Aquaculture of tilapias

Although aquaculture is considered an old tradition, modern aquaculture is essentially a post-1950 phenomenon. The perception that tilapia (*O. mossambicus*) would be a potential panacea to the growing animal protein deficiency in Asia (Lin 1977) began to be dismissed relatively early for reasons indicated earlier. *O. niloticus* became the preferred tilapia species for aquaculture in the region (Smith and Pullin, 1984). Although it is difficult to assess whether this species has made a significant contribution to the animal protein needs of rural Asian communities, it certainly had a major impact on aquaculture developments in Asia and the Pacific since the 1970s.

Production

Aquaculture of tilapias provides a classic example of a success story of a species group outside its natural range of distribution. The group currently contributes about 3.8 percent to the cultured fish and shellfish production of about 40 million tonnes globally (FAO FishStat). The current aquaculture production (2002) of tilapias is about 1.5 million tonnes, the great bulk of which takes place in Asia (Figure 6) accounting for nearly 80 percent of the total world production. It is important to note, however, that tilapia culture in Africa and South America is also increasing.

Prior to the mid-1990s, the yield of tilapia from capture fisheries was greater than that from aquaculture. Currently, the latter accounts for approximately 2.5 times the production from capture fisheries. Tilapia aquaculture production increased from 28 000 tonnes to 1.504 million tonnes globally from 1970 to 2002; in Asia and the Pacific, production increased from 23 000 tonnes to 1.192 million tonnes (Figure 6) equivalent to an annual growth rate of 13.2 percent and 13.1 percent, respectively. In contrast, capture fisheries for tilapias have grown at the rate of 3.5 percent per annum.

The growth of tilapia culture can be exemplified by comparing production with cyprinids and salmonids in different time periods (Figure 7). The trend shows that in all three groups of fish the annual rate of increase declined with time, as in the case of the aquaculture industry as a whole (De Silva, 2001b). However, the rate of increase in tilapia culture exceeded that of cyprinids and salmonids over all the time periods considered, with tilapia culture recording the highest rate of annual growth over the last two decades among all finfish groups. The growth of tilapia culture in Asia and the Pacific however, lagged slightly behind to that of the world. For example, the percent annual increase in tilapia culture in Asia and the Pacific for the 20 (1982–2002), 10 (1992–2002) and 5 (1997–2002) year periods was 12.5 (vs. 12.6), 10.9 (vs. 11.9) and 7.7 (vs. 10.0), respectively. This lower rate of growth in Asia and the Pacific is more a reflection of increased tilapia production in countries such as Egypt, where *O. niloticus* production increased from 9 000 tonnes in 1980 to 168 000 tonnes in 2002. Also the rate of growth observed, in all three groups of fish is considerably higher than that witnessed in the sector as a whole (De Silva, 2001b). Although a number of tilapia species has been introduced into the region (Table 1), only a small number of these are cultured (Table 7).

FIGURE 6
Aquaculture production of tilapia by continent 1970-2002

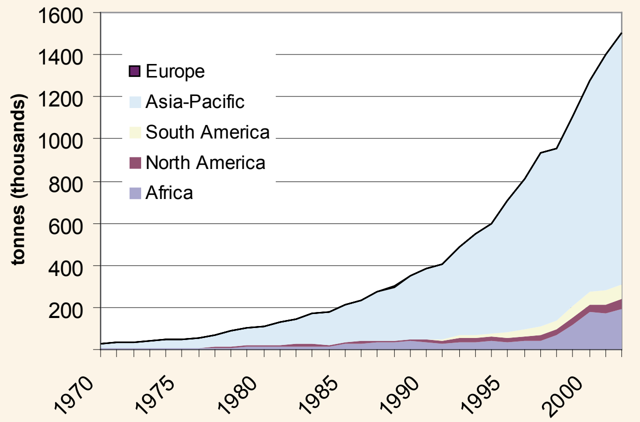


FIGURE 7
Global aquaculture production of salmonids, cyprinids and tilapia 1970-2002

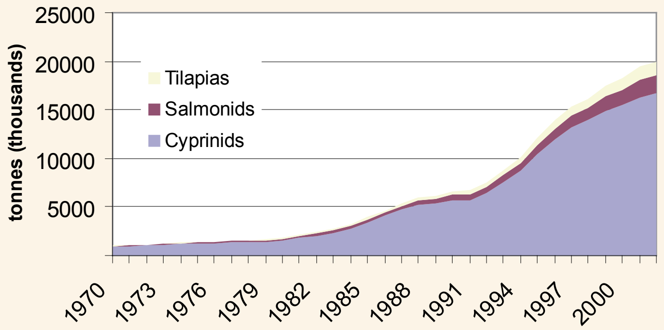
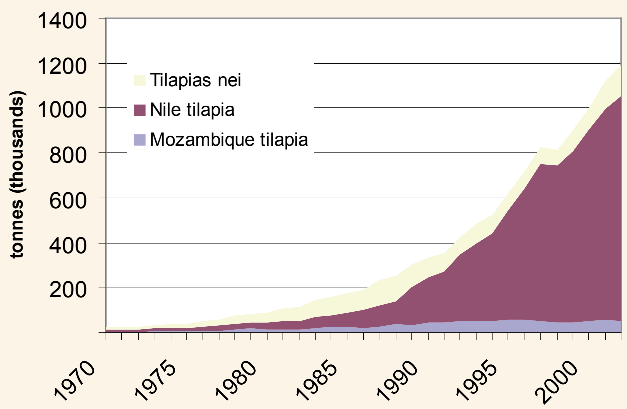


FIGURE 8
Aquaculture production of tilapias by species in Asia and the Pacific 1970-2002



Oreochromis mossambicus and *O. niloticus* are the most widely cultured tilapias in the world. In 15 countries in Asia and the Pacific, only four tilapia species are cultured, dominated by *O. mossambicus* (five countries) and *O. niloticus* (10 countries); the latter accounts for more than 90 percent of the production and its contribution to aquaculture production has been increasing steadily (Figure 8).

