Farm-Level Issues in Aquaculture Certification: Tilapia

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Executive Summary

Tilapias are the ninth most important aquaculture species group in terms of weight of production worldwide. The most important species have been Oreochromis niloticus (Nile tilapia), O. mossambius (Java tilapia), O. aureus, (blue tilapia), and O. hornorum (Zanzibar tilapia). However, hybrids of the major culture species, O. hybrids (red tilapia), are becoming important for export. Tilapias are native to Africa and the Middle East, but they have been introduced into most tropical and subtropical countries. Tilapias also have been introduced as aquaculture species in temperate nations, but geothermal water, waste heat or other sources of providing warm water in winter are necessary. Tilapias have traditionally been important in capture fisheries, but the culture of these species has increased and now exceeds the wild catch. In 2003, total tilapia production was 2.3 million metric tons with about 1.7 million metric tons originating from aquaculture. Tilapias originally were promoted as a pond fish for culture to aid poor, rural families in developing, tropical nations. However, tilapias have attracted the attention of consumers, and there is now a large market for tilapias in Japan, United States, European Union, and other developed countries.

Tilapia production may be separated into two phases; production of fingerlings, and grow-out of fingerlings to marketable size. At tilapia hatcheries, brood fish are spawned, eggs are hatched, and fry reared to fingerling size for stocking in culture units. Tilapias will reproduce at an early age in culture systems. Reproduction in culture systems results in overcrowding and a preponderance of small, unmarketable fish at harvest. The production of fingerlings of a single sex is an important method for controlling reproduction during culture. There are several ways of obtaining single sex fingerlings, but for commercial culture, methyltestosterone treatment to cause sex reversal or reliance on YY male brood stock are commonly used to produce all-male fingerlings.

Grow-out is done in ponds, cages and net pens, raceways, and water re-circulating systems. Ponds may be fertilized with manure, wastewater, and commercial fertilizer to allow production up to 2,000 to 3,000 kg/ha per crop. Much higher production, up to 20,000 kg/ha, can be achieved through application of commercial fertilizer and feed and the use of mechanical aeration. Water exchange is often applied in intensively managed ponds and raceways to improve water quality. Feed usually is offered to fish in all types of production units. Inputs of fertilizer and feed to culture systems results in a pollution load in effluents.

In our opinion, production systems generally may be ranked in the following order of environmental friendliness: (1) raceways and cages integrated into irrigation systems; (2) intensive ponds; (3) water re-circulating systems; (4) semi-intensive ponds; (5) other raceways; (6) other cages; (7) net pens. Of course, the sites where cages and net pens are installed might influence the environmental ranking. If cages and pens are placed in open water areas with good water circulation and in moderate numbers, wastes can be assimilated efficiently.

Escapees from culture systems are a major concern, for tilapias have a high reproductive capacity, wide environmental tolerance, and aggressive nature. They can and have become established outside their native range. When this occurs, tilapias compete strongly with native species and reduce fish biodiversity. The red tilapia (O. hybrids) is less likely to survive and reproduce in natural waters than other tilapias.

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Reviewed by Daniel E. Meyer

Most issues related to tilapia certification will be similar to those for other aquaculture species. Certified producers should be expected to comply with existing regulations, practice water conservation and particularly groundwater conservation, use fingerlings produced by responsible methods, use feed which contains minimal amounts of fish meal, practice good feed management, use fertilizers and liming materials responsibly, avoid use of antibiotics, practice non-destructive bird control, remove dead fish from culture systems in a timely manner, and maintain adequate records.

There also are a few especially contentious issues which are somewhat specific to tilapia certification. Because of the danger of escapees, only all-male fingerlings probably should be allowed at certified facilities. It must be decided if certification of tilapia production in tropical and subtropical countries should be allowed outside of the area where the species is endemic or already established. Also, the wisdom of certifying tilapia in temperate regions to which it is not native and where it normally cannot survive should be discussed. Methods for producing all-male fingerlings will be a major issue in certification. It does not seem wise to allow hormone-induced sex reversal. Certification possibly should be denied to some production systems which have a high potential for causing water pollution, e.g., cages and net pens. Alternatively, certification of cages and net pens might be allowed at some sites but not at others depending upon the ability of ecosystems to assimilate waste and the number of production units installed.

Certification programs probably should be initiated at places where producers already are using good production methods. Production systems integrated with irrigation systems, do not cause pollution and should be prime candidates for trial certification.

Introduction

Tilapia rank ninth in global aquaculture production. Carps are the only category of fish species with greater production than tilapias. Tilapias are a hardy species produced by several culture methods under a wide range of environmental conditions. They are tropical and subtropical species, but they have been cultured at temperate sites by using geothermal water, greenhouses, or other means of providing warm water during winter. Tilapias are produced in many countries, but most production occurs in tropical and subtropical regions in developing countries. Contrary to some aquaculture species, tilapias are important in both local and export markets. They also are produced as foodfish by rural farmers.

The popularity of tilapias with consumers is increasing in western countries and Japan, and exports are expected to increase for years to come. Production methods are highly variable, and less attention has been given to identifying good practices for tilapia production than has been done for shrimp, salmon, and channel catfish. However, experience with other species will be useful in evaluating production practices and suggesting important issues for tilapia certification.

Biology

The name tilapia includes many species of the Cichlidae family. These fish are endemic to Africa and the Middle East, but they have been introduced into most tropical and subtropical countries for aquatic weed control and aquaculture. Tilapias have escaped from these projects have greatly extended their range. Tilapias are deep-bodied, perch-shaped fish (Figure 1). They grow very fast and many species reach several kilograms in weight. They are mainly herbivorous, but most species also consume bottom organisms. Some species are markedly carnivorous, especially on eggs and fry of other fishes.

There are three major taxonomic groups. Species of the genus Tilapia are substrate brooders which deposit their eggs in nests excavated in the sediment. Species of the genus Oreochromis are maternal mouth brooders, e.g., the females incubate the eggs in their mouths. Species of the genus Sarotherdon are maternal and paternal mouth brooders (Teichert-Coddington et al. 1997). The major aquaculture species is the Nile tilapia (O. niloticus). Other important aquaculture species are the blue tilapia (O. aureus), Java tilapia (O. mossambicus), and Zanzibar tilapia (O. hornorum). The red tilapia (O. hybrids) developed from crosses of the main Oreochromis culture species also has become popular in recent years. Other tilapia species are cultured only by small-scale farmers in Africa (Teichert-Coddington et al. 1997).

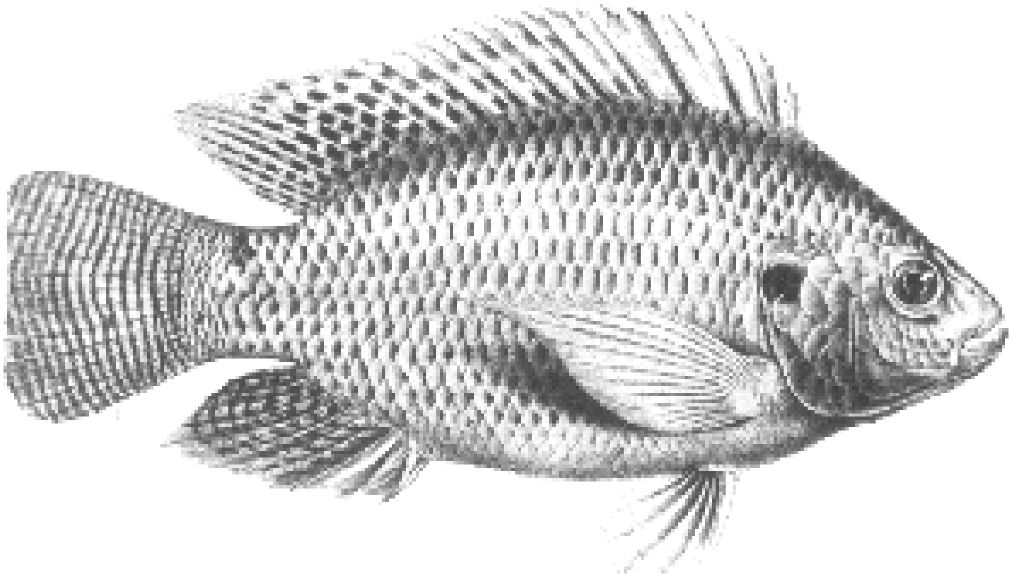

Figure 1. A typical tilapia.

Polygamous males of the genus Oreochromis excavate nests in pond bottoms where water is 1 m deep or less. Females spawn in nests and incubate the externally fertilized eggs in their mouths. Young fry will seek refuge in their mother's mouths for several days.

Tilapia feed on plankton, green leaves, benthic organisms, aquatic invertebrates, larval fish, detritus, and decaying organic matter. They also readily adapt to eating pelleted fish feed. Nevertheless, they often are considered to be filter-feeders because they can trap plankton in mucous excreted from their gills and swallow the plankton-rich bolus (Fryer and Iles 1972). They have a long intestine necessary to digest plant material. Moreover, tilapias are continuous feeders, and when used in their culture, feed should be offered 3 to 4 times per day if practical (Lim 1989).

Tilapia are popular as a culture species because of their ability to efficiently use both natural organisms and manufactured feed efficiently under crowded conditions allowing high levels of production. According to Schroeder (1978), natural food organisms typically account for 30 to 50% of tilapia growth in intensive culture ponds with heavy feeding. The contribution of natural food organisms is much greater in pond culture of tilapia than for culture of channel catfish or marine shrimp in ponds. Tilapia production can exceed 3,000 kg/ha in 6 months in ponds fertilized to enhance the availability of natural food organisms. Production above 10,000 kg/ha may be achieved if feed and aeration are applied in pond culture.

There are other biological reasons that tilapia are good culture species. They resist disease well, and they can tolerate low dissolved oxygen concentration, high ammonia concentration, and impaired water quality in general. This does not imply that disease and water quality-related stress do not occur in tilapia culture. However, there usually are fewer problems with disease and water quality in tilapia culture than in the culture of most species.

A good culture species must be capable of reproducing easily under controlled conditions. The ease with which tilapias reproduce is both a boon and a curse. Reproduction in culture ponds can occur 2 or 3 months after fingerlings are stocked. Ponds quickly become overpopulated with young fish which compete with larger fish for feed. The result is a harvest of relatively small fish unwanted in many markets. Development of methods to control tilapia reproduction in ponds was a major milestone in the culture of these species.

