 seriously interfere with spawning. Successful spawns are prevented in cages because eggs fall through the bottom of the cage before they can be recovered by the brood females. Thus, in these cases, tilapia offspring, even during prolonged growout, are rarely a problem.

Management intensity levels 1 through 5 may present overpopulation problems during extended growout. Producers prefer to stock all-male fish in their ponds, but 100% male populations are rarely obtained by hand-sexing, sex-reversal, or hybridization. Additional females may also gain entry through the water supply. When these few females spawn in a growout pond, their offspring will not be sufficiently numerous to seriously compete with the original fish stocked. Stocked males can reach 400 to 500 g in 4 to 5 months when started at 30 g. However, when offspring of the stocked females, which are 50 % females, reach sexual maturity in 3 to 5 additional months, the progeny are so numerous that competition with the original fish stocked seriously retards growth. Therefore, in order to grow tilapia to sizes larger than 400 to 500 g in most "all-male" culture systems, additional population control practices must be employed.

A low number of predators can be stocked to eliminate offspring resulting from a population that is at least 95% males. In some regions population control with a predator may be the best alternative. However, a predator fish may not always be consistently available.

A second alternative for production of tilapia larger than 400 to 500 g is two-phase growout. Fingerlings that are at least 90 to 95% males are stocked in a growout pond and harvested at 200 to 300 g. The few females and offspring are culled, and the males are restocked in phase-two ponds for further growth. Culling females is relatively easy because they grow slower than males and can be quickly separated by visual inspection or with a grader (a box made with nylon or wire mesh of a size that retains only the larger males). Advantages of two-phase growout are that additional pond space need not be used to produce or maintain predator fish and it also permits more intensive use of pond space. Phase-one ponds can be stocked at a higher density than would be possible if fish were to stay in the same pond until final market size. Disadvantages of two-phase growout are that it is more labor-intensive and increases the risk of disease as a result of handling stress.

The following would be a typical scenario for two-phase growout. First phase growth is from 30 g to 200-300 g and second phase growth is from 200-300 g to 800-1000 g. First phase ponds are stocked at twice the stocking density as second phase ponds. In aerated ponds in which tilapia are fed a nutritionally complete diet, 30-g fish are stocked at 40,000/ha, grown to 200-300 g, harvested when the standing crop is about 7,000 to 8,000 kg/ha, and females are culled. In the second phase the males are restocked at 10,000/ha and reared to 800 g, at which time the standing crop is about 8,000 kg/ha.

Growth as a function of species and strain

Tilapia growth is influenced by genetics as well as quantity and quality of feed, water quality, water temperature, sex, age, size, health and stocking density. Males of pure strains of *O. niloticus* and hybrids with *O. niloticus* as a parent, especially *O. niloticus* x *O. aureus* hybrids, are considered the fastest growers. *O. mossambicus* males grow more slowly, especially when larger than 200 to 300 g. Male *O. niloticus* , stocked at 20-30 g and provided adequate nutrition, water quality and water temperature, can reach 450-500 g in 150 days; subsequent growth to 800-1000 g may be 4 to 5 g/d with good feed and water quality. In general, *O. niloticus* cultured in ideal conditions will grow from 1-g fry to 800 g in 1 year.

Oreochromis spp. hybridize readily in fish ponds. Contamination with less desirable species, such as *O. mossambicus* , and years of inbreeding among pure stains can lead to slower growth. Growth of red tilapia can be especially unpredictable because of the unknown parentage of the many hybrid red strains cultured worldwide.

Tilapia growers should always buy fingerlings and brood fish of known heritage from reputable suppliers. However, reputable suppliers of tilapia are mostly found by word-of-mouth as published scientific growth comparisons are uncommon. Several institutions, including Auburn University, can be contracted to perform electrophoresis tests to determine the genetic makeup of a tilapia strain.

Harvest of growout ponds

Tilapia are difficult to harvest from large earthen ponds without draining the pond. Seine nets are commonly used to partial harvest tilapia from full ponds, but they are adept at escaping by jumping and by burrowing under the seine, especially when the pond bottom is soft mud. To effectively harvest tilapia in ponds, many people are needed to hold the lead or mud line firmly on the bottom and the float line above the water surface. Even with many people, harvest of more than half of the tilapia in a pond is difficult with one or two seine haul. All fish should be harvested to remove the few mature females that may be present. Ponds, therefore, are usually drained to complete harvest.

3. Feeds and feeding

Tilapias effectively utilize natural food organisms not consumed by many other fish. Some people, therefore, erroneously conclude that tilapia must have simple nutritional requirements. The nutritional requirements of tilapia, however, are very similar to other warmwater fish.