Table 8 lists the top ten countries in cultured tilapia production. In each year considered, six or more Asian nations ranked among the highest producers. Since 1995, some South American nations have become significant contributors to cultured tilapia production. Beginning in 1989, Peoples Republic of China (PR China) has dominated global tilapia aquaculture production, accounting for 47 percent of global production in 2002. In Egypt, cultured tilapia production increased from 9 000 tonnes in 1980 to 168 000 tonnes in 2002, thus attaining the second highest production in global tilapia culture.

Farmed red tilapia in Sri Lanka

The principal nations in Asia and the Pacific which have adopted tilapia culture are PR China, Indonesia, the Philippines, Thailand and Taiwan Province of China. Changes in *O. niloticus* production in these countries indicate that PR China currently accounts

TABLE 7
The number of countries/territories in each continent where different species of tilapias are cultured (production greater than 100 tonnes in 2002). Many countries do not report to species level so *Orechromis* spp. is included well

Continent/ Region		***Oreochromis* spp.**					***Tilapia* spp.**	
	not specified (spp.)	*niloticus*	*mossambicus*	*aureus*	*spilurus*	*andersonii*	*rendalli*	*zillii*
N. America	4	7	2	3	0	0	0	0
S. America	3	4	1	0	0	0	0	0
Africa	4	13	1	0	0	1	0	1
Asia-Pacific	9	10	5	0	1	0	0	0
Europe	1	0	0	0	0	0	0	0

TABLE 8
Top ten cultured tilapia producing countries/territories in the world, 1970-2002

1970		1980		1990		1995		2000		2002	
Country	Production (tonnes)	Country	Production (tonnes)	Country	Production (tonnes)	Country	Production (tonnes)	Country	Production (tonnes)	Country	Production (tonnes)
Taiwan POC	11 287	Taiwan POC	33 712	PR China	106 071	PR China	314 903	PR China	629 182	PR China	706 585
PR China	5 828	Indonesia	14 901	Philippines	76 142	Philippines	81 954	Egypt	157 425	Egypt	167 735
Egypt	2 500	Philippines	13 214	Indonesia	53 768	Thailand	76 383	Philippines	92 579	Philippines	122 390
Nigeria	2 129	PR China	9 000	Taiwan POC	52 047	Indonesia	74 125	Indonesia	85 179	Indonesia	109 768
Thailand	1 732	Egypt	9 000	Egypt	24 916	Taiwan	46 293	Thailand	82 581	Thailand	100 576
Philippines	1 417	Thailand	8 419	Thailand	22 895	Egypt	21 969	Taiwan POC	49 235	Taiwan	85 059
Israel	1 400	Mexico	6 907	Japan	5 825	Colombia	16 057	Brazil	32 459	Brazil	42 003
Indonesia	1 191	Nigeria	2 952	Mexico	5 000	Brazil	12 014	Colombia	22 870	Lao PDR	26 872
Hong Kong SAR	450	Israel	2 512	Israel	4 795	Malaysia	8 866	Lao PDR	18 928	Colombia	24 000
Mexico	200	Japan	2 392	Sri Lanka	4 500	U.S.A.	6 838	Malaysia	18 471	Malaysia	20 757

FIGURE 9

Aquaculture production of tilapia by country in the Asia-Pacific region 1970-2002

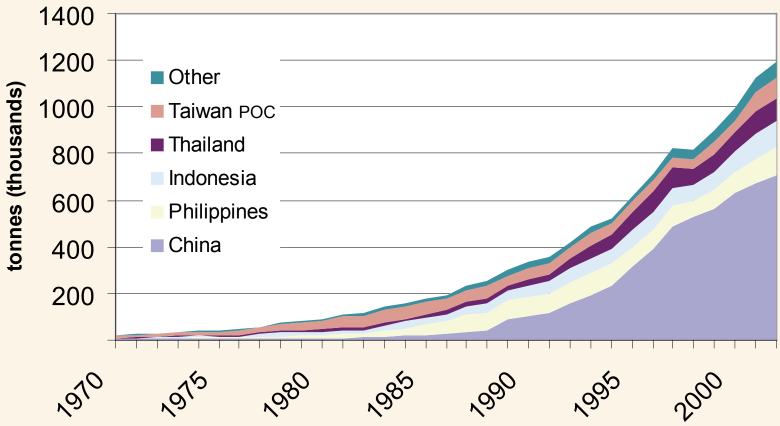
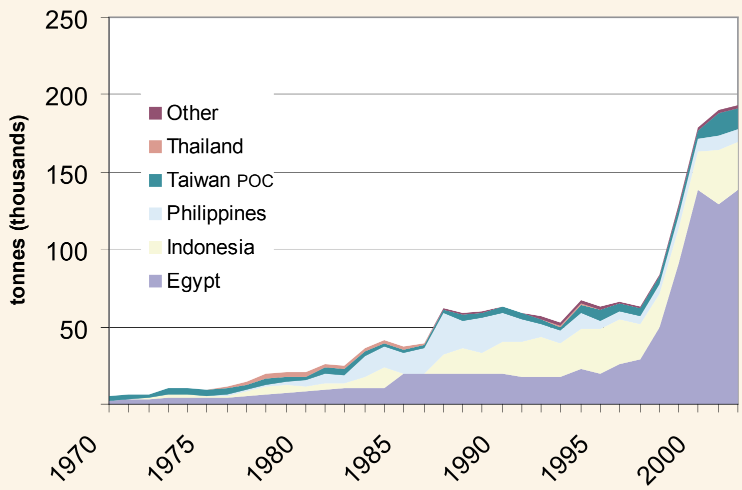


FIGURE 10

Major producers of tilapia in brackishwater 1970-2002



for over 70 percent of the region's production, an increase from 39 percent of Asia and the Pacific production in 1988, before the reported rapid increase in Nile tilapia culture in PR China. This has led to a decreased share of production from the other countries of the region, even when production has exhibited growth. For example, in the Philippines, the proportional contribution to regional Nile tilapia production was 27% in 1988 and only 10% in 2002, even though production increased from 27 000 tonnes to 104 000 tonnes over the period (Figure 9). Indonesia continues to dominate *O. mossambicus* culture, accounting for nearly 50 000 tonnes and more than 90 percent of the global total in 2002. Over 60 percent of this production is reported as originating in brackish waters.