Tilapias are sensitive to low temperature. Optimum growth usually is achieved at 28 to 32°C. Growth declines greatly with decreasing temperature and at 20 to 22°C, growth is about 30% of optimum (Teichert-Coddington et al. 1997). Feeding usually stops at temperatures less than 16 or 17°C, and temperatures below 10 to 11°C are lethal. Tilapias are freshwater species, but the commonly cultured tilapias grow well at salinities up to 25 ppt (Suresh and Lin 1992). The wide tolerance of tilapias to variation in environmental conditions, their amazing capacity to reproduce, and their great ability to compete with other species is a major concern when they are introduced outside their native range. Escapees from weed control or aquaculture projects have reproduced in surrounding waters, and tilapia have become the major species in local fish populations at the expense of native species.

The characteristics of fish flesh are important in the market. The flesh of tilapia usually is light gray to white, but some dark or red muscle tissue may accumulate along the lateral line and on the surface of the lighter-colored muscle in other areas. This red muscle can give tilapia meat a darker color than desired by many consumers. The peritoneal lining of pure tilapias is black and must be removed to avoid consumer complaints. The meat of both red and white tilapia hybrids generally has a whiter color than that of pure tilapia species. Also, red muscle tends to be a greater problem in fish larger than 600 g in weight. When fillets having red muscle tissue attached are frozen, an objectionable fishy taste can result. Tilapias also have bones along the rib cage and small pin bones among the muscle tissue which must be removed from fillets to avoid consumer complaints.

The dress-out percentage of tilapia is rather low. The usual fillet yield is about 33 to 35% of live weight.

Major Production Areas

Tilapias are captured from the wild within their native range and in some areas where they have been introduced. They also are cultured both within their native range and in many other nations. Aquaculture production has been increasing for several decades and now is roughly twice the wild catch. The major tilapia-producing countries are China, Egypt, Philippines, Indonesia, and Thailand. China is by far the major producer.

Data for tilapia imports into the United States (Alceste and Jory 2002) give a picture of the production areas catering to the export market. Asian imports were mainly from Taiwan, China, and Indonesia, but there were significant contributions from Thailand, Vietnam, Philippines, and Hong Kong. Tilapia imports from Latin America originated in Colombia, Panama, Ecuador, Honduras, Mexico, Brazil, Costa Rica, Peru, Jamaica, and other countries. Cuba has a larger production of tilapia than many other Latin American nations. Ecuador imports the most tilapia into the U.S. market, and Costa Rica and Honduras are the second and third leading importers.

Tilapia culture is important in Africa. Most of these tilapias are produced for family consumption or domestic markets rather than for export. However, there are a few large farms which produce tilapia for export such as the Lake Harvest Tilapia Farm at Lake Keraba in Zimbabwe.

Production Statistics

Data from FAO on world tilapia production by capture fisheries and aquaculture from 1993 to 2003 are provided in Figure 2. Total production increased from 1.0 million metric tons (mt) in 1993 to 2.3 million mt in 2003. Aquaculture production increased from about 550,000 mt to slightly over 1.7 million mt during this time, while the production from capture fisheries changed little.

Aquaculture production of tilapias worldwide has more than doubled since 1993. The major culture species has been O. niloticus with O. mossambicus a distant second. Of course, there also has been an increase in production of hybrid tilapias for export. The increase in tilapia production has been greatest in Asia, but there also has been remarkable growth in Latin America. The major tilapia producing countries are depicted in Figure 3. China is by far the major producer of farm-reared tilapias, but Taiwan (given by FAO as a province of China) is the world's major tilapia-exporting nation. Although Latin American countries do not show up in Figure 3, they are important exporters of tilapias, especially into the U.S. market. Brazil may be underestimated as a tilapia-producing country. Official FAO statistics indicated a production of 20,000 mt in 1999, but some surveys claim production may be 50,000 to 60,000 mt/year.

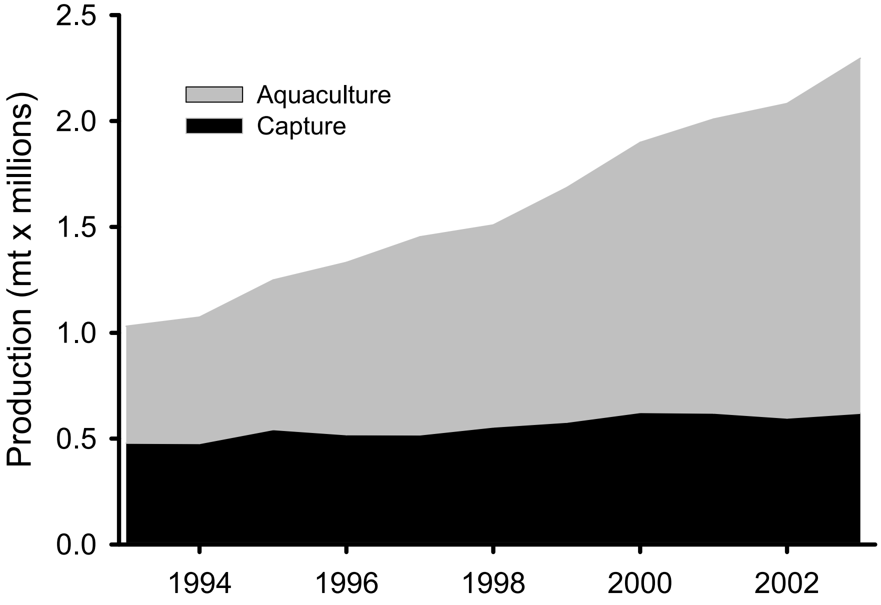

Figure 2. Comparison of tilapia production from aquaculture and capture fisheries. Production values are in metric tons (mt). Source: FAO 2005.

FAO data show tilapia production reached about 2.3 million mt in 2003 with 73% originating in aquaculture. The upward trend in production is expected to continue as consumers become more familiar with tilapias.

In the United States, tilapia imports reached 40,500 mt in 2000 (Alceste and Jory 2002). Production in the United States is slightly more than 8,000 mt. The production by region in the United States for 2000 was as follows: western, 3,180 mt; north-central, 1,723 mt; northeast, 1,592 mt; southern, 1,575 mt; tropical, 180 mt. Tilapia production in the United States is done primarily in intensive systems that utilize external sources of heat, e.g., geothermal water, industrial waste heat, or direct heating systems, to maintain adequate temperature during cold months.

Figure 3. The main countries producing tilapia by aquaculture. Production values are in metric tons (mt).

The world price for tilapia has remained relatively stable for several years. According to FAO statistics, chilled tilapia fillets sold for about $4.00/kg and frozen fillets brought $2.50 to $2.75/kg in the U.S. market between 1995 and 1999. However, there has been a decline in price of about 30% in recent years. This decline probably is related somewhat to the downturn in the global economy during the past 2 years, but the increasing production and greater availability of tilapias in the market possibly has played a

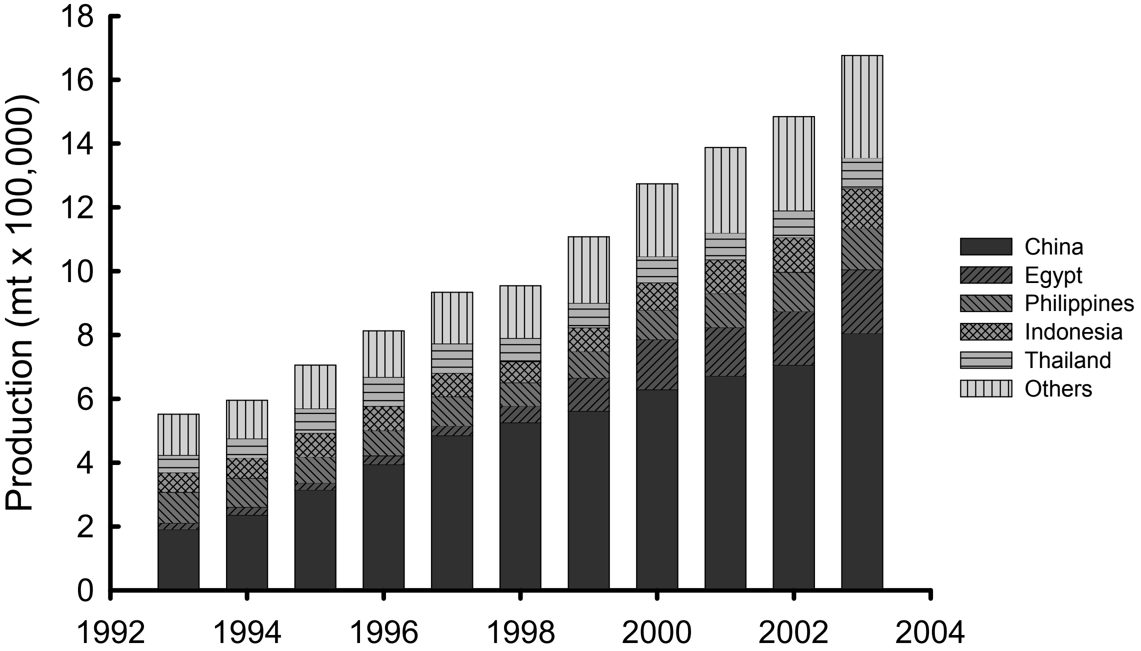

Figure 3. The main countries producing tilapia by aquaculture. Production values are in metric tons (mt). Source: FAO 2005.

larger role in the price decline. Tilapia production is expected to continue to increase with greater demand in importing countries. Thus, prices likely will remain lower than in the 1990s. This scenario is not necessarily bad for efficient producers. It also is favorable to the prospects of product certification provided these products will fetch a greater market price.

Reliable data on the area devoted to tilapia production and amount of water used for it, such as reported for channel catfish production, are not available.

Culture Systems

Tilapia production can be separated into two major activities – fingerling production and grow-out of marketable-sized fish. Fingerling production can be accomplished in earthen ponds, tanks, and hapas (baskets constructed of fine netting). Hapas can be suspended in tanks, ponds, lakes, or other water bodies.

Grow-out of fingerlings to marketable size is done in ponds, raceways, net pens, cages, and water re-circulating systems supplied with freshwater or brackishwater. In some countries tilapia culture also is done in rice paddies to provide a second crop.