Protein and energy

Protein and energy contents of diets are primary nutritional considerations for commercial production of tilapia. Adequate digestible energy (DE) spares maximum dietary protein for growth. Additional dietary protein, without sufficient additional energy, actually depresses growth.

Optimum DE levels in tilapia diets with reasonable protein quality are 8.3 to 9.3 kcal DE/g of crude protein. The high end of the energy range would be recommended for diets with high quality protein. Non-protein dietary energy can be obtained from carbohydrates and lipids. Tilapia are similar to channel catfish in assimilating starch carbohydrate in cereal grains (corn, whole wheat, etc) but are significantly more efficient than channel catfish in the digestion of the more complex carbohydrates in highly fibrous feedstuffs. Tilapia obtain little or no digestible energy from cellulose. Lipids, highly concentrated sources of dietary energy, are highly digestible by tilapia, especially animal and vegetable oils that remain liquid at water temperature.

Maximum growth of tilapia is achieved at crude protein dietary levels of 35-50%, but economically optimum levels in commercial diets for juveniles and adults are usually 25 to 35%. The low end of the protein range is most appropriate at sub-optimal DE levels (diets with little lipid and/or high percentage of the more complex carbohydrates).

Protein quality of a tilapia diet is a function of the combination of amino acids, the building blocks of all protein. Tilapia, like other fish, shrimp and terrestrial animals, require 10 essential amino acids. ("Essential" means they must be included in the diet because they are unable to synthesize them.) Plant protein, in general, is deficient in two of the essential amino acids, methionine and lysine. Approximately 5% of the dietary protein should be lysine and about 3% should be methionine+cystine for optimum growth of tilapia. To supplement these deficiencies, feedstuffs of animal origin (fish meal, meat and bone meals, etc.) usually constitute 7 to 15% of economically optimum supplemental rations for commercial production of tilapia. Soybean meal is probably the most complete of the oilseed meals for meeting the essential amino acid needs of tilapia (although it is slightly deficient in methionine+cystine), but it seldom replaces all animal protein in economically optimum diets. Cottonseed meal can be added to tilapia diets at a level of at least 15% without causing gossypol toxicity. Sunflower seed, peanut, and rapeseed meals are reasonably good protein sources for tilapia diets, but have one or more drawbacks, including antinutritional factors and toxic substances. These drawbacks, however, are no more serious for tilapia than for channel catfish or carp.

Essential lipids

Lipids, in general, are a concentrated source of energy, and have a number of other nutritional functions. Many coldwater and marine fish have a specific nutritional requirement for fatty acids with an unsaturated bond in the n-3 position, whereas many warmwater fish, including channel catfish, are less sensitive to a specific fatty acid deficiency. Little research has been conducted on tilapias. At least one species (*T. Zillii*) appears to need n-6 fatty acids in their diet. Most fish respond well to dietary lipids, but in tilapia the benefit may be due primarily to the digestible energy they provide.

Minerals

Mineral requirements for tilapia are not completely understood. Recommended available phosphorus in diets is 0.5 to 0.7%. Only about one-third of the phosphorus from grains and plant material is nutritionally available to tilapia but inorganic phosphorus is readily absorbed. Most required calcium is obtained from the water by absorption across the gill membranes, but additional dietary calcium is usually added because dicalcium phosphate, added at 15 g/kg to provide adequate phosphorus in intensive culture, is a relatively inexpensive mineral for animal diets. Magnesium, sodium, potassium, iron, zinc, copper, iodine, selenium, and other trace minerals are generally derived from the water to satisfy most nutritional requirements. However, because of the gaps in nutritional information about tilapia and their relatively low cost, mineral supplements are usually added to tilapia diets, especially when standing crop of fish is expected to exceed 2,000 to 3,000 kg/ha.

Vitamins

Requirements for only a few vitamins are known for tilapia, including:

Vitamin	Requirement, mg/kg diet
Vitamin E	25-100
Riboflavin	6
Pantothenic acid	10
Vitamin B_{12}	0
Vitamin C	50

Based on known requirements for other fish species and on the vitamin content of common feedstuffs, vitamins likely to be missing in commercial tilapia diets containing oilseed meals, animal byproducts, and grains are: vitamins C, A, D, niacin, panthothenic acid riboflavin, and possibly vitamins E and K. The remaining vitamins are plentiful in plant feedstuffs and products of animal origin. By careful selection of ingredients it is possible to formulate diets that are probably deficient only in vitamin C. However, because of the possible consequences of vitamin deficiency and the relatively low cost, vitamin premixes are usually added to tilapia diets. Formulations based on channel catfish diets are probably more than adequate.