One of the significant changes that has occurred over the last decade is the increase in tilapia culture in brackish waters (Figure 10). For 2002, brackishwater culture production was 193 000 tonnes. This represents a tripling from the relatively constant values (approximately 60 000 tonnes) for the period 1987-1997. *O. niloticus* accounts for about 73 percent of the brackishwater production, with most of the increase driven by large increases in production in Egypt. On the other hand, brackishwater culture of *O. mossambicus* has not increased as dramatically over the last decade. Egypt dominates *O. niloticus* brackishwater culture with 138 000 tonnes produced in 2002 (FAO FishStat).

Culture practices

Releasing red tilapia fry, Sri Lanka

Culture practices of tilapias in the world are very diverse, perhaps the most diverse among all aquaculture species in the world. It is a group of fish that could be cultured at many desired intensities, thus, appealing to all socio-economic strata, enabling the culture practices to be adjusted to suit their economic capabilities. *Oreochromis niloticus* is commonly cultured in backyard and/or home garden ponds to supplement the income of poor households as well as provide a fresh source of animal proteins to the family. In such situations, the cultured stock is often fed with kitchen waste and supplemented by relatively readily available, often low cost agricultural by-products such as rice bran. However, the direct nutritional value of the latter to the stock is not known and in all probability rather low; the inputs act more as a fertilizer. *Oreochromis niloticus* is cultured in relatively poor quality waters, including: (a) sewage fed ponds (e.g. commercial culture in Calcutta, India) (Edwards. 1990; Edwards *et al.*, 1990); and (b) primary and secondary treated waste effluents (e.g. Egypt) (Khalil and Hussein, 1997). So far, there have not been any reports of detrimental effects of consumption of fish reared in sewage-fed farms on human health even as the practice has been in operation since the 1930s (Nandeesha, 2002).

Tilapias are generally used in other aquaculture systems. *Oreochromis niloticus* is often used in integrated-fish culture. The most extreme development in this system is the integration of commercial poultry farming with *O. niloticus* culture. Cultured stocks are not fed, but depend on poultry waste and the natural food production in eutrophic ponds. *Oreochromis niloticus* is also being increasingly used in rice-fish culture, a traditional system which is gaining revival in Asia and is reported to enhance the overall yields in practices in PR China (Banghuai and Qianlong, 1995) and Bangladesh (Gupta *et al.*, 2002). Similarly, the potential of using *O. niloticus* in biogas slurry has been demonstrated with a view to integrating biogas technology in food production (Edwards *et al.*, 1988).

Tilapia pond culture practices are, in almost all cases, conducted in static systems, which require water replenishment between grow-out cycles and aeration is rarely used. Such minimal requirements reduce the initial investment and also keep the recurrent cost relatively low and therefore, more affordable for poorer sectors of the community. Cage culture of tilapias is also relatively popular,

Cage culture of tilapia in Batanai reservoir, Sarawak, East Malaysia

TABLE 9
Inputs used and yields obtained from freshwater tilapia culture practices in some Asian countries in 1999 (After Dey, 2001)

Parameter	Bangladesh	PR China			Philippines		Thailand	Viet Nam
	Pond	Pond		Cage	Pond	Cage	Pond	Pond
	Mc	Mc	Pc	Mc	Mc	Mc	Pc	Mc
Inputs *								
Rice bran	426	9 472	3 982		3 172		445	79
Commercial feed		2 811	3 998	11 431	2 336	533	3 087	62
Manure		615	1 339		7175		2 035	132
Fertilizer	10				213			
Yield *	1 736	5 860	6 593	5613	2 959	540	6 290	3 020
Harvest wt. (g)	111	310	340	460	130	175	232	241

Mc- mono culture; Pc- polyculture; * kg/ unit area the intensity and the sophistication varying from practice to practice and requiring minimal investment. Tilapia cage culture is effective as a means of providing alternative livelihood to displaced persons during reservoir impoundment (e.g. Jatilnuhur reservoir in Indonesia and Batan Ai reservoir in Malaysia). Operations in these cases are done on an industrial scale when cage construction, feed supplies, marketing strategies etc. are provided as an integrated package.

Most interestingly, tilapia culture is also being conducted in recirculation or closed cycle systems in temperate countries such as Canada, which incorporates expertise on greenhouse operations (Fitzsimmons, 2001). This is an evidence of a growing demand for cultured tilapia in many countries and the subsequent expansion of tilapia culture practices throughout the world.

The diversity of tilapia culture practices is also borne by the fact that tilapias are high salinity tolerant species and could be cultured in brackish waters and in sea cages. For sea cage culture, the appropriate species is *O. spilurus* (Cruz and Ridha, 1990). As mentioned earlier, tilapia production in brackish waters have grown steadily over the last decade with Egypt being the largest producer.

The returns from tilapia culture differ according to the environment, system and practice of culture. According to Dey (2001), the best tilapia culture practices in Asia and the Pacific are encountered in Taiwan Province of China yielding 12 to 17 tonnes/ha/yr in ponds, followed by mean yields of 6.6, 6.3, 3.0 and 1.7 tonnes/ha/yr in Thailand, the Philippines, Viet Nam and Bangladesh, respectively. Cage culture operations in the Philippines and in PR China on the other hand, yielded 0.5 and 5.5 tonnes/100 m^2, respectively (Table 9). Similarly, the mean size at harvest varied considerably among countries; between culture systems, the highest (460 g) being in cage cultured *O. niloticus* in PR China (Table 9).