Freshwater ponds are the most common production system. Ponds for tilapia culture range from tiny, dug-out holes on small, family farms to well-designed, embankment ponds with inlet and outlet gates and harvest basins. Ponds for tilapia production range from less than 1 ha to more than 10 ha. Ponds usually average 1 to 2 m in depth. They may be filled from rainfall and runoff (rain-fed), streams, lakes, reservoirs, irrigation systems, wells, or estuaries. The largest tilapia ponds probably are the converted shrimp ponds used for tilapia production in Ecuador.

Cage culture also is a common production method, and in some countries, this method is used more widely than ponds. Cage design ranges from simple ones of 1 or 2 m^3 volume made on site from netting to large manufactured cages similar to the ones used in salmon culture. Cages may be located in ponds, reservoirs, lakes, streams, irrigation systems, or estuaries. In some countries, regulations have been imposed on the location and number of cages in public waters, but these regulations may not be obeyed. Net pens are used to a lesser extent than cages.

Raceways, also referred to as flow-through production systems, are grow-out units through which water flows continuously. Raceways often are elongated concrete troughs 2- to 4-m wide and 10- to 50-m long. They also may be elongated earthen ponds or plastic troughs or tanks. The rate of water flow through raceways also varies greatly, and the normal range in exchange rate probably is about 0.5 to 4 exchanges/hour. In Colombia, some tilapia farms simply divert water from irrigation systems through earthen ponds and discharge the water back into the irrigation system. The most important variable in raceway culture is the amount of dissolved oxygen available. The dissolved oxygen concentration should not fall below 3 mg/L, and 4 kg feed can be applied daily for each kilogram of available oxygen (Boyd and Tucker 1998). Suppose that 1 m^3/min of water is available with a dissolved oxygen concentration of 7 mg/L. The available oxygen is 5.76 kg/day [$(7-3)\ g/m^3 \times 1\ m^3/min \times 1{,}440\ min/day \times 10^{-3}\ kg/g$] and about 23 kg feed can be applied to the culture system. Large fish are fed at about 2% of body weight per day, so the system could accommodate about 1,150 kg of tilapia. Mechanical aeration could be applied to increase the capacity.

Water re-use systems are employed in countries such as Israel where water is scarce or in temperate climates where heated water must be used to permit year-around production. Of course, in temperate countries, brood stock can be maintained during cold months in heated systems and production done during warm months in ponds, cages, or other units. In Israel, there are water re-use systems where fish production is done intensively in earthen ponds or concrete tanks at high water exchange rates and the water is recirculated through a large reservoir which serves as a water treatment system. The most advanced recirculating systems employ culture tanks and water treatment facilities often located indoors in greenhouses or other heated facilities. The most common methods of water treatment in re-circulation systems are mechanical aeration to add dissolved oxygen, mechanical filters to remove large particles, biological filters to enhance nitrification (oxidize ammonia to nitrate), and sedimentation to remove solids (Soderberg 1994). Treatment with liming materials also is necessary to neutralize acidity from nitrification.

Fingerling Production

Brood fish

Brood fish usually are obtained from fish farms, and suppliers should be able to document the purity and origin of the fish. The fish should be certified disease-free, but they still should be quarantined to ensure no diseases or parasites are introduced to the farm stock. A minimum of 100 to 150 brood fish is needed to avoid inbreeding (Smitherman and Tave 1987).

Brood fish should be held in high quality water in ponds, tanks, or hapas. The water should contain natural food organisms, but a high quality ration containing at least 25% crude protein should be provided two or three times per day (Green et al. 1997).

Spawning

Frequency of spawning varies with environmental conditions and can occur at 4- to 6-week intervals under ideal conditions in natural environments. In hatcheries, the interspawning interval can be shortened and spawning frequency increased by removing eggs from mouth-brooding females. It is possible to obtain 100 to 200 eggs/kg female per day or even more under spawning regimes where spent females are exchanged for females which have been conditioned for 10 days (Little et al. 1993).

Eggs removed from female mouth-brooders must be incubated. Because the eggs sink, they must be incubated in conical, up-welling or down-welling incubators. Stocking rate in large incubators (20 L) is about 4,000 eggs/L, and water flow rate is about 1 L/sec per 10,000 eggs (Little 1989). High quality water saturated with dissolved oxygen is essential in incubators. Survival from eggs to 10-day-old "swim up" fry often is above 80%.

Brood fish usually are stocked in spawning ponds, tanks, or hapas, and the females allowed to mouth-brood the eggs. The fry then can be harvested at frequent intervals with nets, or ponds can be drained and fry captured in nets. Stocking rates in spawning ponds vary from 3,000 to 10,000 fish/ha at sex ratios of 1 female:1 male to 4 females:1 male. Fertilizers are applied to encourage natural food and feed also is applied. Alternatively, brood fish can be placed in hapas suspended in ponds or other water bodies, and after spawning and hatching occurs, fry can be removed. Tanks also may be managed in a similar fashion.

Two methods have been applied in hatcheries to produce all-male fry. Fry can be treated with androgen before the gonads begin to develop. Fry of 9 to 11 mm in total length normally are treated with 17 α-methyltestosterone. The androgen compound is provided to the fish in feed. The usual dose is 30 to 60 mg methyltestosterone/kg feed, and the feed is offered for 3 to 4 weeks. More than 95% of fry treated in this manner will be phenotypic males.

Studies of retention of 17 α-methyltestosterone in tilapia suggested that no more than 10 picograms (pg) of methyltestosterone and its metabolites remained in fillets (Goudie et al. 1986). This was not considered a dose great enough to be of food safety concern. However, little information is available on the possible effects on hatchery workers of handling androgens. A respirator, eye protection, and gloves should be used to prevent contact with the material when it is used in hatcheries.

The other method of producing all-male fry is the use of YY males that sire only male offspring. The procedure of doing this is quite complex and will not be discussed here, but it is presented by Scott et al. (1989).

Nurseries

Fingerlings usually weigh 0.1 to 1.0 g each after completion of sex reversal or harvest from ponds, tanks or hapas. Stocking of such small fish directly into production ponds is inefficient because ponds would be far below carrying capacity for several weeks. Thus, fingerlings are reared to larger size in nursery ponds. Nursery ponds usually are stocked at 25 to 250 fry/m^2, fish are held for 1 to 3 months, and standing crop may exceed 5,000 kg/ha where fertilizers and feeds are applied. Survival usually exceeds 60%. It also is possible to grow fingerlings to a large size in tanks or hapas.

Grow-out

Several methods for growing fingerlings to marketable size also are in common use. Control of reproduction is a major issue in tilapia culture, and culture techniques usually integrate a way of reducing reproduction in culture systems.

Reproduction control

According to Bocek (undated) there are seven methods for controlling reproduction in production systems as listed below:

- use nets to periodically harvest fry and fingerlings from production units to reduce competition for food,
- separate sexes after an initial growth period to allow monosex culture,

- culture fish in cages which are suspended above the bottom so that spawned eggs fall through the cage mesh and die,
- culture fish at very high density in ponds or raceways to take advantage of the repression of reproduction by crowding,
- stock predaceous fish in ponds to eat tilapia fry resulting from spawning,
- stock all-male fingerlings.

A flow chart (Figure 4) shows where each method fits into different tilapia production systems.

Each method of reproduction control has its advantages and disadvantages. Periodic harvesting of fry requires little skill, but it is labor intensive and applicable only to small ponds. Sex separation requires trained labor and is a slow process that is only about 80 or 90% effective. It is most applicable to small farms. Cage culture is convenient at some locations, but cages are expensive, and a high quality feed is necessary. High-density culture is best suited for large farms, because a good water supply, mechanical aeration, skilled labor, and high quality feed are essential. Control of reproduction by predaceous fish generally is difficult to implement, because fingerlings of predaceous fish must be available at the right time, there are then two kinds of fish in the system, and large tilapia fingerlings must be stocked to prevent them from being eaten by the predators. Hormones necessary for producing all-male fingerlings are expensive and difficult to obtain, good hatchery facilities and skilled labor are required, and there may be concerns by consumers over possible residues of hormones in adult fish. Hybrid, all-male fingerlings grow faster than females. However, pure brood stock strains require special hatchery facilities, and the trained labor needed for producing the hybrids increases fingerling cost.

Data are not available on the extent to which each method of reproduction control is applied. However, stocking of all-male fingerlings is the common method for many facilities producing tilapia for export. Use of all-male, hybrid fingerlings would appear to be more consumer acceptable than the use of hormone-treated all-male fingerlings.

Pond systems

It is not possible to describe a typical pond culture system for tilapia. Stocking rate for all-male tilapia will depend upon the objectives for final harvest biomass and average weight of individual fish at harvest, and it must be adjusted for anticipated survival (Table 1). It is not possible to calculate reasonable stocking rates for ponds where reproduction will not be controlled, so the ones provided in Table 1 should be as good as any.

Net production of tilapia in ponds will depend upon the nutrient input rate. Usually, natural fertility of pond waters is not great enough to support more than 250 to 500 kg tilapia/ha. Fertilizers can be used to increase the abundance of natural food organisms and enhance production. Typical production in ponds treated with commercial fertilizer is 1,000 to 1,500 kg/ha, but production in ponds treated with organic fertilizers often exceeds 2,000 kg/ha. Feeding can increase production to very high levels. The combination of fertilization and feeding can increase production to 5,000 to 6,000 kg/ha in semi-intensive systems. Application of water exchange to flush ponds and improve water quality, mechanical aeration to prevent low dissolved oxygen concentration, or both can allow production to increase to 20,000 kg/ha or more.

Organic fertilizer for tilapia ponds usually is animal manure or other agricultural wastes. Organic fertilizers may be applied to ponds at rates up to 50 to 80 kg/ha per day in un-aerated ponds (Collis and Smitherman 1978) and up to 200 kg/ha per day in ponds with mechanical aeration (Wohlfarth and Hulata 1987; Wohlfarth and Schroeder 1979;Wohlfarth et al. 1985). In Asia, it is common to integrate tilapia production with chicken, pig, or duck culture (Boyd and Tucker 1998). For example, in Thailand, chicken houses often are constructed above tilapia ponds and uneaten feed and manure falls into the ponds to serve as food for fish and to fertilize ponds and increase natural productivity. In some areas of Asia, human excrement and municipal wastewater are used to fertilize ponds (Edwards and Pullin 1990).