Water stability

Evidence suggests that tilapias utilize a meal (an unpelleted mix of ingredients) almost as efficiently as a pelleted diet containing the same ingredients in standing water ponds. Tilapia grown in cages or flowing water systems need pelleted diets. However, the pelleting process is a relatively minor cost in the manufacture of reasonably high quality fish diets. Tilapia diets are, therefore, generally pelleted or extruded because pelleting may reduce selective feeding on individual ingredients and loss of micro ingredients, such as vitamins and minerals.

Pelleting or extruding is normally appropriate for commercial diets, but the degree of water stability is less critical for tilapia than for channel catfish and much less critical than for shrimp. Therefore, expensive binders, such as wheat gluten or CMC, are seldom used. Steam pelleted diets for tilapia generally have sufficient water stability if they contain any of the following binders: molasses (3%), finely ground starchy grains, such as corn or sorghum meals (10%), hemicellulose (2%), or lignin sulfonate (2%).

Feeding rates

Recommended feeding rates for tilapia are a function of fish size, water temperature, fish biomass density, and abundance of natural food organisms. As with other fish species, optimum feeding rate is inversely related to fish weight. At 27 to 29°C common feeding rates using high-quality feeds are:

Weight, g	Feeding rate, % body weight/day
1 - 5	7 - 10
5 - 20	4 - 6
20 - 100	3 - 4
100 - 200	2 - 3
200 - 400	1.5

Appetite decreases rapidly at temperatures below 28°C. Maximum feed consumption of tilapia at 22°C is only 50 to 60% of maximum feed consumption at 26°C.

When agricultural by-products are fed, ponds are usually fertilized and feeding rates are often reduced by nearly 50% so that natural food organisms adequately supplement the low-quality feedstuff. Feed conversion efficiency with agricultural by-products may become uneconomical when the quantity of the feedstuff "overpowers" the ability of natural food organisms to supplement the amino acid deficiencies of the feedstuff.

Standard feeding rates, as given above, may be inappropriate under many circumstances because tilapia derive so much nutrition from natural food organisms. Natural pond productivity may be highly variable from site to site and from week to week. Optimum feeding of tilapia, therefore, remains as much an art as science. The use of floating feeds and checking the pond bottom for unconsumed feed at the feeding site help reduce overfeeding.

Manuring has long been practiced in small-scale and subsistence culture of tilapia, but this practice is also often a cost effective means of increasing the food supply in large-scale commercial tilapia ponds during the early part of a production cycle when total fish weight is still low. Where logistically convenient, ponds are usually manured until the combined input of manure plus feed begins to cause water quality problems.

Feeding frequency

Tilapia are continuous feeders during daylight hours, in contrast to more carnivorous species that are opportunistic and capable of taking a single, large meal. Research and field observations have led researchers to conclude that a daily ration should optimally be divided into 2 to 4 daily meals. Logistic considerations on commercial farms, however, commonly limit feeding frequency to once or twice daily.

Feed conversion efficiency

Feed conversion ratios (FCR, g feed/g live weight gain) are usually less than 2.0 for heavy feeding with high quality feeds. Feed conversions using a 28-30% crude protein diet containing adequate energy and vitamin/mineral premixes in standing water ponds yielding about 4000 kg/ha commonly vary from 1.3 to 1.7 for tilapia reared from an initial weight of 20-30 g to a harvest weight of 400-500 g. If final standing crop of fish is less than 3000 kg/ha or if harvest weight is 200-300 g, feed conversion may be 1.2 to 1.5 as a result of the proportionally greater contribution from natural food organisms and greater efficiency of smaller fish. In very intensive systems feed conversion may be 1.8 to 2.0.

4. Processing and marketing

Flesh color

Buyers of whole and processed tilapia in North America are very conscience of flesh and gustatory quality. Consumers prefer white fleshed fish. Tilapia flesh is light gray to white depending on the variety cultured. Pure tilapia species , such as *O. niloticus* and *O. aureus*, have a light gray flesh, while the red tilapia and less common white tilapia have a slightly lighter colored flesh that some consumers find more appealing. However, once the fillet is frozen, differences are less discernible. Tilapia have some dark or red muscle under the skin that accumulates along the lateral line and disperses over the surface of the light colored muscle. The red muscle can give skinned tilapia a darker color that is unappealing to consumers looking for white-fleshed fish. The peritoneal lining of *O. niloticus* , *O. aureus,* and especially *O. mossambicus* is black and objectionable to many buyers of whole or headed, gutted and skinned tilapia. The black peritoneal lining is easily removed with a brush but requires extra labor or specialized equipment. Red and white tilapias have a clear peritoneal lining that does not need removal. Removal of the rib cage during filleting also removes the peritoneal lining so peritoneal color is not a problem when tilapia are filleted. Thus, red and white tilapia may have color and flesh qualities that enhance its marketability. However, the grower should remember that red tilapia are more difficult to raise due to lower survival during culture than normal colored tilapia and the cost/kg live weight to raise the red tilapia is commonly higher than normal colored tilapia.