Why have tilapias been successful as a cultured species group throughout the tropical countries? Bearing in mind that the bulk of tilapia production is a result of farming , its success can be primarily attributed to the following:

- relative ease of culture under extensive, semi- and/or intensive practices, thus relatively less limited by the economic status of the farmer compared to most other finfish species;
- relevant species exhibit many of the desirable traits expected of a species suitable for culture (e.g. relatively high growth rate, wide range of tolerance to physico-chemical characteristics, resistance to disease, easiness of propagation, etc.);
- moderately high dress-weight ratio;
- long shelf-life, and;
- as a white fish, tilapia is mild and lends itself to industrial preparations better than most other white fish (Picchietti, 1996).

In addition to all of the above, most of the commonly cultured tilapias are easily weaned on to artificial feeds. The group has the ability to derive its nutrition effectively from the natural food in the rearing systems particularly in ponds. This attribute makes it the foremost choice in home-garden and/or backyard small-scale, subsistence fish culture in developing countries such as Bangladesh, Viet Nam, etc.

TABLE 10
Summary of different hybrid combinations of tilapias that have known to produce monosex male progeny (from Mair, 2001)

Female parent	Male parent	Remarks
O. niloticus		Applied commercially but results inconsistent
O. niloticus	*O. macrochir*	Majority of broods are all male; some commercial application too
O. niloticus	*O. urolepis hornorum*	
O. niloticus	*O. variables*	All progenies monosex
O. mossambicus	*O. aureus*	
O. mossambicus	*O. urolepis hornorum*	
O. spilurus niger	*O. macrochir*	
O. spilurus niger	*O. urolepis hornorum*	
O. aureus	*O. urolepis hornorum*	
T. zillii	*O. andersonii*	

Notable phases in the development of tilapia culture

Culture of tilapias has gone through a number developmental phases since the nineteenth century (Lin 1977). In confined environments such as ponds, early maturation of the species, which resulted to overpopulation and eventually stunting, needs to be addressed. The earliest approach to overpopulation was stocking of predators, and few examples include *Ophicephalus* spp. and *Clarias* spp. in Asia (Chimitis 1957), L. niloticus and *Micropterus salmoides*) in Africa (Meschkat, 1967) and *Cichalosoma managuense* in Central America (Dunseth and Bayne 1978). Such a strategy requires the following: (a) optimization of predator to prey ratios; and (b) appropriate timing of the introduction with the correct number of predators of appropriate size(s). The effectiveness of such a strategy was limited and "fine tuning" is required so that an optimal balance is formed between the fry production of tilapias and the voracity of the predator(s). This strategy does not eliminate the channelling of food energy for egg and fry production thereby decreasing yields that could have been otherwise attained.

Netload of tilapia, Myanmar

Realizing that male tilapias grow faster, further approaches to solving the problem of overpopulation in culture systems was to develop all-male tilapias. Beardmore *et al.* (2001) summarized the potential advantages of the use of monosex animals in aquaculture:

- higher growth rate;
- elimination of reproduction;

- reduction of sexual/territorial behaviour;
- narrower size range at harvest; and
- reduction of environmental impacts resulting from escapees.

In view of the above considerations, the initial approach was to produce monosex tilapias through hybridization (Hickling, 1960; 1963). Female *O. mossambicus* x male *O. hornorum* (Hickling 1960, 1963) cross generated nearly all-male hybrids. Other cross selection followed which resulted in all-male and/or nearly all-male hybrids (see Table 10). Thus, hybridization strategy minimized overpopulation in the culture environments and also resulted in higher yields because of the faster rate of growth of the males. However, large-scale hybrid production did not always succeed due to instability in production of all-male hybrids and increasing appearance of females among progenies (Wohlfarth, 1994). Only few species of commercial value consistently produced all-male F1 generation. The most notable of these was the *O. niloticus* x *O. aureus* cross, which tolerated winter periods in Israel and became a focal point for a fresh wave of distribution of the parent species to other regions (Pullin and Capili, 1988). Except in a few cases, hybridization did not become established as a commercial method for all-male tilapia production

The hybridization phase gave way to hormonal sex-reversal as a method of producing large quantities of all-male seed stock, an approach perceived to be more practical. At the time that hormonal sex reversal was gaining popularity, a "shift" in the species was taking place, where *O. niloticus* became the preferred species for culture in view of its faster growth rate, attractive coloration and supposedly better taste. Consequently, most of the technological advances on sex-reversal were developed for this species, although the initial discoveries were made on *O. mossambicus* when Clemens and Inslee (1968) succeeded in producing all-males by oral administration of 17α-methyltesterone (male hormone) to early stage fry. Since the original discovery the effectiveness of 17α-methyltesterone, sex-reversal in a number of tilapia species has been demonstrated, e.g. *O. aureus* (Eckestein and Spira, 1965; Guerrero, 1975), *O. niloticus* (Tayamen and Shelton, 1978), *O. hornorum* (Obi and Shelton, 1983), *Tilapia zillii* (Yoshikawa and Oguri, 1978), *O. spilurus* (Ridha and Lone, 1990), among others. In addition, apart from 17α-methyltesterone, the effectiveness of other chemicals incorporated in food and orally administered for sex-reversal in tilapias has also been demonstrated (Varadaraj, 1990).