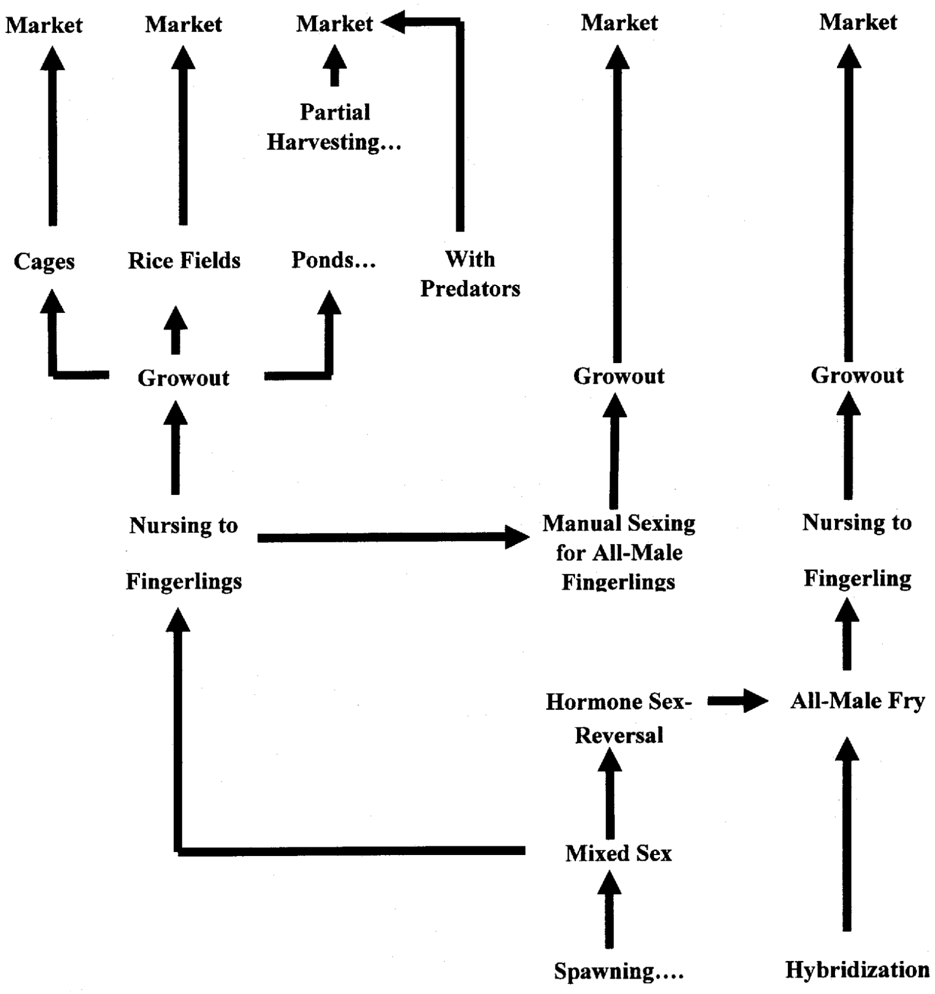

Figure 4. Flow chart showing how different methods of reproduction control are used in tilapia culture. Source: Bocek (undated).

Urea and triple superphosphate are the commercial fertilizers most commonly used in tilapia culture. A common recommendation is to apply fertilizers at a N:P ratio of 4:1 and provide 1 kg P/ha per day (Diana 1997). I believe that this fertilization rate is much too high and contains a wider N:P ratio than necessary. A more reasonable fertilization regime might be the use of a N:P ratio of 2:1 or 1:1 and provide a phosphorus input of 0.3 to 0.5 kg/ha per day. Of course, commercial fertilizers are not applied daily, but at weekly or biweekly intervals.

Table 1. Stocking densities in fingerlings per square meter in pond culture to provide different maximum biomass of all-male tilapia of different average weights at harvest. The entries assume 100% survival.

	Average weight at harvest (g/fish)				
Maximum biomass (kg/ha)	200	400	600	800	1,000
1,000	0.50	0.25	0.167	0.125	0.10
2,000	1.00	0.50	0.334	0.25	0.20
4,000	2.00	1.00	0.668	0.50	0.40
6,000	3.00	1.50	1.00	0.75	0.60
8,000	4.00	2.00	1.334	1.00	0.80
10,000	5.00	2.50	1.668	1.25	1.00
12,000	6.00	3.00	2.00	1.50	1.20
14,000	7.00	3.50	2.335	1.75	1.40

Cage culture

Cages are suspended in bodies of water, stocked with fish, and feed is applied several times per day. Fish are confined in a small area making feeding and harvesting much simpler than for traditional pond culture. It is not practical with existing technology to mechanically aerate cages. Some farms have installed mechanical aeration in areas with cages. These aerators usually are positioned to direct currents of oxygenated water through cages. Thus, cages should be located in an area where there is good water circulation through cages to replenish dissolved oxygen removed by fish respiration. Fish also can feed on plankton and detritus in water which passes through cages. This supplements manufactured feed and improves the feed conversion ratio.

Uneaten feed, feces, and metabolites pass through the cage mesh. Large particles settle to the bottom beneath or near cages, while smaller particles remain suspended or dissolved in the water. If cages are in an area of restricted water movement or in a relatively small water body, dense phytoplankton blooms will develop. Also, in stratified lakes, wastes from cages may accumulate in the hypolimnion. Dense phytoplankton blooms can result in depletion of dissolved oxygen during nighttime or on cloudy days. Sudden destratification of water bodies with large, hypolimnetic oxygen demands also can cause dissolved oxygen depletion. Massive mortalities of fish in cages and wild fish outside of cages have resulted when wastes from cage culture caused eutrophication and dissolved oxygen depletion occurred at night, during cloudy weather, or after thermal destratification (Beveridge 1984; Schmittou 1993; Boyd and Tucker 1998).

Net pens

Net pens for tilapia culture usually are installed in lakes or reservoirs. The principle is basically the same as for cage culture, but the enclosure to hold fish is much larger, and fish have access to the natural bottom (Beveridge 1984). Fish are not stocked as densely in net pens as in cages, but the advantages and disadvantages of cages and net pens are similar.

Raceways

Water is flushed through raceways to provide dissolved oxygen and to remove wastes. Production units often are flushed with up to four exchanges/hour where mechanical aeration is not applied, but lower flushing rates are used in aerated systems. Water for raceways may be used in one pass and discharged downstream, or it may be transferred to a reservoir for treatment and reuse. Thus, raceways are sometimes integrated into water re-use systems.

Raceways where water is used in a single pass often are separated into several units with natural fall between units. Water is re-aerated when it falls from one unit to the next. Nevertheless, when units are operated in series, water quality tends to deteriorate as water flows from one raceway unit to the next. This problem is related to a decline in dissolved oxygen concentration and an increase in ammonia and solids as water passes through successive production units.

Sedimentation units can be constructed at discharge ends of raceways to allow sedimentation of coarse particles, but fine particles and dissolved solids cannot be removed this way.

Source water for raceways include reservoirs, lakes, springs, streams, and irrigation canals. In some places, water from these sources may be too cool for optimum growth of tilapia. The use of irrigation water for tilapia is ideal, for raceways can be installed near the irrigation system and the water diverted through the raceways and back to the irrigation system. Little water is actually consumed for tilapia production and nutrients entering the water will not constitute pollution for they can be applied to crops irrigated with the water.

Water re-circulating systems

These systems are important for tilapia culture in arid climates and in cold climates where water must be heated during part of the year. Water re-circulating systems may be quite simple (Figure 5) with water exchanged between a pond and the culture units. The pond provides natural water treatment through aeration by photosynthesis, sedimentation, mineralization of organic matter by bacteria, phosphorus removal by bottom soil, nitrification, and denitrification. Water re-circulating systems also may be quite complex (Figure 6) with heating of water, mechanical aeration, mechanical filtration to remove coarse particles, sedimentation, biological filtration to mineralize organic matter and oxidize ammonia, and denitrification.

Water may discharge from the treatment pond of a re-circulating system after heavy rains. Water also is discharged from more complex re-circulating systems when filters are backwashed, when it is necessary to improve water quality by dilution with higher quality water, and when sediment must be removed.

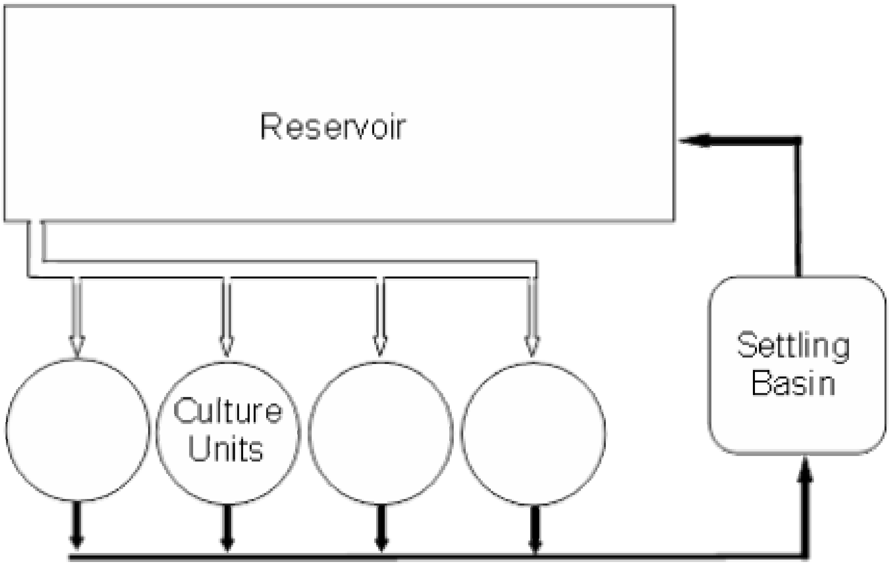

Figure 5. A simple, outdoor water re-circulating aquaculture system.

Fish Health

Tilapia are more resistant to disease than most culture species, and they can tolerate relatively high concentrations of ammonia and low concentrations of dissolved oxygen. Disease problems are most frequent in culture systems where water temperature is less than optimum. There is little use of antibiotics, drugs, and other chemicals for disease control or water quality improvement in tilapia culture.