Flavor and aroma

Gustatory quality is also important. Taste tests have demonstrated that tilapia do not absorb off-flavor from animal manures, but they do absorb off-flavors produced by certain blue-green algae and other microorganisms. The muddy flavored flesh is more prevalent in tilapia cultured in freshwater than in saline water. Muddy flavor can be found in any cultured fish but tilapia appear to have a higher incidence of off-flavor than most freshwater fish because they are reared in highly fertile waters with higher incidence of blue-green algae blooms. Processors and buyers must be vigilant to assure that off-flavored fish are not processed and sold. Processors can generally assure on-flavor fish by placing the live tilapia in clean water for 3 to 5 days to purge them of off-flavors before processing. Bleeding the live fish before processing will also reduce off-flavors. A sample of the tilapia should be flavor-tested by experienced tasters to assure gustatory quality. Tilapia should be microwaved or steamed with no condiments so that even mild off-flavor is detected.

Many tilapia raised in highly eutrophic ponds will have excellent gustatory qualities. Reasons why one pond will produce tilapia with a muddy flavor while a neighboring pond will provide good tasting fish is not well understood. There appears to be a higher incidence of off-flavor in tilapia captured from permanent, eutrophic reservoirs than from farm ponds that are periodically drained. However, there is no way to know if fish will be off-flavor without taste testing. Careful selection of only on-flavor fish can not be over-emphasized if tilapia is to become a major item on the plates of North American consumers.

Red muscle found under the skin accumulates lipids that turn rancid when fish are stored for 1 to 2 months giving the flesh a slight fishy taste. Tilapia larger than 600 g accumulate more red muscle than smaller fish. Rancidity of the red muscle is not a problem when whole tilapia or tilapia fillets are iced and sold fresh. Frozen tilapia products have more problems with a fishy flavor and the red muscle may have to be removed before freezing to maintain gustatory quality for periods longer than a month.

Dress-out percentages

A major disadvantage of tilapia is low dressout and fillet yield compared with some other cultured fish. In general, the dressout yield of tilapia will increase slightly with fish size and if the tilapia is well fed and robust. Interspecific differences in dressout and fillet yield are minimal.

After removal of scales and viscera, heads-on dress out weight is 76 to 80%. Average yield of headed, gutted and skinless tilapia is about 51 to 53 %.

Fillet yield will vary depending on the method employed to fillet the fish. Small pin bones located on the median line between the tenderloin and the rib cage can be troublesome to children and inexperienced tilapia consumers. Fillets that have the ribs removed but retain some flesh from the rib cage and the pin bones yield about 36 to 38 % of total live weight. The same fillet with a triangular notch on the median line to remove the pin bones yields about 32 to 35 % of live weight. Fillets with pin bones and rib cage flesh removed so that only the tenderloin and caudal area remain yield 28 to 31% of live weight. Some large tilapia are " deep skinned " to remove some of the red muscle found under the skin. Deep skinning reduces the filet yield to 22 to 25% of the live weight.

Tilapia can be filleted by machine but the ribs and pin bones must be trimmed by hand. Most processing plants in tropical countries fillet tilapia by hand because more flesh is saved and labor is cheap.

Assuming a 33% fillet yield, tilapia must weight 500 to 850 g to provide two, 3- to 5-oz fillets (1 oz = 28 g) and 850 to 1200 g to provide two, 5- to 7-oz fillets. Fish yielding the larger fillet convert feed less efficiently and require a longer time to reach harvest size, thus increasing production costs per unit weight. However, 800 to 1200 g tilapia have a 1 to 2% higher fillet yield than 500 to 800 g tilapia.

Marketing implications of steroid use

Another consideration for tilapia producers, processors, and marketers is the use of male steroids to sex-reverse tilapia fry. Scientific studies have shown that the steroid is excreted from the fish once treatment is suspended at a size of less than one gram. There is apparently no danger to consumer as the fish are grown for many months without steroids before slaughter. However, consumers that perceive that flesh of chemically treated tilapia is tainted may reject tilapia. Additionally, sale of tilapia treated with steroids is not approved by the Food and Drug Agency (FDA) of the U. S. government. Technically, tilapia treated with steroids at any stage of their life cycle are illegal to sell as foodfish in the U. S.. In reality, thousands of tons of tilapia treated with steroids as fry are currently sold in the U. S.. A number of educational and governmental agencies are working with the FDA to develop the evidence required for approval of the drug for commercial tilapia growers.