Hormonal sex-reversal is effective in early fry stages only (Hiott and Phelps, 1993). The hormones are almost always provided with the feed by spraying an alcoholic solution of the hormone on the feed and allowing the alcohol to evaporate. The dosage (generally 40 to 60 ppm) and treatment duration for the different hormones used for tilapias are well documented (McAndrew, 1993; Pandian and Sheela, 1995). It is also important to note that the orally administered masculinizing hormones, in particular 17α-methyltesterone, are eliminated (converted into polar metabolites) within 72 h of administration and that by day 10 only traces remained (Johnstone *et al.,* 1983; Curtis *et al.,* 1991). Indeed, even in instances when 17α-methyltesterone was used as a growth promoter, the chemical was eliminated from muscle within a very short period of time (Rothbard *et al.,* 1990), thus enablling the continued use of the technique without restrictions on the marketing the final product.

The technology for mass production of sex-reversed juveniles was initially developed by Rothbard et al. (1983) and has been extended into many hatcheries in the region. On the other hand, Beardmore *et al.* (2001) pointed out the main disadvantages of the method particularly in relation to practical difficulties in providing a uniform dose to all of the stock.

Following hormonal sex-reversal of tilapias and the greater understanding of sex-determination systems in a number of key species (Mair *et al.*, 1991a; 1991b), it became possible to develop techniques for the production of genetically male tilapia (GMT) initially on *O. niloticus* (Scott *et al.*, 1989; Mair *et al.*, 1991b). This technique is based on creation of males with two Y chromosomes (supermales) that when mated with other genotypes usually to give all-males and generally only a small percentage of females. Genetically male has also been produced, in this instance, through gynogenesis of XY neofemales (Vardaraja and Pandian, 1989).

The technique of producing GMT, particularly in the case of *O. niloticus*, is well established and is commercially adopted now, achieved through several generations of breeding (Mair and Little, 1991). Beardmore et al. (2001) claimed that the YY/GMT technology in *O. niloticus* is the only genetic technology adopted by the aquaculture industry for the production of all-males. Mair and Little (1991) considered the relative advantages, including commercial viability, of producing genetically all-male tilapia and its, as opposed to hormone induced sex- inversion to be: (a) all genetically male progeny; (b) potential to produce 100 % male progeny; (c) potential that no reproduction will occur in the growout phase; (d) applicability to most fry production systems; (e) not labour intensive after the initial phase; (f) lack of consumer resistance; (g) no centralization of fry production; and (h) comparatively higher growth rate.

Perhaps the best established dissemination programme of the GMT technology is in the Philippines done through an organization named Phil-Fishgen (Mair *et al.*, 2002). Phil-Fishgen is also involved in research and evaluation of the technology and has an accreditation scheme for private hatcheries. It is estimated that the 32 accredited hatcheries currently hold about 40 000 broodstock sets (1YY male: 3 normal females). According to Mair et al. (2002), the broodstocks held in the accredited hatcheries are capable of producing 50 milion GMT fry per year.

Using on-station and on-farm trials, Mair et al. (1995) demonstrated that the yield from GMT was 30–40 percent higher compared to normal mixed-sex tilapia (existing Philippine strains) and the mean grow-out period for GMT was 4.6 months, compared to 4.8 and 5.1 months for GIFT (Genetic Improvement of Farmed Tilapia – see next sectionj) fish and sex-reversed tilapia, respectively (Mair et al. 2002). The comparatively lower price of fry and fingerlings of GMT compared to prices of sex–reversed and GIFT fish appears to lure more growers, particularly the newer ones, to GMT farming (Mair *et al.*, 2002). However, it must be noted that there is increasing evidence that the sex determining mechanisms in fish in general (tilapias in particular) are very plastic and often influenced by environmental factors such as naturally occurring exogenous steroids, temperature and other physical variables and pollution (see review by Devlin and Nagahama, 2002). The environmental factors are often the main cause for the presence of females observed in GMT fish, which at times are potentially capable of mitigating growth advantage otherwise attributed to GMT fish.

Genetically improved tilapias: the case of Nile tilapia

Genetic improvement of most cultured aquatic species lags far behind that of farmed plants and animals. Availability of genetically improved seeds is considered as the single most important factor in the green revolution that became responsible for averting a famine in the developing world during the second half of the last century (Gjedrem, 2002). Gjedrem (2002) in reviewing the degree of response of aquaculture species to selection concluded that the mean genetic gain per generation among ten species was 13.3 percent generation with a range of 9.0 to 17.5 percent in clams and channel catfish, respectively. The gain in tilapia was estimated to be about 13.5percent.

While developments are taking place on all-male tilapia production (hormone treated or genetically), it was increasingly recognised that tilapia genetic resources in its native habitats need to be conserved, wild stocks protected and an international research programme on tilapia genetics be established (Pullin, 1988). Pullin and Capili (1988) also took into consideration the possible bottleneck effects of tilapia introduction to Asia and addressed the need for genetic improvement of cultured tilapias, particularly *O. niloticus*. The increasing interests in tilapia culture and the almost unanimous acceptance that cultured tilapia stocks needed genetic assessment and improvement led to the birth of the regional research and development programme "Genetic Improvement of Farmed Tilapia – GIFT", under the leadership of the WorldFish Centre – WFC, based in Penang, Malaysia (then referred to as the International Centre for Living Aquatic Resources Management – ICLARM, based in Manila, Philippines).

The "GIFT Fish" was the result of this carefully conducted genetic selection and improvement programme based on broodfish collected from four African countries (Egypt, Ghana, Kenya and Senegal) and four commercial *O. niloticus* strains (from Israel, Singapore, Taiwan Province of China and Thailand) used in the Philippines (Eknath *et al.,* 1993; Dey and Gupta, 2000). In the initial phase of the research, it was evident that the gain in growth and survival through crossbreeding was less than expected. This was followed by a pure-breeding strategy among the best performing purebred and crossbred groups that led to the build-up of a genetically-mixed base population. This population formed the basis for the final selection programme through a combined family and within-family selection strategy (Eknath, 1995). Subsequent selection resulted in the emergence of the GIFT strain, which is purported to have an 85 percent cumulative genetic gain compared to the base population (Eknath *et al.,* 1993).