Producers do not like to talk about the disposal of dead fish. We have seen dead tilapia floating in culture systems, and suspect that many producers do not remove dead fish on a regular basis as also has been observed in channel catfish culture. Although this practice may not result in serious disease or water quality problems and carcasses may decompose within grow-out units and not enter the outside environment, carcasses should be removed daily. Most consumers would be appalled to learn that fish had been produced in systems where carcasses were allowed to decay.

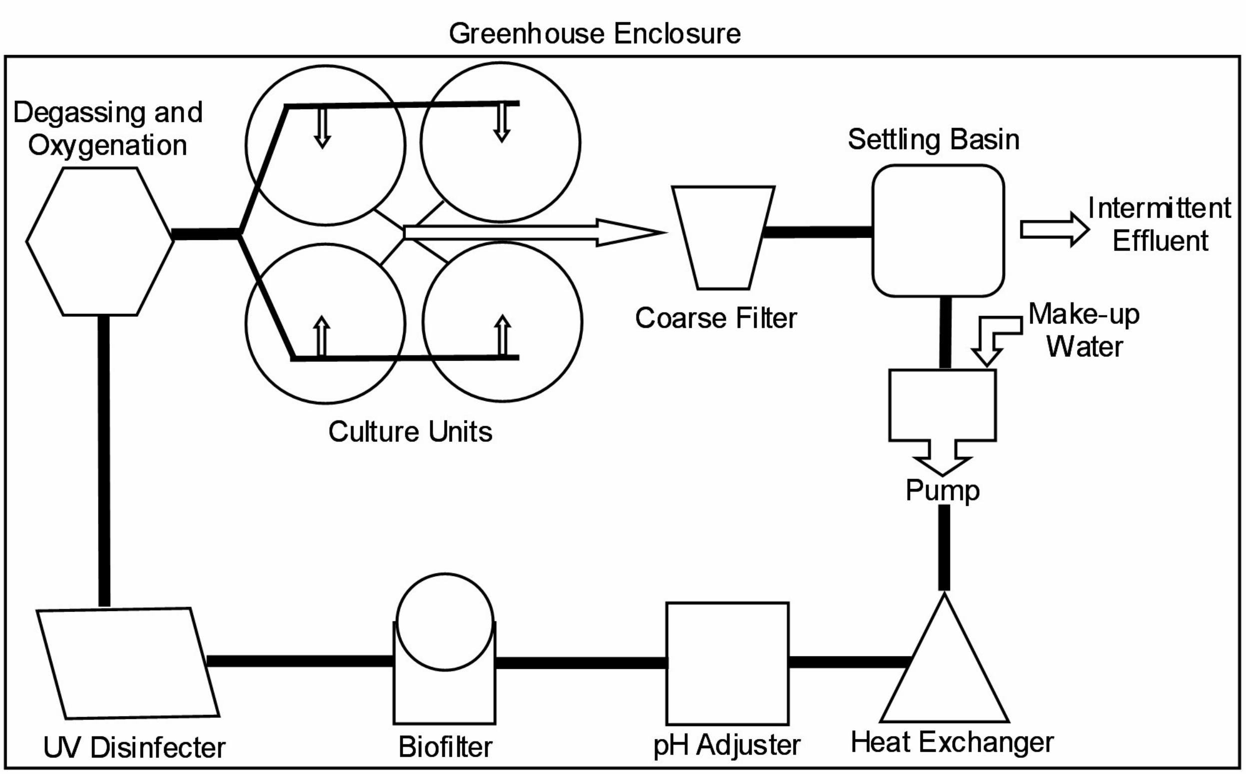

Figure 6. An indoor, heated, water re-circulating aquaculture system.

Feed

Tilapia feeds are made from plant meals, fish and meat meals, and dietary supplements. Fitzsimmons (1997) provided a nice summary of the nutritional requirements of tilapia. The crude protein content of tilapia feed should decrease with increasing fish size as follows: smallest fry (<0.02 g), 45 to 50%; 0.02- to 2-g fish, 40%; 2.0 to 35-g fish, 35%; fish of more than 35 g, 30 to 32%. The percentage of the total dietary protein that should be provided by each essential amino acid is given in Table 2. The sum of the percentages in Table 2 is not 100% because non-essential amino acids are not included. Some producers feel that 24 to 25% crude protein is adequate in feed for grow-out of fish in semi-intensive culture and 28% crude protein is adequate for intensive grow-out (Chhorn Lim, personal communications). The fish meal content of feeds containing 25% crude protein or less is about 5%, while there often is about 6 to 8% fish meal in feeds of higher crude protein content. However, fish meal apparently can be replaced completely with meat, bone, and blood meal in feeds for semi-intensive culture and possibly for those used in intensive culture.

Fish under 2 g in weight should be given a feed containing 10% lipid. Feed for larger fish only needs 6 to 8% lipid (Fitzsimmons 1997). Carbohydrate content usually is less than 25% in feed for fish smaller than 1 g and 25 to 30% in feed for larger fish. Carbohydrate can be supplied by corn, wheat, rice, soybean, or other sources. Some of the lipid can be obtained from other feed ingredients, and the rest can be obtained from vegetable oils. Coconut oil and palm oil have not proven useful in tilapia feed (Chhorn Lim, personal communications).

Tilapia feeds need vitamin and mineral supplements. Typical recommended amounts of vitamins and minerals to be added to feed mixes before pelletizing (Fitzsimmons 1997) are provided in Table 3.

Fish usually are fed two or more times per day. Aquanutro (2002) suggested pellet sizes, feeding frequencies, and feeding rates for different size tilapia in semi-intensive and in intensive culture (Tables 4 and 5).

Table 2. Essential amino acids in experimental tilapia diets.

Amino acids	% of total dietary protein
Arginine	7.5
Histidine	2.3
Isoleucine	4.3
Leucine	7.0
Lysine	5.0
Methionine	1.7
Phenylalanine	4.5
Threonine	3.6
Tryptophan	1.0
Valine	5.8

Source: Fitzsimmons 1997.

Table 3. Recommended amounts (before pelletizing) of vitamins and minerals in tilapia diets.

Vitamins	mg/kg	Units
Thiamin	11	
Folic acid	5	
Riboflavin	20	
Vitamin B12	0.01	
Pyridoxine	11	
Choline	275	
Panthothenic acid	35	
Nicotinic	88	
Ascorbic acid (C)	375	
Vitamin K	4.4	
Vitamin A		4,400
Vitamin D3		2,200
Vitamin E		66
Minerals	g/kg	
Calcium Ca		
Phosphorus P	7.0	
Magnesium Mg	0.5	
Iron Fe	0.15	
Zinc Zn	0.20	(Note: Should not be above 0.3 (300 ppm)
Copper Cu	0.003	
Manganese Mn	0.013	
Selenium Se	0.0004	
Iodine I	0.001	

Source: Fitzsimmons 1997.

Table 4. Suggested pellet sizes and feeding recommendations for tilapia at various stages of development.

Feed range	Fish size (g)	Pellet size (mm)	Feeding frequency (feeding/day)
Pre-starter	<60	<2a	6-8c
Starter	60-200	2b	6-8
Grower (intensive)	>200	4b	3-5
Grower (semi-intensive)	>200	4b	1-2

Source: Aquanutro 2002.

[a] Various size-ranges of extruded crumbles (00, 0, 1, 2, 3, 4, 5).

[b] Extruded pellets.

[c] At 29°C tilapia benefits from multiple feedings because of the continuous nature of its feeding behavior and restricted stomach capacity.

Table 5. Suggested tilapia feeding rates as percentage body weight per day for optimum feed conversion efficiency.

	Production system	
Fish weight (g)	Intensive	Semi-intensive
0-15	15.0	10.0
15-60	8.0	5.0
60-100	5.0	3.0
100-200	3.0	2.0
200-300	2.25	1.5
300-500	2.0	1.4
500 +	1.6	1.3

Source: Aquanutro 2002.

Effluents

All methods of producing tilapias result in effluents. In net pen and cage culture, larger particles of uneaten feed and excrement fall directly from production units onto the sediment. Smaller suspended particles and metabolites excreted through the gills, e.g., ammonia and carbon dioxide, are flushed from production units by water movement. In raceways, a portion of the larger suspended particles settles to the bottom, but the particles too small to settle and soluble metabolites exit in outflowing water. In water re-circulating systems, water treatment such as sedimentation and mechanical and biological filtration may be installed to remove pollutants and improve water quality. Nevertheless, effluents are generated in re-circulating systems because water must sometimes be released to allow new water to be added to enhance water quality by water exchange, filters must be "back-flushed" to improve their performance, and accumulated sediment must be removed.

The portion of fertilizers or feed not converted to fish tissue in pond culture enters the surrounding water just as it does in other production systems. However, in ponds, the water is retained for a long period and may not be discharged except when ponds are drained. Thus, natural biological processes in ponds may assimilate much of the wastes from aquaculture (Gross et al. 2000). Of course, nutrients entering ponds in uneaten feed, feces, and metabolites stimulate phytoplankton growth leading to the production of large amounts of organic matter through photosynthesis (Boyd and Tucker 1998). Organic matter and nutrients in dead plankton also will be assimilated by natural processes in ponds. For example, organic matter is mineralized to carbon dioxide, water, ammonia, phosphate, and other inorganic elements by microbial action. Carbon dioxide can be lost from the system by diffusion into the air. Ammonia also may diffuse into the air (Gross et al. 1999) or it may be oxidized to nitrate by nitrifying bacteria. Nitrate-nitrogen may be transformed to gaseous nitrogen by denitrifying bacteria and lost to the air (Gross et al. 2000). Phosphate may precipitate directly from the water as insoluble calcium phosphate, or it may be adsorbed by bottom soil (Masuda and Boyd 1994).

The ability of ponds to assimilate waste depends upon several factors as follows:

(1) Ponds that have good water quality assimilate wastes better than ponds with impaired water quality. Thus, water quality tends to be poor in ponds that are stocked heavily and/or feed and fertilizer inputs exceed the assimilative capacity of the system. Mechanical aeration greatly enhances the ability of ponds to assimilate wastes, but enough aeration must be applied to maintain dissolved oxygen concentrations above 3 mg/L at all times. Liming of acidic ponds also greatly enhances the ability of microorganisms to degrade organic matter.

(2) Water exchange applied as a management technique or resulting from rainfall and runoff into ponds shortens hydraulic retention time and lessens the ability of natural processes to assimilate wastes.