5. Principal tilapia-producing countries

Tilapia have been introduced into most tropical and subtropical countries. Tilapia are widely distributed in temperate climate countries although they are unable to survive cold winter water temperatures below 13°C in open ponds. Thus, the major tilapia producing countries have tropical or subtropical climates.
Major tilapia producing countries are located in Asia but several Latin American countries are rapidly expanding tilapia culture operations because of their proximity to North American markets. Major tilapia farming countries and the systems used to culture the tilapia are listed below.

ASIA

Philippines

The Philippines produced 91,000 metric tons of farmed tilapia in 1992, 53% in freshwater ponds, 32% in freshwater cages, 6% in freshwater pens, and 9% in brackishwater ponds. *Oreochromis mossambicus* is widely farmed but the government is introducing *O. niloticus* because of its faster growth and more appealing appearance. Most tilapia are raised in small (<1 ha) ponds integrated with animal husbandry activities or cages suspended in lakes. Expansion into brackish water milkfish ponds is beginning as demand for tilapia increases and demand for milkfish decreases. Mixed-sex tilapia are usually monocultured, and small (< 200g) fish are harvested. Fish may be fed with agricultural by-products and aeration is rarely used. Most tilapia are sold whole in domestic markets.

Interest in culturing a bigger tilapia is growing. Sex-reversal technology to produce male tilapia is available but the supply of male fingerlings is limited. Pelleted fish feeds are available but rarely used. To our knowledge, little processing of tilapia is done and exports of fresh and frozen products is small. The Philippines has a long tradition of fish culture and is one of the major tilapia producing countries in the world.

Taiwan

Taiwan produces about 90,000 metric tons of farmed tilapia per year. *Oreochromis mossambicus* was introduced to Taiwan 50 years ago. Tilapia are farmed over the whole island but the majority of fish are raised in the south because of the mild climate resulting in longer growing season and lower chance of winter mortality due to cold water temperatures. Principal farmed tilapias are hybrids of *O. mossambicus* and *O. niloticus*, *O. niloticus* and *O. aureus* and red tilapia. Traditional methods of farming tilapia are a monoculture of mixed-sex tilapia integrated with animal husbandry in small, fresh water ponds. Small, whole tilapia are marketed locally. With economic development, Taiwan has modernized their fish culture practices. Presently, intensive monosex culture of sex-reversed tilapia is widely practiced. Tilapia hybrids or red tilapia are stocked at high densities in small concrete tanks or earthen ponds filled with fresh water and fed pelleted feeds, and provided with aeration and partial water exchange daily. Red tilapia are also cultured in brackish water ponds and sea cages. Farms are small, land is very expensive in Taiwan, and increased tilapia yields will come from intensification rather than expansion of land-based facilities. Expansion of sea cages is possible. Large tilapia are sold domestically and exported. Taiwan is the largest exporter of whole and filleted frozen tilapia to the U. S.
(Table 1).

Thailand

Thailand has a 30-year tradition of farming tilapia and is one of the largest producers of farmed tilapia in the world. Most tilapia are polycultured with other fishes in small, private pond holdings integrated with animal husbandry. The manure from the animals is used to fertilize the ponds. Rice bran may be fed and no aeration is used. Mixed-sex tilapia are produced and small tilapia (< 200g) are harvested. The majority of tilapia are sold domestically. *Oreochromis mossambicus* is still widely farmed but *O. niloticus* is becoming more popular.

Recently, interest has grown in the production of a large tilapia (> 500g) with the introduction of technology to mass produce sex-reversed male tilapia seed. Tilapia are sold whole, fresh domestically or to processors that sell fresh and frozen processed tilapia locally or internationally. Thailand is a major exporter of frozen whole and filleted tilapia to the U. S. (Table 1). Farmers growing large tilapia are moving toward tilapia monoculture, use of formulated feeds and aeration to improve yields. The major tilapia growing regions are around Bangkok in fresh water ponds and southern Thailand in abandoned, brackish water marine shrimp ponds.

Indonesia

Tilapia culture is located almost exclusively on the island of Java. *Oreochromis mossambicus* was introduced to Indonesia by the Japanese during World War II but has never become widely accepted as a culture fish by the Indonesians. Thus, Indonesia is not a major producer of farmed tilapia. Common carp is the principal fresh water species cultured on Java. Numerous brackish water ponds are used to farm milkfish and shrimp. Fish are cultured in small ponds and cages located in rivers and reservoirs. Mixed-sex *O. mossambicus* are cultured with animal and human manures and /or fed agricultural by-products. Traditionally, small tilapia were harvested and sold locally for a low price.