The development of a better strain by itself does not complete the task particularly in regions where tilapia culture is widespread, often rural and very diverse, unless the findings are extended to practitioners to enable them to reap the benefits. This was achieved through another regional project 'Dissemination and Evaluation of Genetically Improved Tilapia Species in Asia or DEGITA' coordinated by WorldFish Centre (ICLARM) and involving five Asian countries. The project aims to ascertain the following:

- genetic, socio-economic and environmental aspects of the production of GIFT strain in different agro-ecological conditions and culture systems;
- the overall impact of the GIFT strain on different socio-economic groups (e.g. farmers, consumers, etc.); and

- disseminate the strain among small farmers if found to be superior to locally available strains (Dey and Gupta, 2000).

The detailed findings which basically evaluated the usefulness of the GIFT strain for improvement of the productivity and the socio-economic well-being of small-scale farmers in Asia are given in Dey (2000). Table 11 summarizes the results of trials conducted in five countries comparing the performance of the GIFT strain with other commercially available strains (after Dey *et al.*, 2000). The GIFT strain performed better in all countries. For example, on an average farm, the harvesting weight of the GIFT strain was 18 percent higher in PR China and 58 percent higher in Bangladesh. It was suggested that the better performance of the GIFT fish, after accounting for the wide heterogeneity of production environments, input levels and other factors was solely a result of the superiority of the strain. The study also demonstrated that the break-even price to be 7–36 percent lower for the GIFT strain (Dey *et al.*, 2000).

The production of the GIFT tilapias and the continuation of the selection strategy for desirable traits are conducted now through a non-profit private foundation, the GIFT Foundation International, incorporated in the Philippines. The Foundation functions through a system of private hatcheries that enter into a mutual agreement that commits the latter to the following:

- supporting the selective breeding and research work of the GIFT Foundation through research and development contributions;
- following the standards established by the GIFT Foundation for hatchery operations and procedures, customer service and support and marketing and promotions; and
- working with the GIFT Foundation and other GIFT hatcheries to improve the entire GIFT network operations, technical expertise, technical support to farmers and, marketing efforts.

Possible implications of genetically improved strains

Unfortunately, there is no information available on the impact of the Foundation on tilapia culture in general. However, what is common knowledge is that GIFT tilapia has been introduced into a number of other Asian countries. *Oreochromis niloticus* is widely distributed in Asia already and there are no reports, even anecdotal ones, that it has been responsible for the decline of indigenous species. As such it may be argued that the “GIFT Fish” may not cause any negative impacts on the environment when introduced and/or established. In contrast, it could also be suggested that “GIFT Fish”, because of its genetic superiority, it could be more invasive and would increase its range of distribution and thereby bring about detrimental environmental impacts which were not evident with *O. niloticus*. The reverse also could occur because of its rather specialized traits (e.g. fast growth) that may have reduced fitness in the wild.

Marketing

Cultured tilapia became an international commodity relatively recently, when frozen farmed tilapia fillets found their way into the mainstream food services and retail establishments of the American foodchain followed by expansion into Europe (Picchietti,

TABLE 11
Results of on-farm trials on the GIFT (G) strain and non-GIFT (NG) strains of tilapias in different culture systems (Modified after Dey *et al.*, 2000)

System	Strain/ trials	Duration (days)	SD (no.m-2)	Weight (g)		Male %	Recovery %	Yield (kg/ha)
				Initial	Final			
Bangladesh								
Pond	NG/ 21	173	20 000	2.99	60.7	38.3	74.1	896
	G/ 23	174	20 000	3.35	107.6	40.4	74.4	1 593
	Difference				46.9***	2.1***	0.2	697***
PR China								
Cage	NG/ 10	111	1 000 050	56.8	263.8	56.1	88.5	310 967
	G/ 10	111	1 000 050	55.2	308.0	56.2	94.6	389 346
	Difference				44.2***	0.1	6.1***	78 380***
Pond	NG/ 7	127	20 686	15.55	220.5	63.8	92.5	4 275
	G/ 7	127	20 257	16.43	245.6	49.6	91.8	4 645
	Difference				25.1	-14.2**	-0.7	370
Philippines								
Cage	NG/ 5	118	213 880	6.33	135.4	55.9	58.5	15 285
	G/ 5	118	213 880	6.33	161.1	55.4	68.3	23 551
	Difference				25.7	-0.5	9.8	8 266**
Pond	NG/ 50	127	21 394	0.76	52.1	46.9	55.2	912
	G/ 58	126	23 976	0.76	67.0	48.2	70.0	1 361
	Difference				14.9**	1.3	14.8**	448*
Thailand								
Pond	NG/ 2	256	62 500	2.14	80.2	65.0	40.2	2 044
	G/ 13	250	49 231	1.22	119.6	69.6	47.6	2 829
	Difference				39.4	4.6	7.4	786
Viet Nam								
Pond	NG/ 6	139	20000	1.01	52.7	52.7	45.9	558
	G/ 7	152	20429	1.31	52.3	52.3	47.8	743
	Difference				-0.4	-0.4	1.9	185

***, ** and * denotes significance of the differences between selected parameters at 1, 5 and 10 levels, respectively.

1996). Initially, frozen fillet imports to America exceeded fresh fillet imports by 30 percent and the author predicted that with time, increasing acceptance of tilapia will eventually outweigh frozen fillet imports. It has been suggested that tilapia would have a place as a generic white fish because of its mild taste and lends itself to industrial preparations better than most other white fish (Picchietti, 1996).