(3) Ponds that are drained frequently assimilate less waste than those that are seldom drained.

The total loads of nitrogen and phosphorus imposed on systems by fish culture can be estimated by subtracting the quantities of nitrogen and phosphorus contained in fish at harvest from the amounts of these two nutrients applied in fertilizer, manure, or feed. Some examples will be given for typical culture conditions. In these examples, tilapias are assumed to contain 26.5% dry matter (DM), and the dry matter is 8.5% nitrogen (N), and 3.01% phosphorus (P) (Boyd and Green 1998).

Example 1. In a manured pond, a total input of 10,000 kg/ha dry manure containing 1% N and 0.2% P results in the production of 2,000 kg/ha of live tilapia. The amount of nitrogen and phosphorus generated in waste will be estimated.

Input in manure:
10,000 kg × 0.01 kg N/kg manure = 100 kg N

10,000 kg × 0.002 kg P/kg manure = 20 kg P

Removal in fish:
2,000 kg × 0.265 = 530 kg DM in fish

530 kg × 0.085 kg N/kg DM = 45 kg N

530 kg × 0.0301 kg P/kg DM = 16 kg P

Nutrient load:
Load = Input - Removal

Nitrogen = (100 - 45) kg N = 55 kg N

Phosphorus = (20 - 16) kg P = 4 kg P

This is 27.5 kg nitrogen and 4 kg phosphorus per metric ton of tilapia.

Example 2. In a fertilized pond, application of 500 kg urea (45% N)/ha and 200 kg triple superphosphate (20% P)/ha results in the production of 2,000 kg/ha of live tilapia. The amount of fertilizer nitrogen and phosphorus remaining in the pond will be calculated.

Input in fertilizer:
500 kg urea × 0.45 kg N/kg urea = 225 kg N

200 kg TSP × 0.2 kg P/kg TSP = 40 kg P

Removal in fish:
2,000 kg tilapia × 0.265 = 530 kg DM in fish

530 kg DM × 0.085 kg N/kg DM = 55 kg N

530 kg DM × 0.301 kg P/kg DM = 16 kg P

Nutrient load:
Nitrogen = (225 - 55) kg N = 170 kg N

Phosphorus (40 - 16) kg P = 24 kg P

This is 85 kg nitrogen and 12 kg phosphorus per metric ton of tilapia.

Example 3. The amount of nitrogen and phosphorus in waste resulting from the production of 1 mt of tilapia with feed (28% crude protein; 4.5% N and 1.2% P) will be determined. A feed conversion ratio (FCR) of 1.5 is assumed.

Input in feed:
1 mt fish ÷ 1.5 kg feed/kg fish = 1,500 kg feed
1,500 kg feed × 0.045 kg N/kg feed = 67.5 kg nitrogen
1,500 kg feed × 0.012 kg P/kg feed = 18 kg phosphorus

Removal in fish:
For above, 1,000 mt live tilapia = 265 kg DM
265 kg DM × 0.085 kg N/kg DM = 22.5 kg N
265 kg DM × 0.0301 kg P/kg DM = 8 kg P

Nutrient load:
(67.5 - 22.5) kg N/mt tilapia = 45 kg nitrogen per metric ton of tilapia
(18 - 8) kg P/mt tilapia = 10 kg phosphorus per metric ton of tilapia

Based on the above calculations it appears that manure-based culture systems produce smaller loads of nitrogen and phosphorus per metric ton of fish than do commercial fertilizer- or feed-based systems. Nevertheless, it should be noted that manures only are used in pond systems where some nitrogen and phosphorus is derived from natural sources (sediment and water). Also, in ponds, tilapia feed on plankton which grows in response to nutrient additions. It is more difficult to estimate the carbon load imposed by tilapia culture, because nitrogen and phosphorus resulting from manure, fertilizer or feed inputs stimulate phytoplankton photosynthesis which increases the carbon load.

There have been few studies of the composition of effluents from tilapia culture systems, and no published reports were found. However, Seim et al. (1997) presented a summary of surface water quality data in aquaculture ponds at different levels of production (Table 6). Concentrations of potential pollutants increase as production intensity increases.

Table 6. Typical ranges for selected water quality variables in surface waters of aquaculture ponds at three levels of production.

	Level of aquacultural production		
Water Quality variable	Extensive > 1000 kg/ha	Semi-intensive 1000-5000 kg/ha	Intensive > 5000 kg/ha
Chlorophyll a (µg/L)	10-50	50-150	150-500
Biochemical oxygen demand (mg/L)	2-5	5-20	20-40
Volatile solids (mg/L)	5-10	10-20	20-50
Turbidity (NTU)	5-10	10-25	25-50
Nitrate-nitrogen (mg/L)	0.01-0.1	0.1-0.2	0.2-0.3
Total ammonia nitrogen (mg/L)	0.1-0.5	0.5-2	2-5
Total Kjeldahl nitrogen (mg/L)	0.5-2.0	2-4	4-10
Total phosphorous (mg/L)	0.05-0.1	0.1-0.3	0.3-0.7
Settleable solids (mg/L)	0.0-0.05	0.05-0.1	0.1-0.5

Source: Seim et al. 1997.

During pond draining, the first 70 to 80% of effluent will be similar in composition to pond surface water, but concentrations of potential effluents, and especially suspended solids, will increase in the final 20 to 30% of draining effluent (Boyd and Tucker 1998).

Possible Impacts on Water Quality

As with other types of aquaculture, tilapia culture can cause water pollution. The three most likely impacts on water quality are increased loads of nutrients, oxygen demand, and suspended solids in water receiving effluent from tilapia culture. Nitrogen and phosphorus are the two nutrients of most concern because they are responsible for eutrophication. The oxygen demand and suspended solids result primarily from uneaten feed, feces, plankton, and mineral particles. Solids discharged from net pens and cages, raceways, and some water re-circulating systems will be comprised primarily of uneaten feed, feces, or their decomposition products, while solids from ponds are mostly plankton and mineral particles. The oxygen demand from plankton is expressed much more slowly than the oxygen demand of uneaten feed and feces (Boyd and Gross 1999). Thus, there is less likelihood of dissolved oxygen depletion around outfalls from ponds than from other culture systems. Also, ponds have a relatively long hydraulic retention time and most coarse particles have already settled from the water. Therefore, the likelihood of sediment accumulation around pond outfalls also is less than for outfalls of other culture systems.

Salinization can be an issue in tilapia culture for these fish have a high tolerance to salinity and can be cultured in brackishwater. However, most brackishwater culture of tilapias apparently is done in coastal areas where the water is removed from estuaries and discharged back into them.

Dissolved oxygen concentration in intensive tilapia culture units may be quite low at times. Tilapias are rather tolerant to low dissolved oxygen, and concentrations of 3 to 4 mg/L apparently are not extremely harmful to them even with long-term exposure. The dissolved oxygen concentration also fluctuates daily in ponds, and water released during the night or early in the morning may be particularly low in this variable. Thus, effluents from tilapia culture may have less than the minimum concentration of 5 to 6 mg/L dissolved oxygen usually recommended for the protection of aquatic life in natural water bodies. The oxygen demand of tilapia effluents also can cause low dissolved oxygen in receiving waters and especially in the vicinity of discharges, e.g., around net pens or cages and in the mixing zone where pipes or small canals release effluent in water bodies. Eutrophication of water bodies by nitrogen and phosphorus from tilapia culture could result in generalized patterns of low dissolved oxygen in receiving waters.

The pH of pond waters may increase above 9 during periods when photosynthesis is high. Waters discharged during afternoon from ponds may sometimes have a pH above the maximum pH of 8.5 to 9 often recommended for natural water bodies. The use of burnt lime in pond culture also can cause temporarily high pH. Nevertheless, high pH in tilapia effluent is a much less likely and less harmful condition than low dissolved oxygen concentration.

Toxic chemicals do not appear to be a significant issue in tilapia culture. Producers do not apply chlorine, formalin, pesticides, or other toxic chemicals to ponds. Also, antibiotic use in tilapia culture is extremely rare. The only chemicals commonly used are liming materials and fertilizers to increase natural productivity in ponds. Of course, the use of hormones in hatcheries might possibly contaminate fish flesh, but there is little likelihood that the amount excreted by exposed fish into culture systems would constitute a water pollution hazard.

As with any kind of agriculture, tilapia producers will likely use various types of machinery, e.g., tractors, trucks, pumps, and aerators. Storage and use of fuels and oils always presents the potential of spills into ponds or natural waters.

Erosion is a common problem at pond aquaculture facilities. Erosion of insides of pond embankments by water currents, stirring of pond bottoms by tilapia, and turbid water supplies are sources of suspended mineral particles. These particles tend to settle in the deeper parts of ponds. After a number of years, it may be necessary to remove sediment from the deeper areas of ponds to prevent excessive depth of soft sediment and loss of deep-water area. This sediment often is put back on insides of embankments, but if disposed of outside of ponds, sediment piles may be eroded by rain resulting in turbid runoff entering natural waters.

Pond embankments and areas around ponds often are denuded of vegetation during construction. Unless proper vegetative cover is re-established, erosion of embankments and surrounding areas will be a source of turbid runoff. Furthermore, improperly constructed drainage canals may be eroded by flowing water and be sources of suspended solids in effluents.

Water pollution by aquaculture effluents can result in eutrophication, sediment accumulation, and low dissolved oxygen concentrations in receiving water bodies. Negative effects of pollution on water quality and bottom habitat in receiving water bodies can decrease biodiversity by favoring the proliferation of certain, undesirable species in favor of others which are more desirable. For example, eutrophication encourages a few species of blue-green algae in great abundance, which is less desirable than a lower abundance of several species of diatoms and green algae.

Resource Use

Pond culture of tilapias causes changes in land use. Concerns often are expressed about conversion of agricultural land, freshwater wetlands, and coastal mangrove forest to aquaculture ponds. The conversion of agricultural land should not be a major concern about tilapia farming, for culture of these species is more profitable than traditional agriculture. Also, tilapia ponds are sustainable for many years. For example, Thunjai and Boyd (2004) found that bottom soils in tilapia ponds in Thailand still were suitable for fish culture after 40 years of continuous use. Abandoned tilapia ponds in freshwater areas can be converted back to agricultural land if desired. However, it will be easier and less expensive per unit area to convert large ponds back to agricultural land than small ones.