Recently, *O. niloticus* and red tilapia have been introduced to Java. Monosex culture of sex-reversed male tilapia or mixed-sex tilapia in cages expanded when pelleted fish feeds became available on Java. . While some large tilapia are sold live and on ice on Java, most of the large cultured tilapia are exported. Indonesia is a major exporter of frozen tilapia fillets to the U. S. (Table 1).

Mainland China

China harvests 25% of all freshwater fish farmed in the world. China has a rich tradition of freshwater fish culture based on the carps. Tilapia are found in the subtropical regions of China but has never been an important culture species ,thus, methods used to culture them are traditional. Mixed-sex tilapia are cultured together with carps in ponds supplied with animal manures, vegetation and agricultural by-products. Small tilapia are harvested and sold live in local markets. Presently, China has very little modern fish processing capability. However, China is a sleeping giant and is rapidly modernizing their fish culture industry. Pelleted feeds and aeration are used to increase fish yields. The Chinese are interested in exporting aquaculture products and is the second largest exporter of whole frozen tilapia to the U. S. (Table 1).

Other Asian Countries

Tilapia are raised in all Asian countries with appropriate climate using mixed-sex cultures and manures and agricultural by-products. Harvested fish are small and sold locally. Lack of commercial feeds, modern processing facilities, knowledge of improved tilapia culture methods and transportation will limit the ability of these countries to grow and export tilapia in the near future.

NEAR EAST

Israel

Israel has been a world leader in the research and culture of tilapia for many years. The major producing region is in the north along the Jordan River and Sea of Galilee. Most tilapia are grown in ponds on cooperative farms. Sex-reversed male *O. niloticus* and *O. aureus* hybrids are polycultured in earthen ponds with carp or monocultured in concrete tanks or plastic-lined ponds at a high stocking density. Pelleted tilapia feeds and aeration are widely used and most tilapia are larger than 400 g at harvest. However, cold winter water temperatures often cause tilapia mortality and many farms have over-wintering facilities that assure that tilapia brood stock and seed survive the winter. In 1994, Israel harvested 5,695 mt of tilapia of which 90% were sold fresh and 10% were processed. Israel did not export any tilapia in 1994. Israel is short of water for agriculture so increases in tilapia harvests will be through intensification in existing facilities or expansion into sea water ponds and cages. Israeli tilapia culture technology and investment capital have been instrumental in the development of the Latin American tilapia industry.

LATIN AMERICA

Colombia

Colombia is the leading producer of cultured tilapia in Latin America, harvesting an estimated 3,000 metric tons in 1994. The major tilapia producing region in Colombia is around Cali. Intensive culture of sex-reversed male, red tilapia with pelleted feeds, aeration and daily partial water exchange dominates. Israeli technology strongly influences tilapia culture in Colombia. Over 60% of the tilapia cultured in Colombia is sold locally for prices that rival those obtained through exportation. Colombia was the second leading exporter of fresh tilapia fillets to the U. S. (Table 1).

Costa Rica

Costa Rica is second to Colombia in farmed tilapia harvests at about 2,500 metric tons annually. However, Costa Rica is the leading exporter of fresh tilapia fillets in Latin America as only a small amount is sold domestically (Table 1). Most of the tilapia grown comes from one farm which stocks sex-reversed male *O. niloticus* at high densities in 100- to 200-m^2 earthen raceways supplied with flowing water from an irrigation canal. This farm air freights 16,000 kg of fresh fillets/week to the U. S and expansion of culture and processing facilities should double yearly output by the end of 1995.

Other Countries in Latin America

Tilapia are found in all Latin American countries with tropical or subtropical climates. Tilapia have been stocked into small family and communal ponds to improve the nutrition of rural populations since the 1960's. Recently, intensive pond culture of male tilapia for internal and export markets has grown rapidly. Honduras, Ecuador, Mexico and Brazil have infant tilapia farming industries. Ecuador is a leading exporter of farmed marine shrimp to the United States and the feed, processing and marketing infrastructure to grow and export aquacultured products is in place. Recent problems with diseases have forced farmers of marine shrimp to look for alternative species to culture in their shrimp ponds. Thousands of hectares of brackishwater shrimp ponds are available for the culture of salt tolerant tilapias. Red tilapias are stocked into brackishwater ponds and may become an economically important export commodity in the near future. Honduras and Mexico have also started to export processed tilapia to the United States (Table 1), while Brazilian tilapia is sold domestically.