The main export market for cultured tilapia is the United States of America. In 2000, imports of tilapia (whole frozen, fresh and frozen fillet forms) in the United States amounted to 40 553 tonnes valued at US$ 101 377 853 and has since been increasing steadily. According to Harvey (2001), tilapia imports to the United States of America increased by 394 percent by between 1993 and 2000. The main tilapia exporting countries are Taiwan Province of China, PR China, Ecuador and Costa Rica. Fresh fillet are currently supplied by Ecuador, Costa Rica and Honduras; frozen fillet and whole frozen fish comes from Asia (Vannuccini, 2001). Chinese imports have been increasing almost exponentially over the past few years. Harvey (2001) predicts that PR China will become the leading exporter of tilapia to the United States.

The European market for tilapia is still rather limited; UK is considered to be the major outlet. Vannuccini (2001) reckoned that the main markets in Europe are the big cities where large communities of African, Chinese and Asian communities live. However, an increase in tilapia consumption has been a recent trend also among non-ethnic communities. European markets prefer larger-sized frozen tilapia. There are growing markets for tilapia in Canada, the Middle East and even in a rather sophisticated market such as in Japan (Vannuccini, 2001). In Japan, high quality tilapias are being used for sashimi and as a substitute to sea bream in traditional Japanese cooking.

It is thus evident that tilapias, commonly considered as the poor man's fish, are now beginning to make major entry to the sophisticated markets of the world. It has also become a popular and sought fish after freshwater fish in countries such as the Philippines and Indonesia, replacing milkfish and gouramy, respectively. These trends are positive signs for all producers and can potentially influence a significant upsurge in tilapia culture worldwide.

TABLE 12
Predicted global and Asia and the Pacific cultured tilapia production (tonnes) for the years 2003 to 2010. Estimates are based on the approximate rate of increase between 2001 and 2002 (6%) and on the approximate average rates for the period 2001-2002 (9%)

Year	Global Production - Rate of mean percent annual growth		Asia and the Pacific Production - Rate of mean percent annual growth	
	6 percent	9 percent	6 percent	9 percent
2003	1 595 000	1 640 000	1 263 000	1 299 000
2004	1 690 000	1 787 000	1 339 000	1 416 000
2005	1 792 000	1 948 000	1 420 000	1 544 000
2006	1 899 000	2 124 000	1 505 000	1 683 000
2010	2 398 000	2 998 000	1 900 000	1 375 000

Future prospects

It is believed that there is potential for further tilapia culture development in the Asia and the Pacific, as well as in Africa and South America. The trends in the growth of tilapia aquaculture production, taking into consideration the mean annual increase in production, over different time periods are summarized in Figure 11. More importantly, the observed decline of the annual growth rates for tilapia production is significantly lower than that for total finfish as described by De Silva (2001b) and is also lower than for any other cultured finfish groups. Tilapia culture in North America is still a young industry and the market for tilapias is being steadily expanded in the United States, Japan and even Europe. This situation might provide an added impetus to increased tilapia culture in developing countries in the immediate future.

In view of the decreasing annual rate of growth in production (note that production is increasing but the rate of increase is beginning to decrease), cultured tilapia production in the world and in the Asia and the Pacific was projected using two rates of increase. The first rate, 6 percent increase per year, approximates the smallest increase in production in the last few years, observed from 2001 to 2002. the second rate, a 9 percent annual increase, approximates the average rate of increase observed for 2000-2002 (Table 12). Taking average rates of increase over longer time periods would result in a larger growth rate and, hence, larger projected production. By 2006, even at a rather modest rate of increase of 6 percent per year, the world cultured tilapia production would reach 1 899 000; whereas, with a 9 percent rate of growth per year production would be over 2.1 million tonnes. By the same year, tilapia production in the Asia and the Pacific is estimated to be 1 505 000 and 1 683 000 tonnes at growth rates of 6 and 9 percent, respectively. The present analysis also indicates that the contribution from the region to the world cultured tilapia production would continue to be nearly 80 percent.

Table 12 also extends the projections beyond 2006 to 2010 for information, but obviously caution should be used when projecting too far into the future. The above computations are based on production trends over the last few years. They do not take in to account plausible changes that could occur in tilapia aquaculture practices, which would be likely to have a significant positive impact on production, and the industry as a whole. An example of this is the relatively recent, but the increasing emphasis of tilapia culture in brackish waters. This trend is likely to continue with the possible adoption of tilapia culture in unused or abandoned shrimp ponds – a viable proposition for many Asian farmers. Possible increases in production through expanded integrated rice-fish farming of tilapias may also be realized.

The upsurge in culture-based fishery activities in Asia and in the Americas is also likely to contribute to significant increases in production. Considering prospects for tilapia aquaculture in the Americas, Fitzsimmons (2001) believes that by 2010 total production will exceed 500 000 tonnes/year. This might be possible as most developing nations are embarking on tilapia aquaculture and there is an increasing emphasis on high density, intensive culture in recirculating systems in nations such as the United States of America and Canada.

The growth in cultured tilapia production will also likely be augmented by technological developments and more effective extension of the technologies that are already commercialized or being commercialized. A good example of this is the production and availability of genetically improved seed such as GMT. Most of these improved seed types (specifically GMT), as yet, are not readily available to most rural farmers in Asia, except perhaps in Thailand and to a certain extent in the Philippines. Ready availability of such seed to rural farmers throughout Asia is bound to have a positive impact on production.

The potential development of strains with a better growth rate, such as the "GIFT fish" and indeed the greater popularization of already developed better performing strains are also likely to impact tilapia culture. Tilapia culture is currently restricted to warm tropical climates. Tilapia culture in northern Viet Nam requires facilities for over-wintering. Progress has been made with the development of cold resistant *O. niloticus* strain (Dr T. M. Thien, personal communication, 2003). Development and popularization of a cold resistant strain of *O. niloticus* would provide the opportunity to extend the range of its culture in relatively cold climates, thereby positively impacting overall production. These developments will, however, be affected to varying degrees by policies which countries would adopt with regard to the use of genetically improved organisms in food production.