Water for pond and raceway culture of tilapias normally is derived from surface runoff, lakes and streams, springs, or irrigation systems. Use of well water, which is common in channel catfish farming, is not a frequent practice in tilapia culture. Pond culture of tilapias creates a large water surface and increases evaporative loss of water. This probably is not a significant hydrological factor where rain fed ponds are used, but it could compete with traditional agriculture for water where ponds are filled from irrigation systems. Water that seeps from ponds either enters underground aquifers or flows downslope into streams. Tilapias contain about 75% water, but the amount of water contained in tilapia biomass, around 0.75 m^3/mt fish, is rather small. Except for evaporation, tilapia culture consumes little water. Water is retained in culture systems temporarily before being passed downstream. Water consumption does not appear to be a major environmental or resource use concern in tilapia culture. However, fish culture can lessen the quality of water as already discussed.

Tilapia feeds seldom contain more than 8% fish meal, and feed with lower fish meal content should be used. Assuming a FCR of 1.5, 1,500 kg of feed yields 1,000 kg live tilapia. This amount of feed could contain as much as 120 kg fish meal. Fillets are the most popular form of tilapia for export. The dress-out percentage for fillets may be only 20% of body weight. Thus, 120 kg fish meal in feed would give 200 kg fillets. Although this is a much better return on fish meal than usually obtained for shrimp, trout, or salmon, it is less than for channel catfish. It would be highly beneficial from an environmental standpoint to reduce the amount of fish meal in tilapia feed.

Energy use in tilapia culture has not been evaluated. However, the main inputs are in construction of culture systems, feed production, pumping water, mechanical aeration, transportation, and processing. There is no reason to believe that energy use in tilapia production would be less efficient than in other types of aquaculture.

Biological Pollution

Tilapias have become the second most common aquaculture species and they have been introduced into at least 90 countries on all continents except Antarctica (Fitzsimmons 2001). Many of the early introductions were for insect and aquatic weed control, and in some countries, tilapias had been dispersed widely before tilapia farming began. Tilapias thrive in disturbed habitats, they reproduce and spread rapidly, they are carnivorous on the eggs and young of other species, and they are strong competitors with other species for food and other resources. Thus, the introduction of tilapias can have serious consequences on the biodiversity of natural fish populations.

Lake Victoria in east Africa often is used as a warning of the potential for damaging impacts of introduced fish species. Following the introduction of Nile perch (Lotes niloticus) and three species of tilapias (Oreochromis niloticus, Tilapia melanopleura, and Tilapia zilli) in the 1950s, hundreds of the lakes' endemic fish species declined in abundance. Nile perch and tilapias now dominate the fisheries of Lake Victoria and species diversity has declined greatly (Kaufman 1992).

The lower Colorado River in North America provides another example of the negative impact of tilapia introduction (Fitzsimmons 2001). A series of dams and diversions of most of the river's water caused massive environmental changes. The dams stopped the normal flooding cycle, increased salinity, and altered the normal flora. Introduction of tilapias for aquatic weed control in irrigation canals allowed them to migrate into the main stream of the river. Tilapias now represent 90% of fish biomass in the river and most native species are endangered.

In many countries, populations of tilapias have become a permanent and dominant aspect of fish communities. Nevertheless, there are many natural waters where tilapias could thrive but into which these species have not been introduced. Thus, precautions should be taken to prevent further damage to the biodiversity of natural fisheries communities by tilapia introductions.

Tilapias will eventually escape from any type of culture system. In tropical and subtropical climates, tilapias can survive and reproduce in almost any aquatic habitat into which they escape. Thus, fully domesticated strains of tilapias with little chance of surviving outside of culture units should be developed (Fitzsimmons 2001). The red tilapia is an important first step towards fully domesticated tilapias. Red tilapias are found in domesticated populations and they have little chance of surviving in the wild. Predation from birds, fish, and humans is great because red tilapias are highly visible. The red tilapia has been morphologically modified through breeding to have a more rounded body form which also decreases its chances for survival in nature. Moreover, all male populations developed from hybrid, sex-reversal, or genetically male parentage are not likely to establish breeding populations following escape into the wild (Fitzsimmons 2001).

Social Issues

In the past, most tilapias were produced in developing countries by small-scale farmers to provide table fish or for sale in local markets. This type of aquaculture normally is considered to have a positive socioeconomic influence.

In recent years, tilapias have become a major export species in some countries. Large farms that produce hundreds or thousands of metric tons of tilapia per year have been constructed in countries such as Ecuador, Costa Rica, Colombia, Mexico, and Zimbabwe. These farms employ many people and have interactions with local communities and other land and water users. Processing plants associated with large farms also are major employers. Thus, tilapia production can be a source of income for owners and workers. Farms purchase many supplies locally to further stimulate the economy, and exported fish represent a source of foreign exchange.

There has been much concern about the negative impacts of shrimp farming and some other kinds of aquaculture on local communities. There are cases where land use changes have deprived local residents of traditional fishing, hunting, and gathering privileges. Local people occasionally have been forced from the land in places by aquaculture projects. Moreover, workers for aquaculture projects may sometimes be brought in from other regions rather than hired locally. We were unable to find documented cases where tilapia farms have caused conflicts with local communities or deprived local residents of traditional privileges. Nevertheless, the possibility of such negative socioeconomic impacts exists when a large commercial enterprise of any type is superimposed upon a traditional, rural society.

Governmental Regulations

Most governments have regulations about the importation of non-native species, but in the case of tilapias, these regulations have not been enforced well for the species has been introduced into almost all tropical and subtropical nations. Although tilapias are widely distributed, they do not occur in all tropical and subtropical watersheds, and existing regulations about tilapia importation should be enforced, or if such regulations do not exist in a nation, they should be made and enforced.

Many countries also are developing general environmental regulations for aquaculture. The most important regulations are those related to siting, use of drugs and chemicals, and effluents. Farms should not be sited in sensitive ecological habitats such as wetlands, in flood-prone areas, or in areas where conflicts with other land and water users are likely. Antibiotics and other chemicals used should be strongly regulated to prevent these substances from having undesirable ecological effects and from leaving residues in fish sold in the market. Regulations related to effluents are critical in avoiding pollution of natural waters into which tilapia production systems discharge.

The United States Environmental Protection Agency has developed a proposed effluent rule for aquaculture which was finalized in June 2004. These regulations include the definition of concentrated aquatic animal production facilities. A concentrated warm water aquatic animal production facility is one which produces at least 100,000 lbs (45,454 kg/year) and does not discharge for more than 30 consecutive days per year excluding excess runoff following rains. A warm water aquatic animal production facility is subject to a National Pollution Discharge Elimination System (NPDES) permit. The draft rule excludes ponds from effluent limitation guidelines, but guidelines proposed for raceways, net pens and cages, and water re-circulating systems will apply to tilapia culture. Pond culture systems which qualify as concentrated aquatic animal production facilities are subject to NPDES permits. However, because no federal effluent limitation guidelines were recommended for ponds, individual states will be at liberty to regulate such facilities as they see fit. The USEPA recommended the use of best management practices in aquaculture, and most states will probably mandate BMPs for farms that must be issued NPDES permits. It is likely that the aquaculture effluent regulations developed in the United States will serve as a model for aquaculture effluent regulations in many developing nations.

Best Management Practices

Best management practices have been prepared for use in channel catfish, salmon, trout, and shrimp culture (Boyd 2003). There also has been considerable effort to entice producers to adopt BMPS. At least one program to certify that BMPs were used to produce shrimp sold under a particular label has been launched. Also, some salmon produced according to BMPs are sold under environmental labels.

There has been less effort to develop BMPs for tilapia production. However, Boyd (2004) noted that the BMPs developed for channel catfish production in Alabama ponds would all be applicable to pond production of tilapia. Of course, BMPs for tilapia production should extend to certain issues not pertinent in catfish farming. These include methods for preventing escapees from reproducing, use of hormones in hatcheries, and good practices for siting operations and producing fish in culture systems other than ponds. It seems premature to recommend additional BMPs until formal discussions are held among all stakeholders.

Certification Issues

Some issues related to tilapia certification can be dealt with easily because they are common to other kinds of aquaculture and solutions already have been suggested. However, there are several issues about tilapia production for which it will be difficult to clearly define the most responsible approach. Thus, standards for tilapia certification should not be developed until the environmental consequences of some of the management options available to tilapia producers have been thoroughly deliberated by all stakeholders.

General considerations

Existing regulations – A certified producer obviously is expected to be in compliance with all existing regulations required by local, state, and government agencies. Thus, the first step towards certification should be to verify that the producer is in compliance with all governmental regulations and laws. Failure to comply with these requirements at any time after certification is granted should constitute grounds for immediate cancellation of certified status.

Water use – Ground water is a valuable resource, and aquaculture operations that do not rely on ground water are environmentally more desirable than those that do. At least initially, I believe that a tilapia certification program should be initiated with farms that use little or no ground water.

> *Comment*: The initial rule probably should be that ground water from wells should not be used. In the future, a set of guidelines for using ground water in a conservative manner might be formulated to allow certification of selected farms operating on well water.

Fingerlings - There would be little incentive to certify fingerling producers, but some use much better practices than other. Thus, the certifying body should inspect a number of fingerling operations and select some satisfactory sources of fingerlings for certified farms. Acceptable fingerling operations should use surface water, employ good water quality management, avoid medicated feed, produce YY all-male fingerlings, and drain ponds in a manner to prevent the discharge of large amounts of suspended solids. They also would be expected to use high quality brood stock which are not genetically modified through any procedure other than selective breeding.

> *Comment*: The rule regarding fingerlings should be to use only fingerlings from a source approved by the certifying body.

Feed – Tilapia feed for grow-out does not contain a lot of fish meal, but environmentally, it would be desirable to eliminate fish meal from the diet entirely. Research studies have shown that all plant diets can give high production, or diets that use “non-fish” meat and bone meal could be used. The issue would need to be discussed with a specialist in tilapia nutrition and a suitable diet formulated.

Tilapia farmers, like most other aquaculturists, tend to overfeed and FCR values often exceed 2.0. It is possible to obtain lower FCR values with careful feeding.

> *Comment*: One rule might be that certified producers must use a feed that is free of fish meal and does not contain more than 30% crude protein. Another rule probably should be that an FCR of 1.8 or less, or possibly 1.6 or less, is necessary to maintain certification.