CARIBBEAN ISLANDS

Jamaica

Jamaica was the first western hemisphere country to demonstrate that modern commercial tilapia culture could provide economic benefits. Jamaican farmers began farming tilapia in the early 1980's and presently about 2,000 metric tons of tilapia are harvested annually. Male *O. niloticus* or red tilapia for stocking growout ponds were obtained initially by visual separation of males and females. Hormone sex reversal is now the primary technique for producing male fingerlings. Males are stocked in earthen ponds supplied with fresh water and grown on domestically manufactured and imported pelleted fish feeds to 300 to 400g. Total estimated production in 1998 was 4,200 MT. Normally, no aeration or water exchange is used. Most of the farmed red tilapia is sold domestically, although frozen filleted tilapia are exported to the United States (Table 1) and Europe. Expansion of fresh water tilapia culture is limited by a lack of land and water. Expansion may occur in brackish water ponds and cages placed in the sea.

NORTH AMERICA

United States

An estimated 6,000 metric tons of tilapia were raised in the U. S. in 1994, up approximately 42% from 1992. Tilapia growers estimate that domestic production will top 7,300 metric tons in 1995. Most tilapia are raised indoors in closed recirculation systems utilizing solar, geothermal and other sources of low-cost heat to warm water. Water must be reused to lower the cost of heating water. Some open pond culture of tilapia is practiced in southern Florida. Most tilapia are sold in the live-fish markets in large cities. Some U. S. tilapia growers have their own processing plants and sell fresh and frozen whole and filleted tilapia. However, U. S. tilapia growers must sell directly to the consumer if they hope to compete with fresh and frozen tilapia imported from tropical countries.

In 1994, the U. S. imported over 14.5 mt of fresh and frozen tilapia (table 1). Approximately 5,150 mt where imported during the first 6 months of 1995, a decrease over the same time period in 1994. However, the value of tilapia imports has increased as the demand for higher valued tilapia fillets grows. Consumption of tilapia will continue to grow in the U.S. but increased imports and higher domestic output will likely produce downward pressure on prices, making tilapia even more competitive with other seafood products.

6. Suggested reading

TEXT BOOKS

Boyd, C. E. 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama. 482 pp.

This practical handbook describes the physical and chemical principles of water quality, with special emphasis on techniques to manage water quality in aquacultural ponds.

Bromage, N. R. and R. J. Roberts, Editors. 1995. Broodstock management and larval quality. Blackwell Science. Oxford, England. 414 pp.

A collection of 15 papers each describing the reproduction, and care of eggs and larvae of a cultured finfish. A chapter on Nile tilapia reproduction and production of mixed-sex and male tilapia seed provides the latest information on the subject.

Fishelson, L. and Z. Yaron, Editors. 1983. International symposium on tilapia in aquaculture, Proceedings. Tel Aviv University, Tel Aviv, Israel. 624 pp.

The proceedings of this first international symposium on tilapia culture contains 65 scientific articles. General themes include biology and ecology, physiology and pathology, reproduction and genetics, nutrition, and management and production.

Hepher, B. and Y, Pruginin. 1981. Commercial fish farming. John Wiley and Sons, New York, N.Y. 261 pp.

A description of Israeli carp and tilapia farming practices.

Hepher, B. 1988. Nutrition of pond fishes. Cambridge University Press. Cambridge, England. 388 pp.

The Israeli author provides more theoretic detail on digestion and absorption of food, energy pathways, and nutrient requirements than Lovell (1989) but a greater understanding of physiology, anatomy and nutrition is required by the reader.

Lovell, T. 1989. Nutrition and feeding of fish. Van Nostrand Reinhold, New York, New York. 260 pp.

The author describes general aspects of fish nutrition, including nutrients (protein, energy, vitamins, essential lipids, minerals, and vitamins), digestion and metabolism, and feed formulation and processing. The book is very practical and highly specialized training is not required by the reader. It includes chapters on feeding several species, including one 14-page chapter on the tilapias.

Muir, J. F. and R. J. Roberts, editors. 1982. Recent advances in aquaculture. Westview Press, Boulder, Colorado. pp 355.

Chapter by Balarin and Haller reviews information on the intensive culture of tilapia in tanks, raceways and cages.

Nash, C. E. and A. J. Novotny, Editors. 1995. Production of aquatic animals: fishes. Elsevier, Amsterdam, The Netherlands. 405 pp.

A collection of invited chapters by knowledgeable authors detailing the reproduction and culture of 20 of the most widely farmed fresh and seawater finfishes including the Tilapias.