Commercial feed manufacturers in developing countries in Asia often view tilapias as a suitable group of fish to market their feeds through community-based subsidy schemes. Tilapia's robust characteristics, such as fast growth rate and relative resistance to disease, satisfy the aspirations of rural farmers who are new to aquaculture, thus would be willing to consider such schemes. With the current trend towards increasing competition among industrial suppliers of "aquaculture goods" and primarily feeds, such feed subsidy schemes are likely to become popular among rural communities and can thus contribute to the overall increases in production.

In Asia, tilapia cage culture has been one of the primary ways of providing alternate livelihoods to displaced persons from dam building and reservoir impoundment in inland areas. Although dam building, particularly across major rivers, is subjected to increasing community disapproval (Roy, 1999), it goes on unabated in most developing countries (McCully, 1995) primarily for purposes other than fisheries. It is being considered in many instances that tilapia cage culture could be an alternative livelihood for displaced persons, and such programmes might contribute to the overall tilapia production in the coming years.

Twenty-five years ago, predictions were made with regard to sewage treatment plants becoming large centres for food production (Borgstrom, 1978), and that excreta use in aquaculture would become an increasingly important form of waste disposal and food production (IRCWD, 1985). Use of excreta for food production is not a new phenomenon; night soil is used for agricultural production in some countries, although this practice has now become controvercial on food safety grounds and is gradually diminishing. These predictions have not yet been fully realized. As we progress through the new millennium, there will be more demand for waste management and recycling of biological wastes for food production, directly and indirectly, will become paramount.

Tilapias have shown to be ideal candidates in this regard. As pointed out earlier, tilapias are already cultured in sewage ponds as well as in wastewater treatment plants. With increasing pressures on communities to recycle nutrient resources, there is real prospect for expansion of such activities and the potential for contributing to the overall cultured tilapia production in the tropics.

Prospects for tilapia culture will remain an attractive proposition both to the poor sectors of communities and those who are embarking on aquaculture, either to supplement the household income or as an alternative livelihood, because of the following characteristics: (a) need for only modest investments; (b) relatively low recurrent costs for the culture of the tilapias; (c) ease of breeding and growout; and (d) ability to do well in waters of relatively low quality. The fact that tilapia culture can also be conducted on a large-scale, on an intensive basis, or integrated with other forms of agriculture such as rice-fish farming or livestock-fish farming, also provides greater scope for expansion of its culture practices.

Culture-based fisheries

The distinction between culture-based fisheries, stock enhancement and aquaculture is often difficult to determine. It is considered that culture-based fisheries fall into the realm of aquaculture with the following characteristics:

- it is a farming activity;
- it involves intervention in the lifecycle;
- more often than not ownership (singly and/or collectively) is defined.

Public perception on relatively intensive forms of aquaculture is not favourable and environmental lobby groups are becoming increasingly opposed to aquaculture development (De Silva *et al.*, 2001b). In such a climate, it is likely that there could be an upsurge in culture-based fishery activities in the region and elsewhere (Quiros and Mari, 1999) depending on the availability of small water bodies. A conservative estimate of the water surface area classified as small-scale irrigation schemes in developing countries in Asia is estimated to be 66 710 052 ha (FAO, 1999), a huge resource that has been established for purposes other than fisheries. Utilization of such water resources for culture-based fisheries has the added advantage of not being dependent on feed inputs, but, and by and large, depends on the natural food productivity of the systems, thereby becoming a non-polluting aquaculture activity.

A day's harvest of tilapia from a culture-based fishery in Mandalay, Myanmar

Culture-based fisheries are in a development phase in Asia. The social and institutional implications and economic viability are being evaluated (Lorenzen *et al.*, 1998a; 1998b). The general consensus is that it is a viable practice and has a major role to play in poverty alleviation in Asia. It is currently recognized that all forms of stock enhancement of existing water bodies is a major development strategy that would significantly increase the world's food fish supplies, especially in developing countries (Welcomme and Bartley, 1998).

Culture-based fisheries generally use species combinations with *O. niloticus* as the common species. In initial trials conducted in Sri Lanka, it was demonstrated that the stocked tilapias accounted for a production range of 32–91 percent, in systems that yielded 838 to 1 030 kg/ha/cycle, where tilapia accounted for the highest production (Chakrabarty and Samaranayake, 1983). On the other hand, culture-based fishery activities in northeast Thailand, tilapia (*O. niloticus*) gave median yields per fingerling stocked, as compared to Chinese carps, but yields per fingerling of tilapia spanned a wide range up to 0.83 kg seed/fish, considerably higher than the financial break-even level. This indicates that there is great scope for improvement (Lorenzen *et al.,* 1998a).

Potential constraints

With the envisaged developments and expansion in tilapia culture and the trend towards intensification of farming systems, feed supply and cost of production will become issues for consideration. Tilapia has some advantages in view of its omnivorous feeding habit which requires less protein as compared to other species cultured using intensive systems (De Silva *et al.*, 1989). Although there have been considerable advances in laboratory research on partial replacement of fish meal in tilapia diets, it has never been demonstrated in any cultured fish species that effective diets can be prepared without fish meal. Inclusion of fish meal in feeds remains essential.

Future growth in tilapia culture will be triggered primarily by export markets to the United States of America, Japan and some European countries, and even to the Near East. These countries have stringent quality requirements concerning chemical and veterinary drug residues. Therefore, in order to be competitive, developing country producers have to satisfy such requirements and endeavour to produce high quality products that are safe to eat and satisfy consumer demand and expectations. Tilapia culture practices will need a general uplift in facilities and attitudes in dealing with a commodity that is not considered as high value, profit margins are relatively narrow and market demand is a possible constraint.

There are increasing concerns on the potential threats to biodiversity in countries where tilapias have been introduced. It was also shown that most, if not all, of the perceived effects of tilapias on biodiversity are primarily due to factors other than tilapias and explicit evidence in this regard, at least to date, are wanting.