Antibiotics and other chemicals. – The use of fertilizers and liming materials for adjusting phytoplankton blooms, alkalinity, and pH must be allowed. Also, certified producers must be allowed to apply salt to ponds (up to 100 mg/L chloride) and to treat blooms of blue-green algae with copper sulfate (0.01 × total alkalinity). The use of rotenone to kill unwanted organisms in puddles in bottoms of empty ponds should be permissible. The use of other chemicals would not be acceptable.

> *Comment*: The rule for certification might state that antibiotics, formalin, and pesticides (herbicides included) must not be applied in any form to ponds.

Bird control – Even though governments may allow some species of fish-eating birds to be killed at will and gives permits for destruction of a proportion of farm populations of other species, the certified producer should not do so.

> *Comment*: The rule for certification should specifically state that only non-destructive methods of bird control may be employed.

Dead fish – The consumer would not like to learn that a certified aquaculture product came from a pond in which dead fish were left to float around the edges until eaten by scavengers or decomposed by organisms of decay.

> *Comment*: The rule for certification might require ponds to be inspected at least twice weekly and all visible dead fish removed and buried, composted, or incinerated.

Record keeping - The producer should be required to maintain the following records:

- Source of fingerlings
- Date and amount of all fingerlings stocked
- Amount of feed applied daily
- Date and amount of all fertilizer, lime, salt, and copper sulfate applied to ponds
- Number of dead fish removed on each date
- Weight of fish harvested on each date
- FCR
- Production in kg/ha
- Fertilizer N and P used per ton of fish produced
- Survival

These records can be of use to the producer in determining how to be more efficient. The data also can be used to develop indices for production that can be expected for certified farms.

More contentious considerations

Location – Tilapias are native to a particular part of the world from which they have been introduced into many other areas where they have become established. Nevertheless, there are many watersheds outside the current range of tilapias where they have not been introduced. Tilapias also are maintained for aquaculture purposes in some places where they cannot survive outside culture systems because of low water temperature during part of the year.

Tilapias are aggressive and can out-compete most native fish species when introduced into new habitats. Tilapia certification definitely should include a standard for preventing the spread of these species. A certified tilapia operation should not present any risk of escapees which can reproduce in surrounding waters. Two questions should be carefully considered:

(1) Should certification prohibit the introduction of tilapias on tropical and subtropical watersheds where they are not endemic and/or established, or should certification allow only the use of fingerlings incapable of reproduction on such watersheds?

Comments: There is no method for containing fish on farms that is "fail-safe." Fingerlings incapable of reproduction would have to be produced in areas where tilapias are endemic and/or established. However, it is not clear that 100% of fingerlings in batches of all-male or sex-reversed tilapia are incapable of reproduction. Apparently, the tilapia hybrids (red tilapias) are the most certain source of fingerlings incapable of reproduction and survival outside of culture systems.

(2) Should tilapia certification be allowed for facilities located in temperate areas where escapees would not be able to survive the winter?

Comments: Cold-water adapted strains of tilapia are not likely to develop, and escapees from farms would die in winter. However, some tilapia operations might discharge into thermally polluted water where survival could be possible in the mixing zone of heated effluent and normal waters. Moreover, fish escaping early in the growing season might reproduce and develop large enough populations to compete with local species during summer and early fall. The risk could be reduced by restricting certification to facilities which only stock fish incapable of reproduction. In our opinion, tilapia certification should be allowed in temperate areas, but the issue should be discussed with all stakeholders.

<u>Species</u> – There may be a valid environmental reason for limiting certification to hybrids. Hybrid, red tilapia appear to present the least danger of surviving in natural waters. Also, this strain of tilapia is desirable to consumers. At least initially, these two reasons strongly favor red tilapia over others. The main argument against this practice may be that it will tend to deny small producers in developing nations an opportunity for participating in certification because of difficulty in obtaining red tilapia fingerlings.

<u>Preventing reproduction</u> – Most of the techniques for preventing reproduction would not be permissible in areas where tilapias are not endemic. Periodic harvesting of small fish from culture units could not be used because of the high risk of escape. Separation of sexes is not 100% accurate. In cage culture, eggs fall from cages, but escapes of large fish are inevitable. High-density culture in ponds or raceways also would have a high risk of escape, and so would the use of predaceous fish in ponds to eat small fish.

The use of hormones to produce all-male fingerlings and production of all-male fry using YY males are possible ways of producing fingerlings for certified tilapia facilities.

Comments: The use of YY males to provide all-male fingerling seems most acceptable for certification. Exposure of fry to hormones for sex-reversal is a more common practice. Although studies suggest that the risk to consumers is insignificant, many consumers may not want to eat fish which have been treated with hormones. The idea of allowing hormone-treated fingerling in a certification program for tilapias should be considered by stakeholders, but it is unlikely to be adopted.

<u>Production systems</u> – The grow-out systems by which tilapias are produced are quite varied, and each has both negative and positive environmental aspects.

Ponds are the traditional and most frequently used grow-out systems. If managed properly, much of the waste from tilapia propagation will be assimilated in ponds. Ponds managed for semi-intensive production have better quality water than those managed for intensive production. However, per unit of production, waste load, water and land requirements, and energy use consumption usually is greater for semi-intensive production than for intensive production. Ponds in general require much more land than other production units.

Net pens, cages, and raceways tend to release much larger amounts of waste in effluent per unit of production than pond culture systems (Boyd and Queiroz 2001). Therefore, the siting of these systems should be a critical issue in certification. If net pens and cages are properly sited, waste can be effectively assimilated by natural waters. However, if they are located in an area with poor water circulation or if too many units are placed in one area, serious eutrophication may result. Cages or raceways integrated into irrigation systems would not cause pollution, but raceways discharging into a stream or cages installed in a stream could cause serious pollution downstream. Water treatment, such as sedimentation, could be installed to reduce pollution from raceway effluent, and water quality limits could be imposed on effluents from raceways.

Water re-circulating systems can be operated with a minimum impact on downstream waters. However, the relatively small amount of effluent discharged by these systems can be highly concentrated. Thus, a standard for treating the effluent would be essential.

> *Comments*: In our opinion, production systems generally may be ranked in the following order of environmental friendliness: (1) raceways and cages integrated into irrigation systems; (2) intensive ponds; (3) water re-circulation systems; (4) semi-intensive ponds; (5) other raceways; (6) other cages; (7) net pens. Of course, the position of cages and net pens in the ranking might be improved at certain sites.

<u>Methods for increasing production</u> – Methods commonly used to increase tilapia production in ponds are application of manure, commercial fertilizers, liming materials, feed, water exchange, and mechanical aeration. In a few Asian countries, Vietnam and India in particular, human wastes may be applied to aquaculture ponds. In the other production systems, manures, commercial fertilizers, and liming materials are not used to increase production, and water exchange is an integral part of the system. Feed is applied to net pens, cages, raceways, and water re-circulating systems. Mechanical aeration normally is used only in water re-circulating systems, but it also may be applied in some highly intensive pond culture operations.

The use of animal wastes as fertilizers carries the risk of antibiotic and microbial contamination of fish. Use of human wastes would risk contamination of fish with human pathogens. Moreover, consumers would not expect a certified product to be produced with animal or human wastes. Certification probably should strictly forbid the use of animal or human wastes as fertilizers.

Liming materials and commercial fertilizers can be used in aquaculture without causing adverse environmental impacts. However, excessive use of liming materials can cause pH to rise above 9, and too much fertilizer encourages high nutrient concentrations in effluents. Thus, certification programs should insist on conservative use of liming materials and commercial fertilizers.

Feed should be used conservatively to prevent the input of more nutrients than necessary, to avoid the waste of feed ingredients, to increase the efficiency of feed use, and to reduce production costs. The dress-out percentage for tilapia is not great – usually less than 33%. Thus, the conversion of feed protein to fish protein is relatively low compared to channel catfish and some other species. Therefore, the fish meal content of tilapia should be reduced to the lowest concentration practical. By increasing the amount of meat scrap and blood meal in feed, the fish meal content can likely be reduced to 4% or less. Ideally, certification should not allow any fish meal in tilapia feed.

Certification should forbid the use of water exchange in pond culture, because water exchange reduces hydraulic retention time flushing out wastes before they can be assimilated by natural processes.

On the other hand, mechanical aeration should be encouraged for it improves pond water quality and increases the capacity of natural processes to assimilate wastes.

Possible Areas for Initiating Certification

Because tilapias are cultured in many nations, there are many possible areas where product certification could be considered. It is our opinion that certification should be done in areas where producers are innovative, relatively good practices already are in use, serious negative environmental impacts are unlikely, and prospects for sustainability are good.

In Colombia, some tilapia production has been integrated into irrigation schemes. Thus, one of the possible major impacts, water pollution, can be avoided on these farms. Moreover, producers there appear to be rather innovative and receptive to new ideas. Ecuador has considerable tilapia production in renovated, former shrimp ponds. These production systems do not appear to be causing serious pollution problems in estuaries into which they discharge. There are only a few large producers, and some of them probably would be willing to work with a certification body. These individuals are innovative as evident from their willingness to convert from shrimp to tilapia farming. The main issue in certification might be the fact that some of the farms contain former mangrove land. Tilapia production also is growing in Brazil, and an investigation of farm locations and methods of production would be useful in determining if this country is a suitable area for trial certification.

Aquaculture producers in Asia tend to use production techniques that generally are less environmentally friendly than those used elsewhere. In particular, the large amount of animal manure, and sometimes human wastes, used in tilapia culture in Asia would be a serious problem in certification. Thus, Asia probably is not a prime area for certification trials.

South Africa does not have a well-established tilapia industry. However, there is an effort towards developing one. The farmers tend to be quite innovative and they are quick to adopt new ideas or new crops that can improve their income. Thus, a program to encourage tilapia production in South Africa using cages or “in-pond” raceways in irrigation systems with emphasis on developing certified production might have success. The major obstacle to South Africa as a place for trial certification is the climate. Tilapias cannot be produced year around and the reliance on externally-heated systems might be cost prohibitive. Nevertheless, there are excellent prospects for certification of a single crop per year.

In the United States, a number of farmers use heated, water re-circulating systems to produce tilapia in areas where cold winter climate will prevent breeding populations from becoming established. These systems also can be prevented from causing water pollution if appropriate water treatment is employed. Thus, they have potential for trial certification efforts.

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