Pullin R. S. V. and R. H. Lowe-McConnell, Editors. 1982. The biology and culture of tilapias. ICLARM Conference Proceedings 7, International Center for Living Aquatic Resources Management, Manila Philippines. 432 pp.

Chapters in this book were written by eminent scientists in areas of their specialization. Topics include: taxonomy, ecology and distribution, life histories, reproductive physiology, feeding and digestion, pond and cage culture, diseases and parasites, population control and hybridization. Technology developed or tested since 1982 are not included, but most information contained remains relevant in 1995.

Pullin, R .S. V., T. Bhukaswan, K. Tonguthai, and J. L. Maclean, Editors. 1988. The second international symposium on tilapia in aquaculture, Bangkok, Thailand, March 1987. ICLARM Conference Proceedings 15. International Center for Living Aquatic Resources Management, Manila, Philippines. 623 pp.

This book is a compilation of 82 scientific articles presented at the symposium. Seven sessions included in the conference were: culture systems, pathology, genetics and reproduction, nutrition, physiology, biology and ecology, and economics and sociology.

Shilo, M. and S Sarig, Editors. 1989. Fish culture in warm water systems: problems and trends. CRC Press, Inc., Boca Raton, Florida. 259 pp.

This book describes unique features of warm water systems as exemplified by the Israeli type of fish culture. Topics discussed include selective breeding, natural and induced reproduction, fish nutrition, environmental factors, and fish health. Discussions are not limited to, but include, tilapias.

Steffens, W. 1989. Principles of fish nutrition. Ellis Horwood Limited. West Sussex, England. 384 pp.

This book on fish nutrition is similar to Hepher (1988), with a more European perspective.

Stickney, R., Editor. 1986. Culture of nonsalmonid freshwater fishes. CRC Press, Inc., Boca Raton, Florida. 201 pp.

This book describes production techniques for nine different groups of non-salmonid fish. One 16-page chapter is specifically about the tilapias, focusing on water quality requirements, production and fertilization techniques, reproduction , nutrition, and diseases.

AUBURN UNIVERSITY RESEARCH AND DEVELOPMENT SERIES

Popma, T.J. and B.W. Green. 1990. Sex reversal of tilapia in earthen ponds. Research and Development Series No. 35. Alabama Agricultural Experiment Station, Auburn University, Alabama. 15 pp.

A practical description of techniques to produce tilapia fry and treat them with hormone to produce male fingerlings.

Green, B.W. and D. R. Teichert-Coddington, and R. R. . 1994. Development of semi-intensive aquaculture technologies in Honduras. Research and Development Series No. 39. Alabama Agricultural Experiment Station, Auburn University, Alabama. 47 pp.

A summary of aquacultural research conducted in ponds in Honduras since 1983. Stocking densities of tilapia usually ranged from 10,000 to 20,000 per hectare and nutrient inputs included organic and inorganic fertilizers and supplemental feeds.

Castillo, S., T.J. Popma, R.P. Phelps, L.U. Hatch and T.R. Hanson 1992. Family-scale fish farming in Guatemala: an example of sustainable aquacultural development through national and international collaboration. Research and Development Series No. 37. Alabama Agricultural Experiment Station, Auburn University, Alabama. 34 pp.

A biological and socio-economic case study of small-scale, low-input tilapia farming in Honduras. Nutrient inputs were primarily agricultural by-products and organic fertilizers.

Lovshin, L.L., N.B. Schwartz, V.G. de , C.R. Engle, and U.L. Hatch. 1986. Cooperatively managed rural Panamanian fish ponds: the integrated approach. Research and Development Series No. 33. Alabama Agricultural Experiment Station, Auburn University, Alabama. 47 pp.

An aquacultural development project among indigenous communities in Panama. The principal integrated systems described are tilapia-swine, tilapia-poultry, and tilapia-cattle.

Popma, T.J., F.E. Ross, B.L. Nerrie, and J.R. Bowman. 1984. The development of commercial farming of tilapia in Jamaica, 1979-1983. Research and Development Series No. 31. Alabama Agricultural Experiment Station, Auburn University, Alabama. 18 pp.

The early years of commercial tilapia production in Jamaica. Commercial feeds and hand selected male fingerlings were used by most farmers.

Hishamunda, N. and J.F. Moehl, Jr. 1989. Rwanda national fish culture project. Research and Development Series No. 34. Alabama Agricultural Experiment Station, Auburn University, Alabama. 19 pp.

A summary description of small-scale, low-input tilapia culture in highland Rwanda where fresh grasses were the most common nutrient input.